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

Training Module

CCET
IGES Centre Collaborating with UNEP on Environmental Technologies

IGES
Institute for Global Environmental Strategies

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

Training Module

Preamble

This training Module was developed as a supplementary training and learning resource for the "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka," published by Ministry of Environment, Sri Lanka. The training Module was designed under the guidance of the Secretary, Director, Assistant Director and staff of the Environmental Pollution Control & Chemical Management, Division of the Ministry of Environment and also IGES Centre Collaborating with UNEP on Environmental Technologies (CCET), United Nations Environment Program - International Environmental Technology Centre (UNEP-IETC), and Ministry of Environment, Japan (MOEJ).

It draws on information from a number of publications, 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, as well as other publications by individuals and publishers, all of which we would like to acknowledge here for enriching our understanding on the subject.

This training Module is aimed at raising the level of understanding, for users, of the concepts and guidance given in the "Guidelines" mentioned above, with the hopes that it will play an instrumental role as a tool in developing training and awareness programs on MSW dumpsite risk assessment, rehabilitation, and safe closure.

Project Team

This training Module was developed by the following project team:

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

Currently, around the world, a trend of converting linear economies to circular economies is emerging in many developed and developing countries, involving moving away from landfill disposal of Municipal Solid Waste (MSW) towards waste resource recovery as part of a material recycling-based society. While sanitary landfilling is the most widely prevalent means of ultimate solid waste disposal in the world, developing countries are taking measures to avert the use of landfills themselves and close existing landfills. On a global scale, although disposal of MSW in landfills is on the decline, landfills are likely to remain an important component of integrated solid waste management systems. Conversely, however, in Sri Lanka, open disposal on the ground, or "open dumping," has been the standard approach used to dispose of MSW, until very recently. Open dumpsites represent one of the major sources of environmental pollution, as they not only pollute the environment but also pose a high risk to human health and degrade the utility value of land in urban areas. Thus, it is now widely acknowledged that MSW needs to be better managed to avoid it ending up in uncontrolled landfills, illegal dumpsites or waterways.

Since the 2000s, the government and private sector in Sri Lanka have invested in constructing new sanitary landfills, composting facilities, recycling facilities, and waste to energy facilities, thereby reducing the need for uncontrolled disposal of MSW in open dumpsites. Nevertheless, until all LAs gain access to such advanced facilities, they will continue to face the need to expand the capacity of existing open dumpsites as well as control the levels of pollution and health risks related to open dumping. Given the circumstances, therefore, the current situation presents an ideal opportunity to develop strategies that can enable a shift away from the use of open dumpsites, either through appropriate rehabilitation of existing dumpsites or by closing those that are highly polluting.

It has been identified that one of the gaps in the waste management sector in the country is the absence of appropriate technical guideline for LAs and practitioners. To fill this gap, in 2021 the "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka" (also referred to as "Guideline" throughout this book) was developed by the Ministry of Environment in order to officialize the process of environment-friendly planning and operation of dumpsite rehabilitation as well as closure of waste dumps at the local government level. This training Module is designed to equip officers and practitioners in the MSW sector with an understanding of the importance of dumpsite rehabilitation, the benefits, appropriate methods, and the main challenges.

Learning outcomes for the Training Module

Trainees completing this Module are expected to be able to:

1) Explain the basic concepts of land disposal of MSW.
2) Understand the pollution risk assessment process of dumpsites.
3) Make appropriate decisions on strategy for and approach to dumpsite rehabilitation.
4) Understand the technical options for dumpsite rehabilitation and closure.
5) Describe the essential operation and maintenance activities of rehabilitated and closed dumpsites.
6) Understand the site-specific design concepts based on rehabilitations caried out in the past.

Use of this Training Module

This training Module is designed for delivery through training workshop(s) for LA staff, whom are often key to implementation of dumpsite rehabilitation and closure, but can also be flexibly tailored to suit specific technical or non-technical stakeholders in the MSW sector, depending on the needs of the Government, Provincial Councils, or any other relevant organization.

While this Module is designed for delivery through a training workshop, it may be used for self-study or group study. Regardless of the method, it is recommended to keep notes in a notebook while working through the Module to note down answers to questions or any other important points.

It comprises five (5) separate study sessions, each expected to take 2-4 hours to complete. All study sessions have a similar format. Following a brief introduction there are a set of learning outcomes, which are linked to the Self-Assessment Questions (SAQs) at the end of the session. Within the text can be found In-Text Questions (ITQs), with answers to be discussed during the training. For each question, try to answer it in your head first or by making notes in your notebook before the answer is discussed. This will aid you to learning.

Each session ends with a summary, which lists the key points raised, and the SAQs. Each SAQ tests one or more of the learning outcomes stated at the beginning of the session. When you have finished studying, you should work through the SAQs, writing down answers in your notebook. Writing down answers, rather than just thinking about them will reinforce your understanding and enable you and others to check your progress in relation to the learning outcomes. All answers to the SAQs from all sessions can be found at the back of this book.

Important terms are highlighted in bold and defined in the text. Understanding and being able to use these key terms is the first learning outcome for all study sessions. All key terms in this Module are listed alphabetically at the back of this book with a reference to the study session where they were introduced.

You will see that the sources of information used in the text are indicated by the name of the author or organization, followed by the date of publication in brackets; e.g., '(Ministry of Environment, 2021)'. Full details of these sources are listed alphabetically by author in the References at the back of the book.

Session 1: Open MSW dumpsites and their impacts

LEARNING GUIDE

Prior to reading this session, the trainee should read the following chapters from "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka":

Chapter 1: The need and objectives of dumpsite rehabilitation guidelines

Chapter 2: Types of final disposal facilities

Learning outcome of Session 1

1) Explain the impacts of MSW open dumps on the environment, human health, and socio-economic development in global and local perspectives
2) Specify different types of open dumpsites
3) Discuss the need for dumpsite rehabilitation and closure

Resources

1) Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka
2) Presentation handouts
3) Flip charts, drawing paper, pens, color pencils/pastels, calculator

Total time: 2 hours

1.1 MSW management: global perspectives

The recent World Bank publication *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*) states that world generates 2.01 billion Metric Tons (MT) of municipal solid waste annually, of which at least 33% is not managed in an environmentally safe manner (Kaza et al., 2018). Poor solid waste management affects everyone in society. The most vulnerable groups in society are directly impacted by poorly managed waste, such as through loss of life and homes from landslides of waste dumps, working in unsafe waste-picking conditions, and suffering profound health repercussions due to emissions, water pollution and contaminations.

The environment is also heavily affected. Every year, about 8 million tons of plastic waste escapes into the oceans from coastal nations, while world plastic waste generation remains as high as 242 million MT, equal to 12% of all municipal solid waste (Kaza et al., 2018). Plastic waste is choking freshwaters and oceans.

Meanwhile, an estimated 1.6 billion MT of carbon dioxide equivalent ($CO_{2\text{-}eq}$) greenhouse gas (GHG) emissions were generated from solid waste management in 2016 (Kaza et al., 2018). This is about 5% of global emissions. Without improvements in the waste management sector, solid waste related emissions are anticipated to increase to 2.6 billion MT of $CO_{2\text{-}eq}$ by 2050. On 12 December 2015, 196 parties including Sri Lanka adopted the Paris Agreement which entered into force on 4 November 2016, with a commitment to reduce emissions through several sectors including waste management (UNCC, 2021).

There are several tools available for calculating GHG emissions from a landfill, such as the IPCC FOD model, Emission Quantification Tool (EQT), and the USEPA Landfill gas emissions model: LandGEM). One of the most widely used tools is IPCC FOD. According to the 2006 IPCC guideline, IPCC FOD is adopted as a relatively simple model for estimating CH4 emissions from Solid Waste Disposal Sites (SWDS), and expresses overall decomposition process of a series of chain reactions of anaerobic decay of DOC (IPCC, 2019). The amount of degradable organic matter (DOCm) is waste disposed into SWDS. The estimation is based on information on disposal of different waste categories (MSW, sludge, industrial and other waste) and the different waste types/materials (food, paper, textile, etc.). Information is also needed on the types of SWDS in the country and some other parameters, as in IPPC guideline under chapter 3 (Solid waste disposal) section 3.2.3 (IPCC, 2019).

Emission Quantification Tool (EQT) is another tool, which was developed by Institute for Global Environmental Strategies (IGES) on behalf of the Climate and Clean Air Coalition Municipal Solid Waste Imitative (CCAC-MSWI) to support the rapid assessment of GHGs and Short-lived Climate Pollutants (SLCPs) from all stages of municipal solid waste management, including landfill, though Life Cycle Assessment (LCA) methodology (IGES, 2018). Similarly, another tool is available, called The Landfill Gas Emissions Model (LandGEM), which is an automated Excel-based tool that can be used to estimate rates of emissions of total landfill gas, methane, carbon dioxide, non-methane organic compounds and individual air pollutants from municipal solid waste landfills. The manual and tool are freely available on the EPA website under the Clean Air Technology Center (EPA ,2021). The LandGEM model has not been accurately validated for estimation of GHG from open MSW dumpsites in Sri Lanka; however, several researchers have validated the model for open MSW dumpsites in Thailand (Chiemchaisri et al., 2007) and India (Gollapalli and Kota, 2018) with reasonable assumptions.

