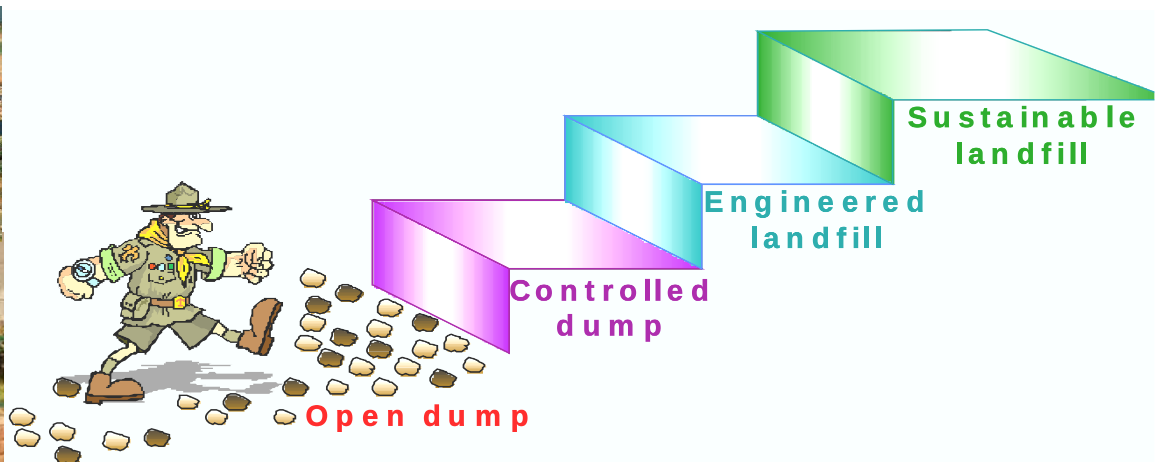
DUMPSITE

REHABILITATION MANUAL



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Dumpsite Rehabilitation Manual

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NOTICE/DISCLAIMER

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PREFACE

The Asian Regional Research Programme on Environmental Technology (ARRPET) funded by Swedish International Development Cooperation Agency (Sida) is aimed at research on environmental concerns relevant to Asia. The issues covered include wastewater, air pollution, solid and hazardous wastes. The project is coordinated by the Environmental Engineering and Management Programme, Asian Institute of Technology (AIT), Thailand, involving National Research Institutes (NRIs) in eight countries.

This manual is an outcome of the research on Sustainable Solid Waste Landfill (SWLF) management in Asia under ARRPET. Four NRIs: National Engineering Research Center for Urban Pollution Control, Tongji University, China; Centre for Environmental Studies (CES), Anna University Chennai, India; Faculty of Agriculture, University of Peradeniya, Sri Lanka and Faculty of Engineering, Kasetsart University, Thailand representing the respective countries have been coordinated by AIT. This joint research was to investigate suitable methods for sustainable SWLF management.

This manual is a compilation of the research findings on "Dumpsite Rehabilitation and Landfill Mining" to support the worldwide initiatives on Sustainable Landfill Management. Sustainable landfill management in Asian region can be a reality in the long term. The emphasis shall be on a phased approach to the implementation of more sustainable processes that make up the desirability hierarchy of waste management in addition to solving immediate problems.

The objectives of this manual are to ensure that the open dumps are fully characterized, investigated, remediated and closed properly and to assure public health and safety. Primary focus was given to the upgrading of the operating/existing dumpsites, the most common practice of waste disposal in Asian countries. Open burning, stagnant pools of polluted water, infestations by rats and flies, scavenging by domestic animals and rag picking through the wastes by scavenging community are a common sight. The presence of waste pickers has a major impact on the operation of the dumpsite as they pose a safety hazard not only to the scavengers but to the dumpsite employees as well. It reduces the efficiency of waste disposal due to the interference with operations at the tipping face and starting of fires by the scavengers, which cause air pollution problems.

When used appropriately, the process described in this document will help to ensure that a good strategy is developed and implemented effectively.

It is hoped that this report will be useful for the government agencies and policy makers involved in urban planning and development, in general, and in the Municipal Solid Waste Management (MSWM), in particular to plan and implement sustainable urban solid waste management programme.