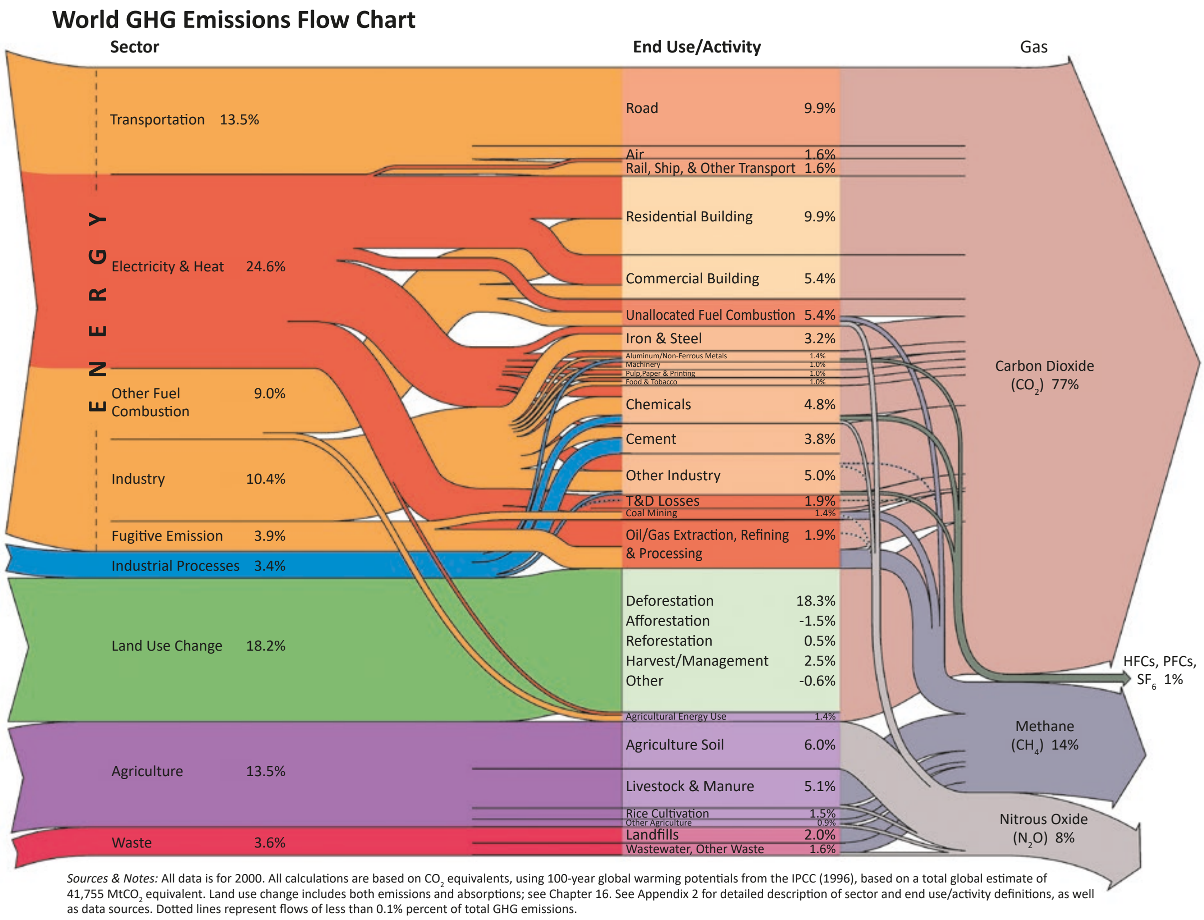


Figure 1. Flow chart of global GHG emissions (Source: World resources institute)

Globally, most waste is currently dumped or disposed of in some form of landfill. In the global context, open dumping accounts for about 33% of waste, 37% of waste is disposed of in some form of landfill, 19% is recovered through recycling and composting, and 11% is incinerated prior to final disposal. Adequate waste disposal or treatment, such as controlled landfills or more stringently operated facilities, is almost exclusively the choice of high- and upper-middle-income countries. Lower-income countries generally rely on open dumping; 93% of waste is dumped in low-income countries and only 2% in high-income countries. Upper-middle-income countries have the highest percentage of waste in landfills, at 54%. The landfilling rate decreases in high-income countries to 39%, with diversion of 35% of waste to recycling and composting and 22% to incineration. Incineration is used primarily in high-capacity, high-income, and land-constrained countries.

For Local Authorities in low-income countries, about 20% of their budgets is consumed by waste management; however, over 90% of waste in low-income countries is still openly dumped or burned. Along with the accelerated growth of these low- and middle-income cities and countries, systems to manage their growing waste and mechanisms to safeguard public health and the environment are desperately needed.

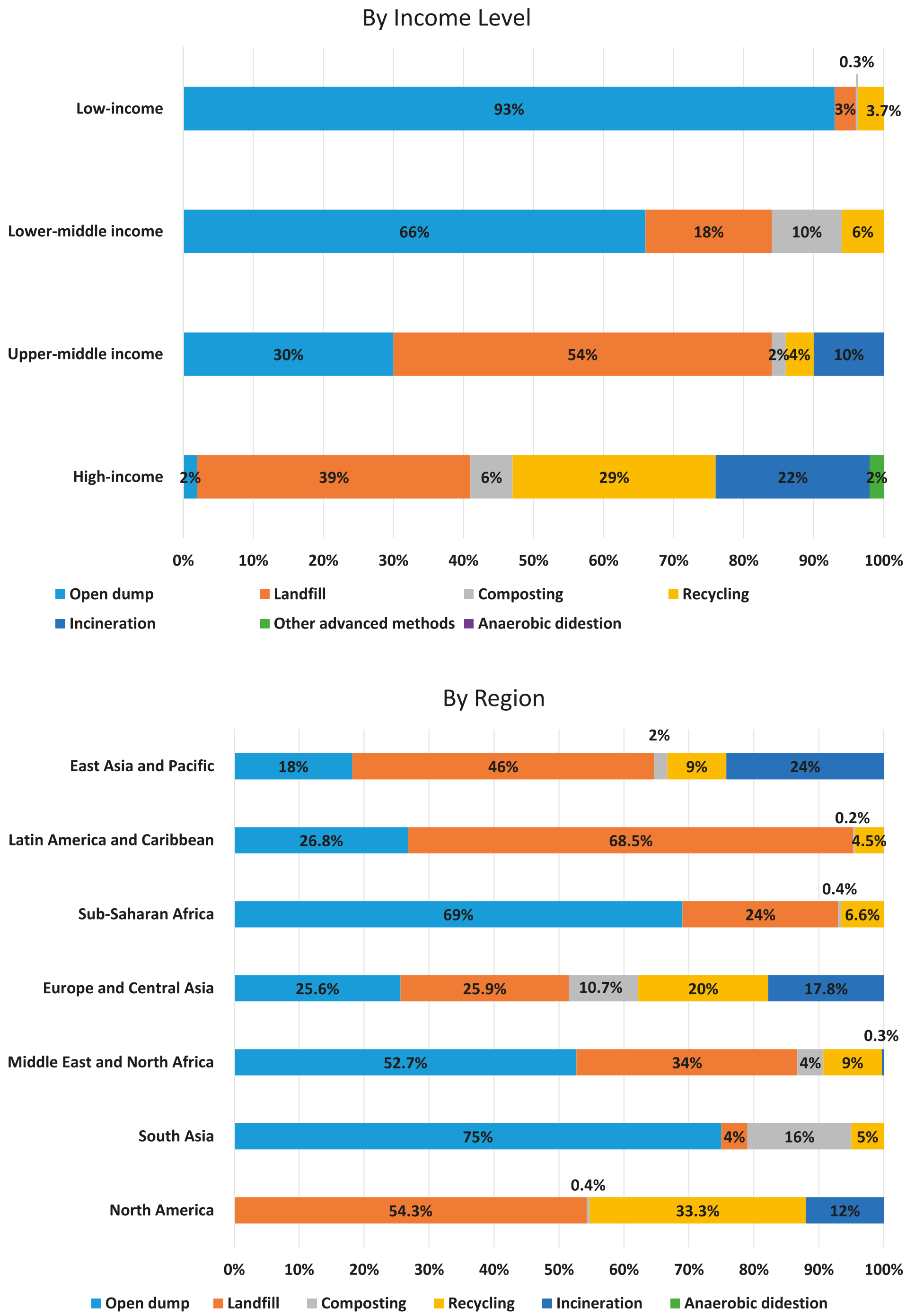


Figure 2. MSW disposal methods in use throughout the world (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050)

It is a frequent misconception that technology is the solution to the problem of unmanaged and increasing waste. In reality, however, technology is only a one factor to consider when managing solid waste, as countries that advance from open dumping to proper waste management systems only succeed if they select solutions appropriate for their locality.

Quiz 1-1: *What is the cause of methane emission from MSW landfills/open dumpsites?*

a) Waste burning | *b) Leachate accumulation*
c) Anaerobic degradation of organics | *d) Plastics in waste*

1.2 MSW disposal: Sri Lankan perspective

Sri Lanka has 24 Municipal Councils (MCs), 41 Urban Councils (UCs) and 276 Pradeshiya Sabhas (PSs). Average per capita solid waste generation in Sri Lanka is approximately 0.47 kg/person/day, which can range from 0.2 kg in rural villages to 0.85 kg in highly urbanized cities. The country generates in total an estimated 8,142 MT per day of waste, of which 3,855 MT per day is collected by local authorities at present National Program for Solid Waste Management", 2020, and there are about 339 dump sites, receiving around 2,020 MT per day of waste for open disposal.

Table 1. MSW statistics for Sri Lanka (Source: National Program for Solid Waste Management 2020)

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**

1.3 Open dumpsites vs Sanitary landfilling

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. While the term 'landfill' usually relates to sub-surface waste disposal, it also generically encompasses 'land-raise', i.e., above ground disposal. Further, the common distinction between sanitary and semi-engineered landfills is that the latter provide no treatment for methane gas collected, whereas the former do. 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 odors, the spreading of litter and to prevent access to the waste by birds and vermin.

More information on types of final disposal facilities is available in pages 5-10 in "Guideline for safe closure and rehabilitation of municipal solid waste dumpsites in Sri Lanka."

Table 2. Differences between sanitary landfills and open dumpsites

Open dumpsite	Sanitary landfill
	
No impermeable liner; waste dumped on ground	Properly designed impermeable liner is available
No leachate collection system; surface/lateral seepage diversion pipes/drains are occasionally available	Properly designed leachate drainage layer; collection pipes and diversion pipe network are present
No leachate treatment system; simple nature-based treatment systems such as constructed wetlands may be available	Leachate is diverted to a highly engineered treatment system (biological & chemical) followed by nature-based wastewater treatment systems for secondary/ tertiary treatment
No gas venting/collection system; passive surface emission or simple vertical gas vents may be available	Properly designed gas emission pipe network is connected to centralized collection system that permits only controlled emissions
Occasionally employs earth-moving machinery to secure space and stabilize shape; occasionally applies thin layer of cover soil	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
Occasionally conducts visual observations and emission tests as per regulatory requirements	Often conducts visual observations and regular emission tests, including groundwater monitoring. Monitoring is an integral part of management plan. Complies with regulatory requirements
Closure, rehabilitation, or improvement plans are not available	The closure and post-closure plans are developed at inception and strictly followed by operators

Quiz 1-2: *What is the component of a landfill that must be site-specifically designed?*

a) Weighbridge *b) Bottom liner*
c) Leachate/gas collection pipes *d) Landfill machineries*

1.4 Dumpsite rehabilitation vs dumpsite closure

The term "dumpsite rehabilitation" refers to any work carried out on a MSW dump site to minimize hazard risks caused by leachate contamination, gaseous emissions, waste burning, collapse due to instability, and all other associated socio-economic issues. A rehabilitated dumpsite can continue to operate, as long as it can be confirmed not to cause pollution.

The term "dumpsite safe closure" refers to any work carried out on an existing or abandoned MSW dumpsite to minimize hazard risks 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 a condition as possible.

1.5 Learning activities

1. Describe the status of MSW management in Sri Lanka (Table 1) compared to the world (Figure 2) with particular emphasis on waste disposal.
2. Draw a schematic diagram and show different components of the dumpsite you manage/monitor/have observed in Sri Lanka and compare it with the standard features of a typical sanitary landfill.

1.6 Assessment questions

1) Select the most appropriate statement to describe the difference between open dumpsites and sanitary landfills from the below:
   a. Open dumpsites are always located on unsuitable land, whereas sanitary landfills are built on suitable land.
   b. Different types of solid waste are disposed of in open dumpsites, but landfills are only used for MSW disposal.
   c. Open dumpsites lack facilities and methods to control environmental pollution, whereas sanitary landfills are built with waste containment facilities.
   d. Unlike small open dumpsites, sanitary landfills are larger waste disposal facilities that cannot be used by small Local Authorities.
2) What is the factor that will have a certain global impact due to open MSW dumpsites?
   a. Groundwater pollution b. GHG emissions c. Health and hygiene issues d. Land degradation
3) Which of the following waste handling methods do you think reduces environmental pollution caused by landfilling?
   a. Disposal of nondegradable waste into landfill.
   b. Disposal of only degradable waste into landfill.
   c. Disposal of residual waste after composting and recycling.
   d. Disposal of a mixture of sewage and solid waste into landfill to increase stabilization.
4) What is the landfill component that you could exclude, if a Local Authority wants to transform its open dump site into a semi-engineered landfill?
   a. Installation of flexible membrane liner at the bottom.
   b. Installation of leachate collection system.
   c. Installation of landfill gas venting system.
   d. Construction of stormwater collection and diversion system.

Session 2: How to assess the pollution risk of dumpsites

LEARNING GUIDE

Prior to reading this session, the trainee should read the following chapter from "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka":

Chapter 3: Dumpsite pollution risk assessment

Learning outcome of Session 2

1) Explain the purpose of conducting a dumpsite pollution risk assessment study prior to making a decision on rehabilitation
2) Demonstrate the ability to develop the Source-Pathway-Receptor (S-P-R) conceptual model for a dumpsite
3) Describe a simple technical approach to conduct dumpsite pollution risk assessment
4) Analyze and interpret the outcome of a dumpsite risk assessment study

Resources

1) Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka
2) Presentation handouts
3) Flip charts, drawing paper, pens, color pencils/pastels, calculator

* Experience and awareness of managing, operating, assessing, or studding dumpsites will be advantageous.

Total time: 2 hours

2.1 Risk assessment

Risk assessments consider the likelihood of occurrence and the consequences of occurrence of events. It represents a systematic means of determining and evaluating the nature, effect, and extent of exposure a vulnerable receptor may experience in relation to a particular hazard, provides information for the management, and communicates the level of risk. An environmental hazard is an event or continuous process which, if realized, will lead to potential degradation, direct or indirect, of the quality of the environment (Royal Society, 1992).

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.

2.2 Source-Receptor-Pathway conceptual model

A 'pathway' is a route by which a particle of water, substance or contaminant moves though the environment and comes into contact with 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.

Source	Pathway	Receptor
Size and amount of waste	Leachate and contaminated water flow	Proximity to residential areas
Depth and degradation process	Types of pollutants in water and air	Exposure duration
Waste characteristics	Soil permeability and wind velocity	Effect on flora & fauna
Management practices	Surface and ground water flow	Adverse health impacts

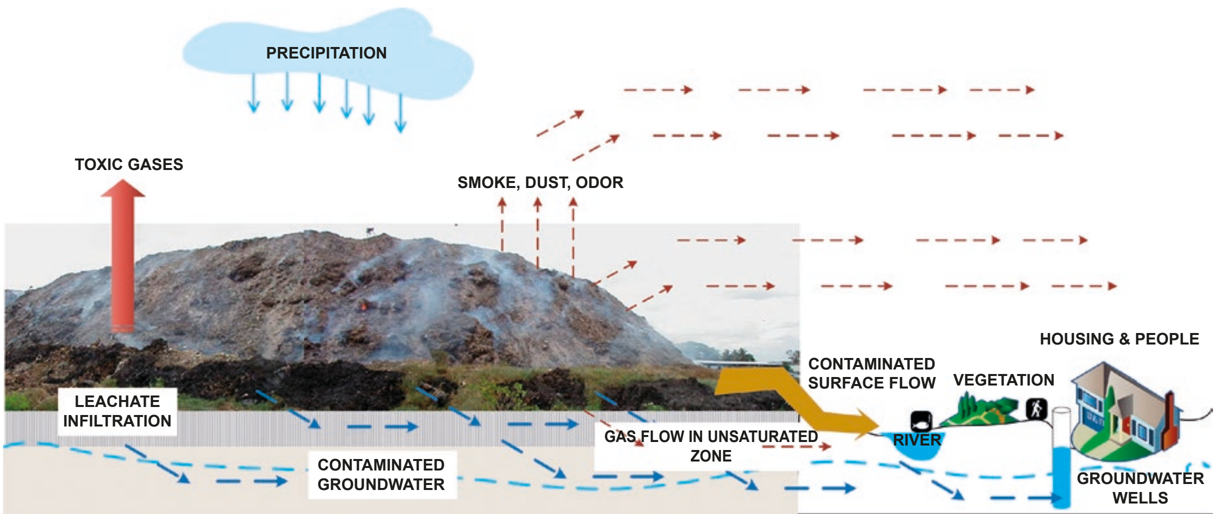


Figure 3. Source-Pathway-Receptor (S-P-R) conceptual model

Quiz 2-1: *What is the most accurate statement regarding an S-P-R for an open dumpsite?*

a) S-P-R is a process that must be conducted based on site assessment.
b) Laboratory studies are necessary to develop an S-P-R model.
c) S-P-R can be developed as a simple diagram based on secondary data.
d) All statements are true.

2.3 How to conduct a pollution risk assessment study

A three-tier stepwise approach is often used in the risk assessment methodology, as shown in Figure 4.

i. Development of Conceptual Site Model (qualitative)

ii. Site Investigations and Testing (quantitative)

iii. Refinement of CSM based on qualitative and quantitative assessments

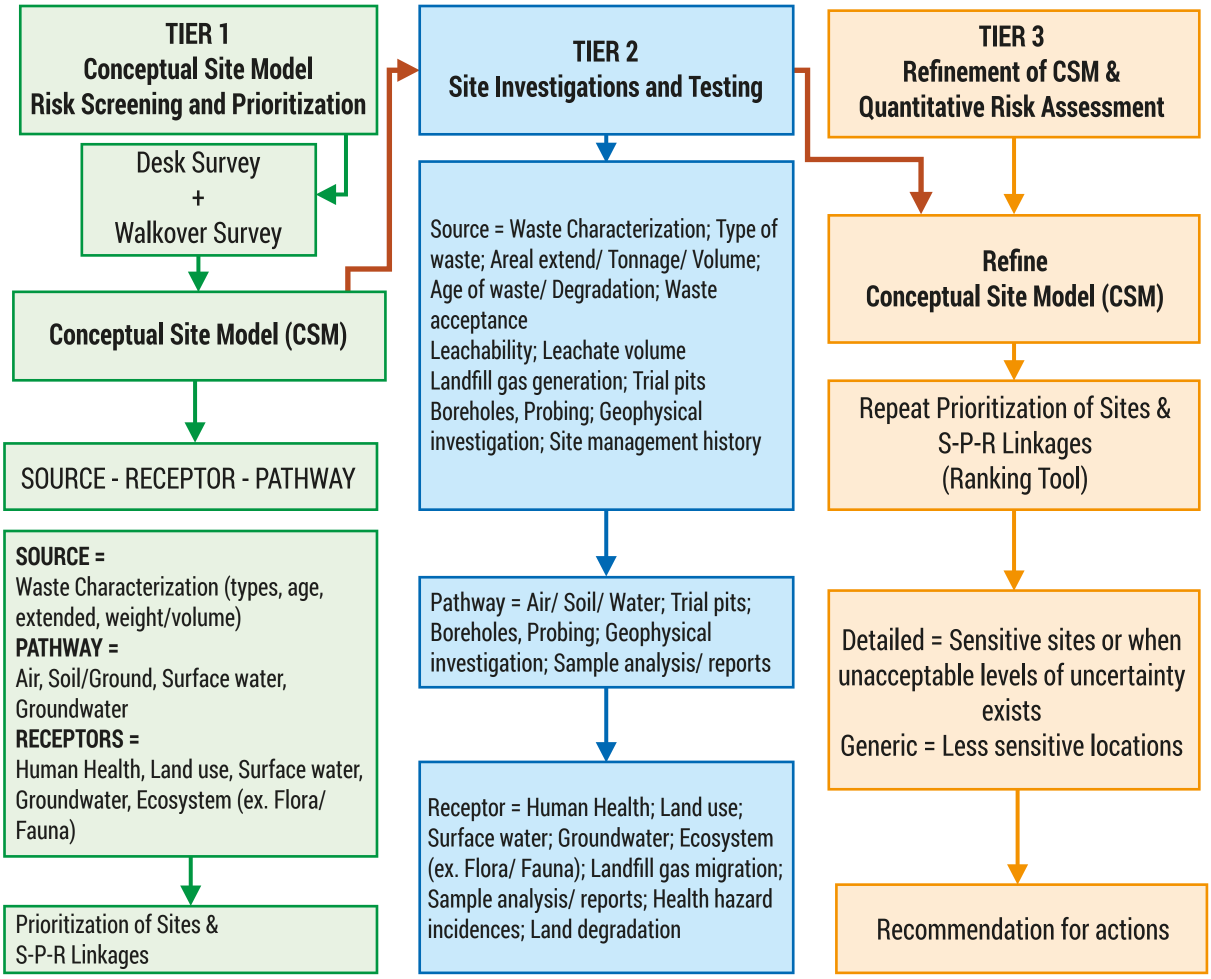


Figure 4. Risk Assessment Methodology - Phased approach (modified from EPA IRELAND, 2007)

2.4 Risk screening - a simple methodology for quantitative assessment

The main goal of carrying out a scientific risk assessment is objectivity, though it is still subjective to a certain extent due to the non-availability of specific data (pollutant types, concentration, transport velocities, accumulation, reactions, geology, hydrology, etc.) and various assumptions and interpretations made in the process. Consequently, some simple quantification tools have been developed to analyze the risk conditions (as presented in the Guideline), based on expert judgment.

Lesson 2- Activity 1

The following diagram shows a simplified S-P-R model of an open dumpsite in Sri Lanka.

i. Refer to Table 3-1 of the Guideline and calculate the cumulative Risk Index (RI).
ii. Evaluate the hazard based on criteria shown in Table 3-2 of the Guideline.

2.5 Learning activities

1. Develop an S-P-R conceptual model of the dumpsite you manage/monitor/have observed in Sri Lanka.
2. Calculate the Risk Index (RI) based on the developed S-P-R conceptual model and Table 3-1 of the Guideline.
3. Decide the hazard level of the dumpsite as shown in Table 3-2 of the Guideline.

2.6 Assessment questions

1) Why are risk assessment attributes weighted differently in risk screening?
   a. In order to compare different sites.
   b. Due to different levels of uncertainties.
   c. For easy calculation.
   d. Due to relative importance of different attributes in a given context.

2) Why is the amount of biodegradable waste disposed of in a dumpsite considered an important criterion in the environmental risk assessment?
   a. Biodegradable waste is harmless.
   b. Biodegradable waste determines the hazardousness of leachate.
   c. Biodegradable waste amount is an indicator of size of dumpsite.
   d. Biodegradable waste determines the amount and characteristics of gaseous emissions and leachate.

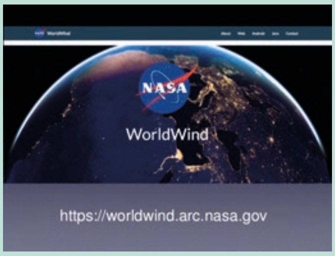
3) Which is the most appropriate statement describing the factors that determine the quantity of leachate generated by an open dumpsite?
   a. Amount of stormwater percolation to dumpsite, amount of hazardous waste, and amount of biodegradable waste.
   b. Amount of plastics in waste, amount of biodegradable waste and atmospheric pressure.
   c. Amount of stormwater percolation to dumpsite, precipitation, and area of the dumpsite.
   d. Composition of disposed waste, groundwater quality, and age of dumpsite.

4) What is the most critical factor influencing the stability of a dumpsite?
   a. Dumpsite age.
   b. Height of the dumpsite.
   c. Type of soil beneath the dumpsite.
   d. Type of waste disposed of.

5) Which is the most appropriate statement about the Environmental Risk Assessment of an open dumpsite?
   a. Environmental risk assessment can be performed based on records and secondary information.
   b. Environmental risk assessment does not require field surveys or evaluations.
   c. Environmental risk assessment is a qualitative assessment.
   d. Environmental risk assessment requires site-specific information.

GEOBROWSERS

Geobrowsers, also known as virtual globes or Earth browsers, such as Google Earth and NASA World Wind, are two commonly used sources enabling you to view, retrieve, and download data and information on the earth's surface. Google Earth is a geobrowser that accesses satellite and aerial imagery, topography, ocean bathymetry, and other geographic data over the Internet to represent the Earth as a three-dimensional globe. Geobrowsers can be effectively used for gathering information about dumpsites in a preliminary environmental risk assessment



Session 3: How to start the planning process

LEARNING GUIDE

Prior to reading this session, the trainee should read the following chapters from "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka":

Chapter 4: Planning requirements

Chapter 5: Collection of technical information for planning

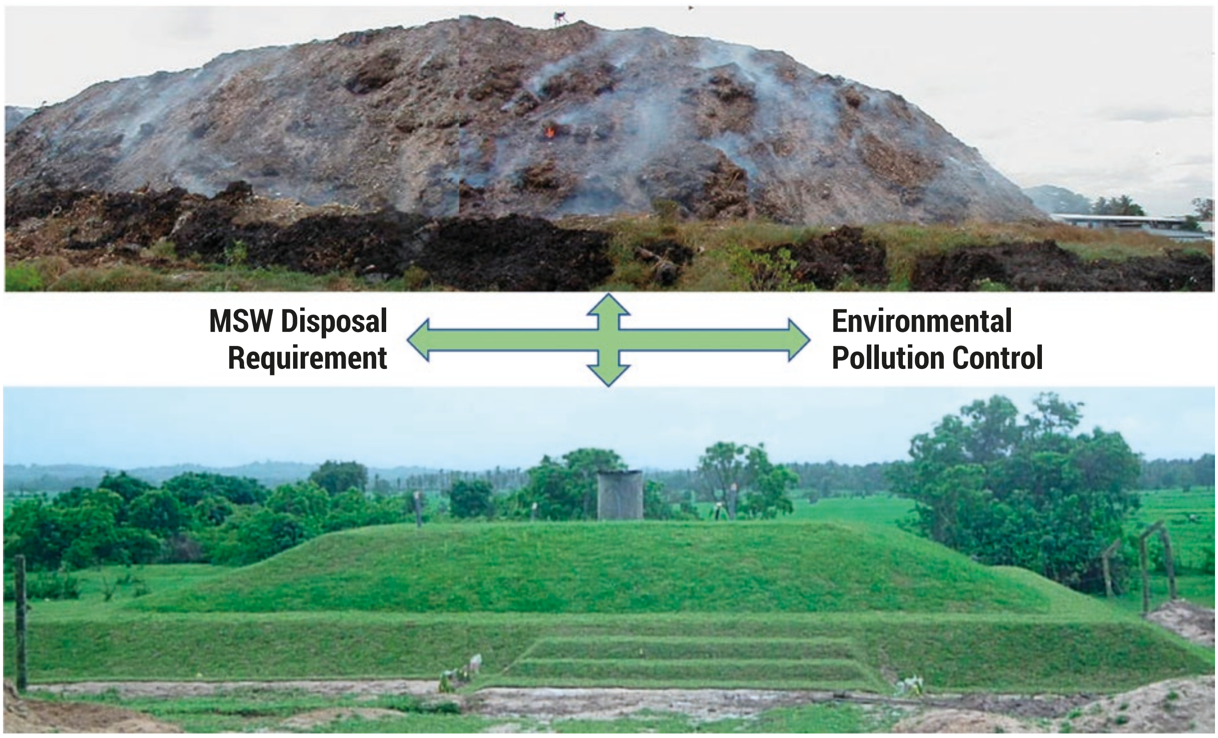
Learning outcome of Session 3

1) Explain the general objectives of dumpsite rehabilitation to landfill.
2) Describe the need for dumpsite closure for high-risk sites.
3) Prepare lists of general, site-specific, and secondary information required for decision making.
4) Specify potential sources to obtain general and technical information.

Resources

1) Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka
2) Presentation handouts
3) Flip charts, drawing paper, pens
4) Internet facilities

Total time: 1.5 hours



3.1 Objectives of planning

The Technical Guidelines on Solid Waste Management (Central Environmental Authority, 2005) recommends only properly designed land disposal facilities (sanitary landfills) be used for MSW disposal. It specifies that a landfill should be a properly engineered facility which is located, designed, operated, monitored, closed, and thereafter cared for to ensure minimal impacts on the environment and human health. Further, the national Waste Management Policy states that landfilling should be for non-biodegradable, inert waste and other waste unsuitable either for recycling or biological processing. Consequently, the dumpsite rehabilitation project plan can aim at:

1. Rehabilitating an open dumpsite by rearranging the scattered waste into a properly-designed landfill cell, and reclaiming the space at the same location to construct a new sanitary landfill for future use.
2. Rehabilitating a part of or the entire dumpsite, enabling future extension and use at the same location.
3. Safely closing the dumpsite and ceasing future operation.

Quiz 3-1: *What is NIMBY syndrome?*

a) A disease cause by leachate contamination.

b) An acronym to describe opposition of residents to a proposed development plan.

c) A skin disease caused by waste contamination.

d) A mental disorder caused by inhaling smoke from a burning dumpsite.

In order for the rehabilitated site to achieve the planned objectives, an Implementation Plan needs to be drawn up for the rehabilitation project, to determine the best policies and implementation steps necessary for preparing and arranging the required facilities.

Table 3. Objectives of dumpsite rehabilitation planning

General technical objectives	Specific objectives in converting to sanitary landfill	Specific objectives for safe closure
To prevent slope failure	To make and maintain slopes	To establish proper final cover
To prevent littering	To prevent littering	To control leachate and gas emissions
To control gaseous emissions	To collect and treat gaseous emissions	To conduct post monitoring
To minimize health risk	To ensure no health risk	To transit from closure plan to post-closure land use plan
To control leachate generation	To manage stormwater	
To prevent water contamination	To collect and treat leachate	
To stabilize waste	To monitor groundwater	
	To accelerate waste stabilization	
	To implement maintenance program	
	To continue environmental monitoring	
	To establish auxiliary facilities	

3.2 How to gather technical information necessary for planning?

Table 4. Technical information for planning

Type	Description	Secondary data sources	Field surveys
Climate	Daily rainfall, evapotranspiration, wind patterns, temperature, and humidity data for minimum of 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 aerial 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

Quiz 3-2: *The amount of waste disposed at a dumpsite should be available at:*

a) Relevant Local Authority (LA)

b) National Solid Waste Management Support Center (NSWMSC)

c) Waste Management Authority-Western Province (WMA-WP)

d) Central Environmental Authority (CEA)

3.3 Learning activities

1. Note down general and specific objectives to rehabilitate the dumpsite you manage/monitor/have observed in Sri Lanka.
2. Prepare a list of secondary data relevant to dumpsite rehabilitation planning which are readily available from the following organizations.

   - Department of Meteorology, Sri Lanka (https://meteo.gov.lk)

   - Central Environmental Authority (http://www.cea.lk)

   - Urban Development Authority (https://www.uda.gov.lk)

   - National Physical Planning Department (http://www.nppd.gov.lk)

3.4 Assessment questions

1) What is a modern, non-destructive investigative technique that can be used to understand belowground soil/geological condition and groundwater occurrence in a dumpsite?
   a. X-rays
   b. Neutron Probe
   c. Ground Penetration Radar (GPR)
   d. Global Positioning System (GPS)

2) What is the most convenient technique that can be used to develop high-resolution digital ground elevation and land use maps?
   a. Drone survey
   b. Google maps
   c. Satellites
   d. Land survey

3) What are the on-site assessment tests/surveys that must be conducted for every dumpsite in order to gather technical information?
   a. Ground profile, rainfall amount, and wind pattern
   b. Surface hydrology, ecological assessment, and ground profile
   c. Soil type and classification, rainfall measurement and ecological assessment
   d. Air quality, rainfall amount, and leachate quality

Session 4: How to make appropriate technical decisions based on risk

LEARNING GUIDE

Prior to reading this session, the trainee should read following chapter from "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka":

Chapter 6: Decision-making approaches.

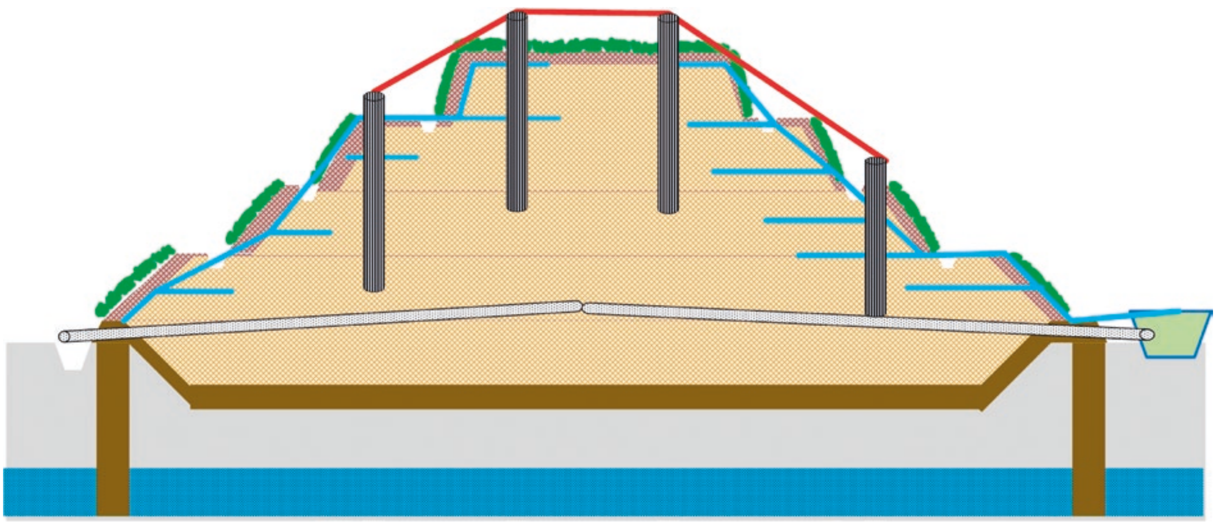
Learning outcome of Session 4

1) Explain the decision-making process.
2) Demonstrate ability to make appropriate decisions based on risk assessment.
3) Describe different classes of dumpsites with respect to risk categories and potential restoration.

Resources

1) Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka
2) Presentation handouts
3) Flip charts, drawing papers, pens

Total time: 1.5 hours



4.1 Key decision-making criteria

The key decision is based on knowing whether the dumpsite can be developed into a sanitary landfill or needs to be safely closed. A site for a sanitary landfill should fulfill strict location-specific technical, ecological and socio-economic criteria; 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.

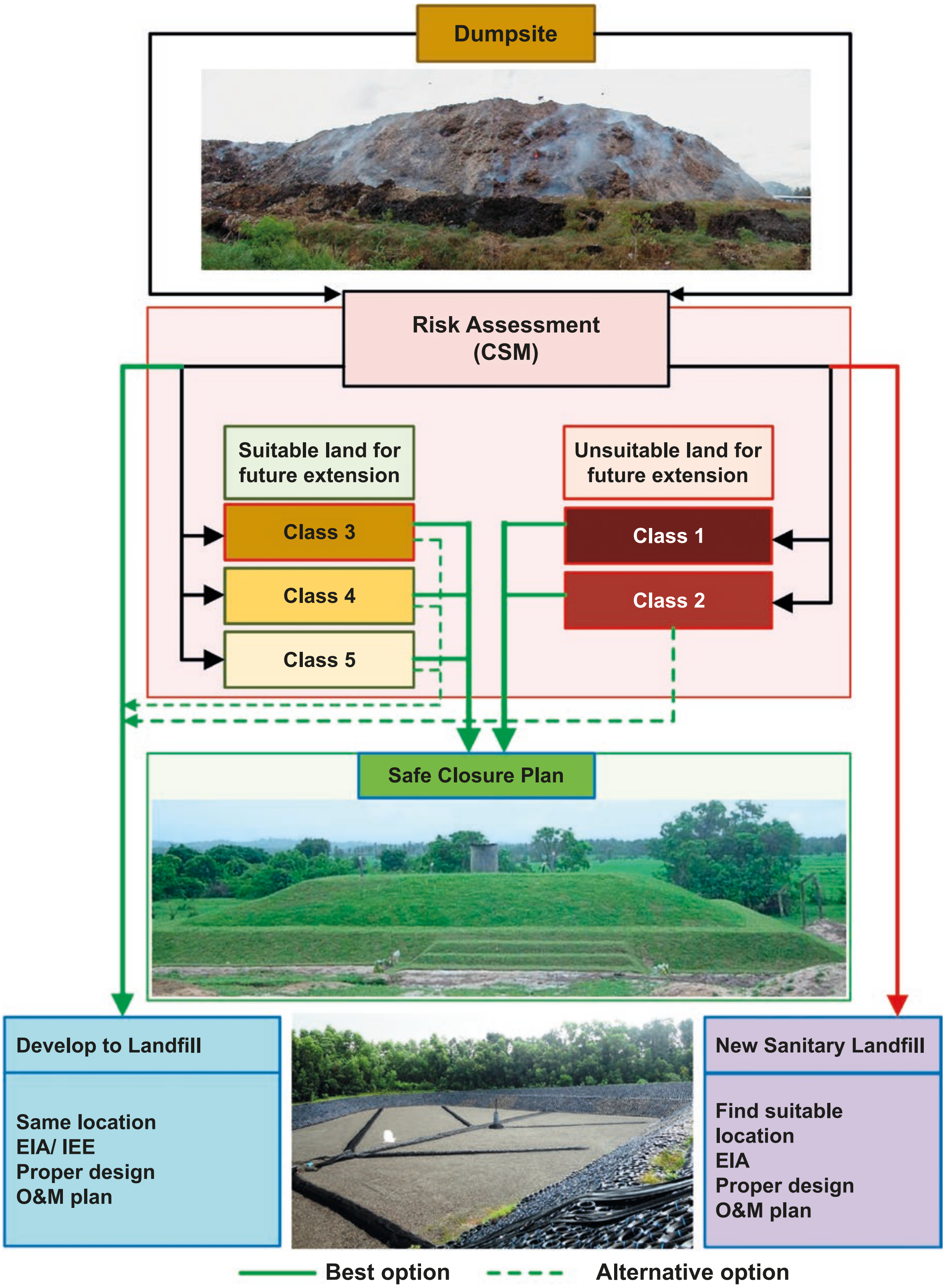


Figure 5. Hazard risk assessment-based decision-making process

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 as well.

Landfill site selection

Currently, there are no direct landfill siting criteria legally established in Sri Lanka. However, site selection is considered a complex process and is restricted by numerous natural and artificial factors, and indirect regulations.

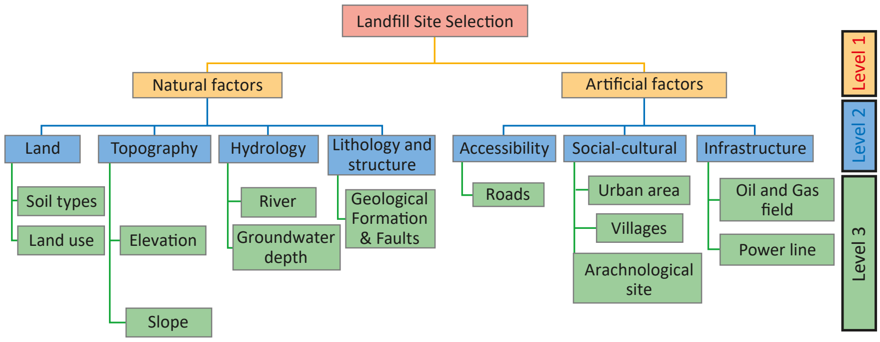


Table 5. Typical landfill site selection criteria

Waste management aspects	Site-specific requirements	Socio-economic criteria
Haulage distance	Location restrictions (Ex. near airports, floodplains, riverside slopes and wetlands)	Social acceptance
Extent of land requirement • Operated for a minimum period of ten years. Extent calculated on basis of daily/annual disposal amounts, as well as peak generations of seasonal variations, compaction density, daily cover and depth, and decomposition of wastes.	Geological and hydrological conditions: • Significant thickness of vadose (unsaturated) zone beneath landfill. • Underlain by strata with low hydraulic conductivity • Does not overlie sole source or usable aquifer	Population: • Urban planning required and shanty dwelling should be avoided • Cultural aspects
Site access roads and traffic	Located outside floodplain area • Limits storm water runoff (SWRO) to the landfill site. • Limits impact of both SWRO and leakage from the landfill site. • Has adequate setback from populations, lakes, streams and wetlands	Archaeological and historical sites • Cultural heritage and practices, community resources, proximity to schools and hospitals, public safety and health, sensitive receptors (religious places)
Ultimate use for completed landfill	Local environmental/ecological conditions	Capital and operational costs
Waste Management Policy	Regulatory requirements (Ex. EIA)	Waste Management Policy

4.2 Categorization of dumpsites

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.

Class 1 dumpsites

- Hazard potential index > 750 (Extremely high)
- Highest priority sites for immediate rehabilitation
- Often located in water bodies
- Immediate closure is recommended

Class 2 dumpsites

- Hazard potential index 600-749 (High)
- Second highest priority sites for rehabilitation
- Often located in upstream of water bodies
- Unsuitable for developing to landfill

Class 3 dumpsites

- Hazard potential index 450-599 (Moderate)
- 3rd priority sites for rehabilitation to landfill/closure
- Often located in upstream catchments
- Has a potential to rehabilitate to landfill

Class 4 dumpsites

- Hazard potential index 300-449 (Low)
- Rehabilitation is recommended to minimum risk
- Often located away from water bodies, but upstream
- Moderate closure is recommended

Class 5 dumpsites

- Hazard potential index < 300 (Very low)
- Rehabilitation is recommended to minimum risk
- Often located away from water bodies, dry areas
- Can be continued with appropriate rehabilitation
- Has higher potential to develop to a sanitary landfill

Figure 6. Classification of dumpsites based on Hazard potential index

4.3 Dumpsite mining

Dumpsite/Landfill mining is a process in which solid wastes dumped at dumpsites or landfills are excavated, processed and reused. The objectives of mining are to:

- Recover and conserve landfill space
- Reduce landfill footprint
- Eliminate potential contamination source and rehabilitate dumpsites
- Recover combustible material for energy recovery
- Reuse and recycle recovered materials
- Reduce costs of post-closure care and monitoring of landfill sites

Landfill mining process

The process involves a series of operations based on the principle- excavate, sieve and sort. However, the complexity of the process increases depending on the type of landfill. The machinery used includes:

- Excavators
- Conveyor belts
- Trommel screens
- Magnetic separators
- Front end loaders
- Odor control sprayers, etc.

However, waste recovery or remediation measures are expensive. And to compensate for the costs of reclamation, it is essential to turn to enhanced mining. The enhanced mining process involves generating energy and recyclable goods that can provide the revenue to counterbalance the cost. The energy recovery potential is primarily depends on amount of high calorific combustibles, especially plastic waste.

Quiz 4-1: *Which is the most obvious benefit of mining MSW dumpsites in Sri Lanka?*

a) Recovery of recyclable materials

b) Recovery of combustible waste for energy recovery

c) Reclamation of space for future disposal

d) Recovery of compost from mined waste

4.4 Learning activities

1. Discuss the major risk factors that determine dumpsite classes.
2. Determine the dumpsite class you manage/monitor/have observed in Sri Lanka.

4.5 Assessment questions

1) What is the importance of conducting trial excavations prior to developing a dumpsite mining program?
    a. Trial excavation reveals information about recoverable resources in the dumpsite.
    b. Trial excavation gives sufficient information about dumpsite stability.
    c. Dumpsite mining cost can be estimated by trial excavations.
    d. Trial excavations are used to develop site excavation plans.

2) What are the five dumpsite classes derived from?
    a. Size of the dumpsite
    b. Location of the dumpsite
    c. Sensitivity Index of the pollution attribute
    d. Hazard Potential Index of the dumpsite

3) What is an Environmental Monitoring Plan (EMP)?
    a. A document prepared to satisfy regal requirements of dumpsite rehabilitation.
    b. An executable plan to conduct assessments/tests to ensure integrity of applied remedial measures.
    c. The leachate quality testing schedule.
    d. A checklist to fill during site visits.

4) What is the most appropriate statement about the regulatory framework for dumpsite management and rehabilitation in Sri Lanka?
    a. The dumpsite owner or operator should inform the Central Environment Authority about the rehabilitation plan, preferably prior to the risk assessment.
    b. The dumpsite owner or operator should wait until the Central Environment Authority issues a directive to rehabilitate or safely close a dumpsite.
    c. Only privately own dumpsites need to comply with regulatory requirements.
    d. The operation of MSW open dumpsites is not regulated by law.

Session 5: Dumpsite rehabilitation levels, operation, and post-rehabilitation maintenance

LEARNING GUIDE

Prior to reading this session, the trainee should read the following chapters from "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka":

Chapter 7: Dumpsite rehabilitation and closure levels

Chapter 8: Maintenance of rehabilitated or closed facilities

Learning outcome of Session 5

1) Explain the difference between the four different closure levels.
2) Describe the design requirements for each closure level.
3) Describe the major operation and maintenance activities of a rehabilitated dumpsite.
4) Explain phytoremediation and permeable reactive barrier as appropriate remediation techniques.

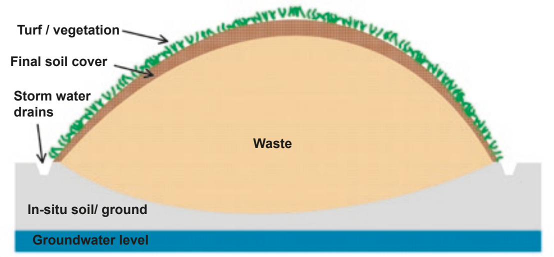
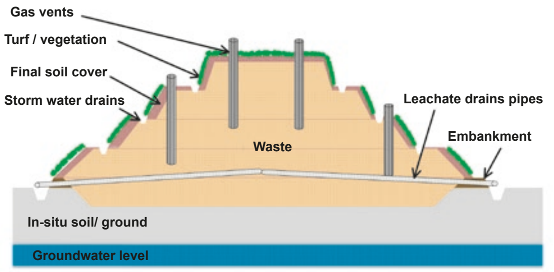
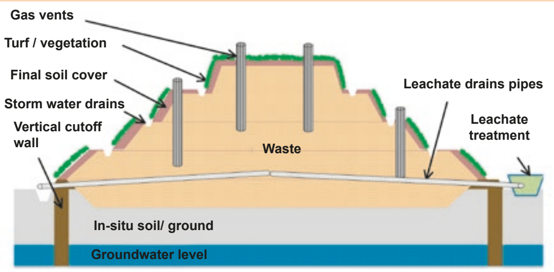
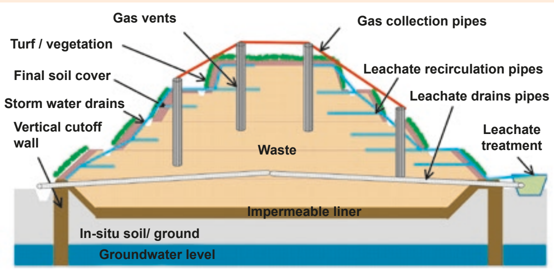
Resources

1) Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka
2) Presentation handouts
3) Flip charts, drawing paper, pens

Total time: 2 hours

5.1 Dumpsite closure levels

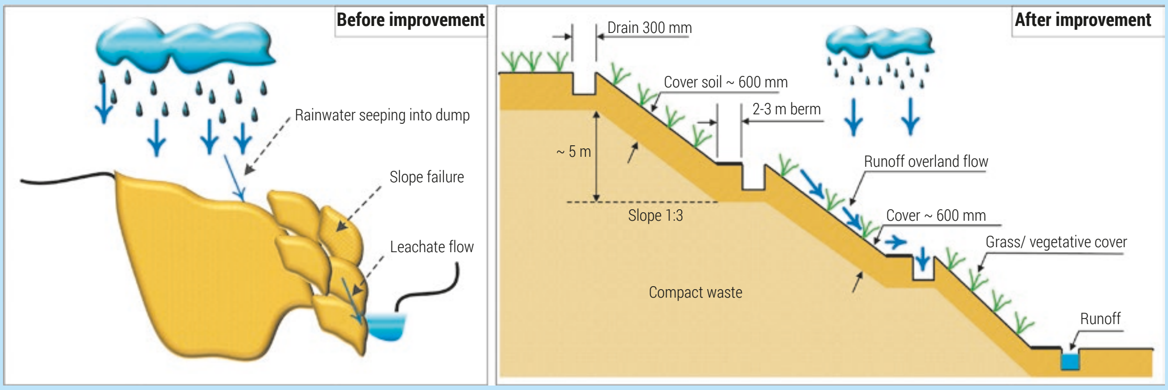
The level of safe closure for each group can basically be set according to the priorities shown in the following Table. To estimate the scale of the budget required as well as other items, it is necessary to estimate which closure level from C1-C4 should be applied to each dump site.

Closure level	Requirements
C1 Minimum closure level  Dumpsite closure: Level C1	✓ 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  Dumpsite closure: Level C2	✓ Waste dump is reshaped and restructured to ensure stability ✓ Vegetative cover is established on cover soil to protect from erosion ✓ Drains are established on terraces, slopes and around the closed dumpsite ✓ Leachate drain pipes are installed on slopes and bottom ✓ Vertical gas vents are installed to reasonable depth on the dump
C3 Moderate closure level  Dumpsite closure: Level C3	✓ Waste dump is reshaped and restructured to ensure stability ✓ Vegetative cover is established on cover soil to protect from erosion ✓ Drains are established on terraces, slopes and around the closed dumpsite ✓ Leachate drain pipes are installed on slopes and bottom ✓ Vertical gas vents are installed to reasonable depth on the dump ✓ Leachate treatment system is installed ✓ Vertical gas vents are installed to a reasonable depth on the dump ✓ Groundwater monitoring wells are installed
C4 Advance closure level  Dumpsite closure: Level C4	✓ Waste dump is reshaped and restructured to ensure stability ✓ Vegetative cover is established on cover soil to protect from erosion ✓ Drains are established on terraces, slopes and around the closed dumpsite ✓ Leachate drain pipes are installed on slopes and bottom ✓ Vertical gas vents are installed to reasonable depth on the dump ✓ 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

Final cover design

The final cover should comprise the cover soil laid on top of the final waste layer, after the waste dumping has been completed. The purpose of the final cover is to improve the sanitary conditions, landscape, and post-closure land use, and to reduce leachate quantities, etc., as below:

- Prevention of breeding of vectors, such as flies and mosquitoes
- Prevention of scattering of waste (i.e., to ensure waste is not exposed)
- Reduction of offensive odor (smell)
- Prevention of outbreak of fire
- Minimize the production of leachate by reducing the percolation of surface rainwater into waste layers, hence minimizing groundwater contamination
- Minimize gas emissions at least by partial oxidation of methane generated




a) Unstable slope


b) Making stable slope


c) Making gentle slope by excavators


d) Applying final cover on slope


e) Applying turf and berms on slope


f) Stabilized slope after final cover

Quiz 5-1: *What can be achieved by installing a bench terrace on a landfill slope?*

a) Easy stormwater diversion

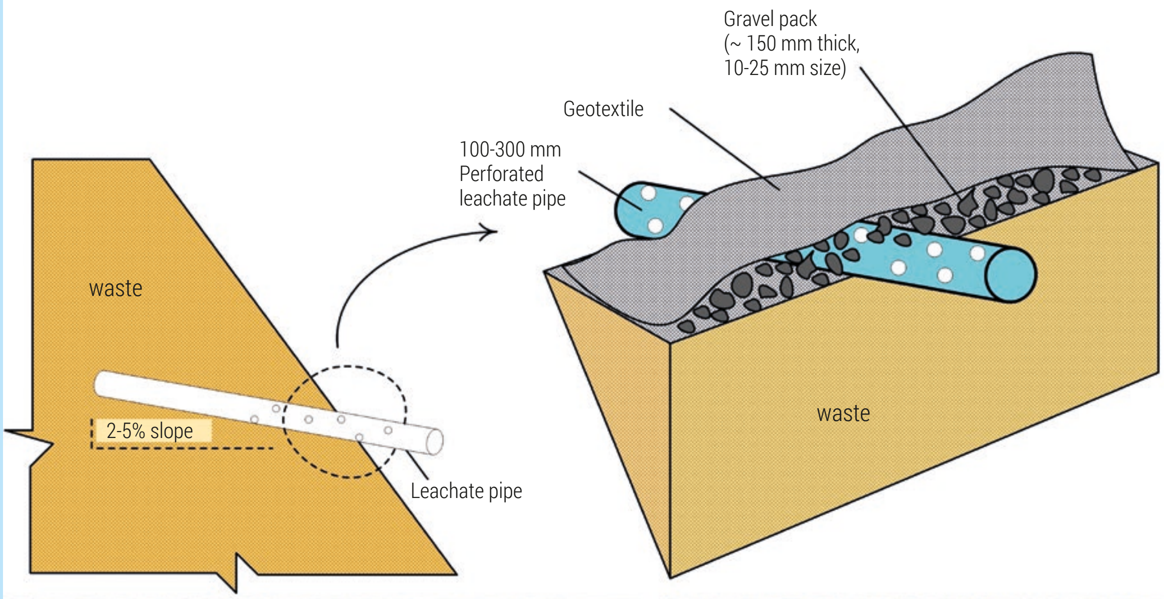
b) Increased slope stability

c) Assists in operation and maintenance activities

d) All of the above

Leachate collection systems

The primary purpose of installing a leachate collection system is to lower the leachate entrapment and ponding inside the waste fill, which will increase stability of the dumpsite. Also, collection of leachates from the dump greatly reduces the leachate percolation to groundwater. Removal of excess leachate within the dump, as well as gas venting and air supply helps stabilize the dumped waste by transforming the interior of the dumpsite from an anaerobic to a semi-aerobic condition.



Leachate treatment systems

The purpose of installing a leachate treatment system is to prevent surface and groundwater pollution by the discharge of untreated or partially treated leachate into the environment. Leachate treatment also avoids health-related factors in water utilization in the downstream region. The optimal leachate treatment method should be designed by combining various systems. Leachate recirculation or primary aeration in a retention pond achieves only partial treatment of leachate, therefore the designer should consider appropriate options for treating the leachate if the treated water is to be discharge into surface water bodies or the surrounding environment.

a) Attached growth biofilm (Coconut fiber Biofilm - COTS) treatment system installed at the Moonplains rehabilitated dumpsite in Nuwara Eliya, Sri Lanka

b) Attached growth biofilm on a roughing filer installed at a rehabilitated landfill in Malaysia

c) Series of stabilization ponds installed in a semi-engineered landfill in Ampare, Sri Lanka

c) Treatment watland ditches installed in a semi-engineered landfill in Addalachchenei, Sri Lanka

Quiz 5-2: *What types of leachate can be effectively treated by constructing a wetland system?*

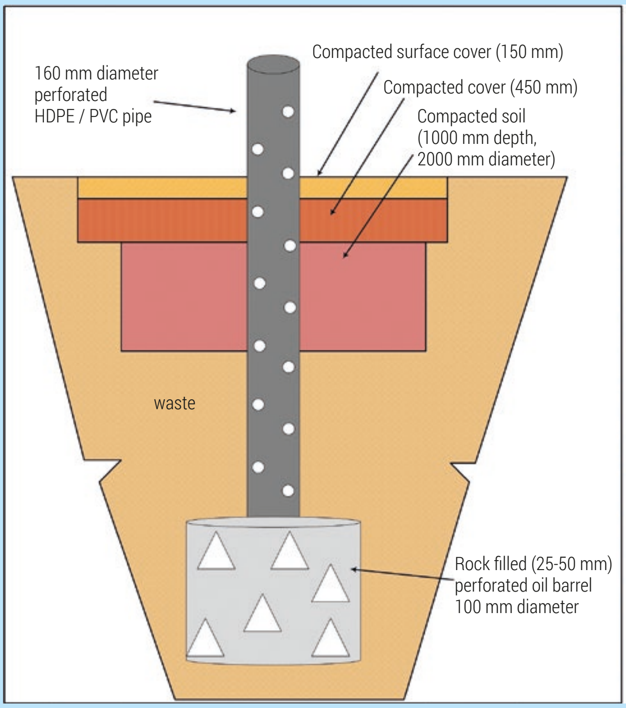
- *a) Fresh leachate from an active dumpsite*
- *b) Leachate from an old dumpsite*
- *c) Effluent from a primary leachate treatment system*
- *d) Leachate mixed with sewage*

Quiz 5-3: *Which method can be used to control leachate generated in a dumpsite?*

- *a) Compacting waste*
- *b) Applying a thin layer of cover soil on a flat surface*
- *c) Installing leachate collection pipes*
- *d) Installing stormwater interception drains*

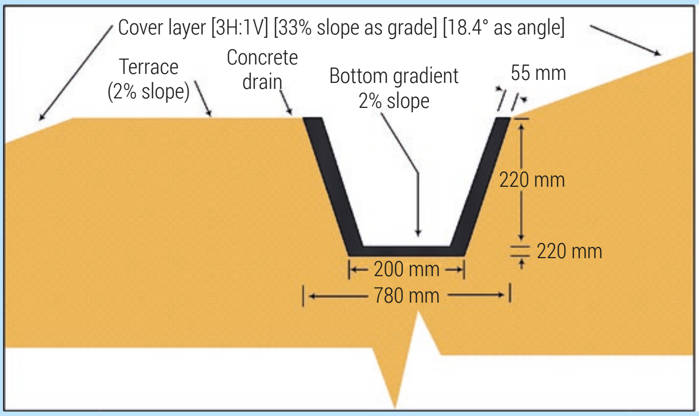
Passive ventilation systems

The waste decomposition process will generate a large amount of landfill gasses such as methane and carbon dioxide, which rises and escapes through the surface. The gas vents should be provided and installed deep into the waste layers to allow the gasses to escape and vent to the atmosphere. The vents also act as air pipes to supply air deep into the waste layers to promote the decomposition process and to accelerate the stabilization of closed dumpsites.



Surface water drains

The purpose of establishing a proper surface water drainage system is to channel rainwater from the cover surface site to the discharge drains on berms and at the base of the dumpsite. This will reduce surface water percolating into the waste layers and prevent soil erosion.

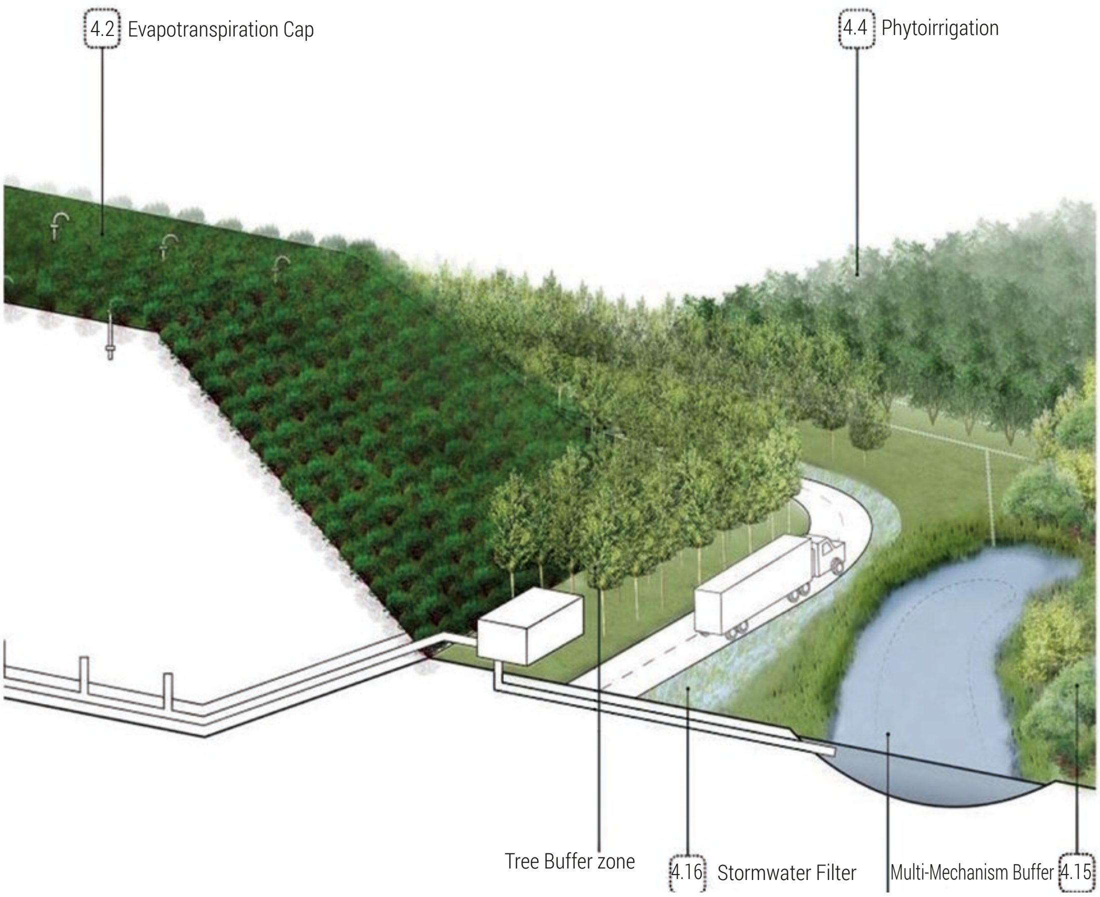


5.2 Dumpsite and landfill site remediation

The use of phytoremediation, i.e., use of plant and vegetation to remediate contaminated land and water, has been demonstrated to assist in waste management. 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.

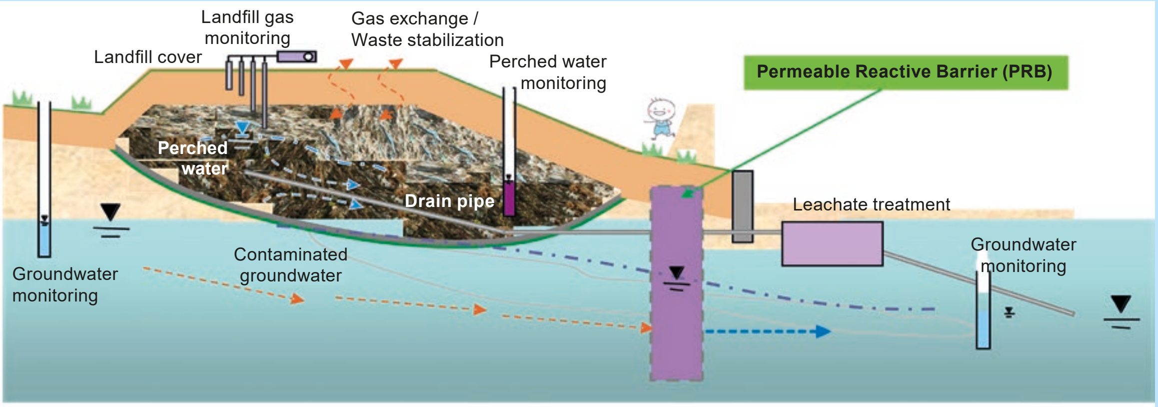
Phytoremediation

Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater.



Permeable Reactive Barrier (PRB) for groundwater remediation

A permeable reactive barrier (PRB) is one of the in-situ methods available for treating contaminated groundwater. PRB is an 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 an environmentally acceptable form(s) to attain the target remediation concentration on the down-gradient of the barrier.



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

5.3 Learning activities

1. List appropriate dumpsite slope stabilization measures that could be applied to the dumpsite that you manage/monitor/have observed in Sri Lanka.
2. List the different types of cost-effective leachate treatment systems available in Sri Lanka.
3. Prepare a schedule for maintaining a rehabilitated dumpsite.

5.4 Assessment questions

1) What is the most important factor that decides the rehabilitation/closure level of an open dumpsite?
   a. Cost
   b. Environmental risk
   c. Post-closure land use
   d. Climate

2) What is the essential component that must be established for all dumpsite closure levels?
   a. Dumpsite cover system
   b. Impermeable liner at bottom
   c. Leachate treatment system
   d. Landfill gas treatment system

3) What is the purpose of installing a PRB system in MSW dumpsites?
   a. To increase stability of the dumpsite.
   b. To treat leachate.
   c. To prevent groundwater flow.
   d. To reduce pollutants in contaminated groundwater.

4) What is the benefit of landfill gas flaring?
   a. Maintains a lower risk of landfill fires.
   b. Reduces bad odors emitted from dumpsites.
   c. Reduces the impact of greenhouse gas emissions.
   d. Helps lower landfill gas produced by the landfill.

5) Which statement best describes the functions of a vegetative buffer zone?
   a. It purifies landfill gases.
   b. It treats leachate.
   c. It has multiple benefits, the major ones being prevention of littering, dust emissions and erosion control.
   d. It increases oxygen levels around the landfill site.

Additional readings

Prospective users 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 in 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://jkspcb.nic.in/ContentGuidelinesforDisposalofLegacyWaste.aspx?id=10484 (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* https://www.cseindia.org/content/downloadreports/10487 (accessed on 18/01/2021).

A Roadmap for closing Waste Dumpsites - The World's most Polluted Places, ISWA Scientific and Technical Committee Work-Program 2015-2016. Auerspergstrasse 15, Top 41 1080 VIENNA-AUSTRIA. *This document is available at* https://www.resource-recovery.net/en/content/roadmap-closing-waste-dumpsites-world%E2%80%99s-most-polluted-places (accessed on 18/01/2021).

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Answers for the quizzes and evaluation questions

Session 1	Quizzes	1-1	(c)
		1-2	(b)
	Assessment questions	1	(c)
		2	(b)
		3	(c)
		4	(a)
Session 2	Quizzes	2-1	(a)
	Assessment questions	1	(d)
		2	(d)
		3	(c)
		4	(b)
		5	(d)
Session 3	Quizzes	3-1	(b)
		3-2	(a)
	Assessment questions	1	(c)
		2	(a)
		3	(b)
Session 4	Quizzes	4-1	(c)
	Assessment questions	1	(a)
		2	(d)
		3	(b)
		4	(a)
Session 5	Quizzes	5-1	(d)
		5-2	(c)
		5-3	(d)
	Assessment questions	1	(b)
		2	(a)
		3	(d)
		4	(c)
		5	(c)

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