We take this opportunity to thank Sida for facilitating this phase of an important and opportune research. We look forward to the adoption of integrated methodology for MSWM in the study countries as well as in other Asian countries.

This report also includes the outcome of discussions with those involved in MSWM in the South Asian countries, literature review and project activities during the study period. The project team acknowledges with thanks the contribution of the participants in the discussions.

In conclusion, we express our gratitude to the following experts for critically reviewing this report and their valuable suggestions prior to its publication:

- Dr. K.R. Ranganathan, Member Secretary, Loss of Ecology (Prevention & Payments of Compensation) Authority for the State of Tamil Nadu, Ministry of Environment and Forests, Government of India, Chennai, India.

- Dr. Vijay Joshi, Vice-President, IL&FS Ecosmart India Limited, Chennai, India.

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EXECUTIVE SUMMARY

Municipal solid waste management is an important part of the urban infrastructure that ensures protection of environment and human health. The accelerated growth of urban population, increasing economic activities and lack of training in modern solid waste management practices in the developing countries complicate the efforts to improve this service sector. Although the urban residents of the developing countries produce less solid waste per capita than the high-income countries, the capacity of the cities to collect, process or reuse and dispose solid waste is limited. The most prevalent way of disposing MSW in the developing countries is open dumping, besides dumping on riverbanks and directly into the sea, which is the easiest and considered to be the cheapest method of removing waste from the immediate environment. The decomposition of biodegradable wastes in open dumpsites will result in the production of leachate and gas long after the site has stopped receiving wastes. The increasing awareness on public health and environmental quality concerns are expected to provide the impetus that is needed to develop and implement a sustainable approach to manage solid wastes and rehabilitation of the existing open dumps.

It is a matter of policy in most of the Asian cities that dumpsites be closed because of the adverse effects on society and the environment. The present report focusing on “Dumpsite Rehabilitation” recommends a phased approach to move from open dumps to sustainable landfills, taking into account the different physical and economic situations prevailing in developing countries. It is aimed at helping the national and local authorities to adopt better and environmentally sound waste disposal methods by shifting from their practice of open dumping to controlled dumping and transition to sanitary landfilling and ultimately to sustainable landfilling.

Prior to actual closure of the dumpsite, an investigation of the existing conditions of the site is conducted and the risk evaluated. This will enable planners to draw up the practical options to meet the objectives, and will be used in the development of a closure plan. The closure plan will detail the various activities to be implemented including the stabilization of steep slopes to prevent erosion hazards, the implementation of leachate and gas management systems, and the design of the final cover.

The concept and utility of landfill mining is presented as a key part of this new approach for sustainable waste management, especially for the rehabilitation of the Municipal Solid Waste (MSW) dump sites in Developing Countries. "Landfill mining" is the process of excavating existing or closed solid waste landfills or dumpsites, and sorting the excavated materials for recycling, processing, or other disposition. The success of materials recovery is dependent on the composition of the waste, the effectiveness of the mining method. This will not only be useful in rehabilitating the dumpsites and conserving of landfill space, but also eliminate potential sources of land and groundwater contamination and recover valuable resources.

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LIST OF ABBREVIATIONS

AIT	Asian Institute of Technology
AOX	Adsorbable Organic Halogens
ARRPET	Asian Regional Research Programme on Environmental Technology
BOD	Biochemical Oxygen Demand
CES	Centre for Environmental Studies
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
HDPE	High Density Poly Ethylene
HHVs	High Heating Values
KDG	Kodungaiyur Dumping Ground
LCSWMA	Lancaster County Solid Waste Management Authority
LFMR	Landfill Mining and Reclamation
MITE	Municipal Innovation Technology Evaluation
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NHDES	New Hampshire Department of Environmental Services
NRIs	National Research Institutes
NPC	National Productivity Council
NYSERDA	New York State Energy Research and Development Authority
PADGER	Pennsylvania Department of Environmental Resources
PDG	Perungudi Dumping Ground
PMC	Pune Municipal Corporation
RDF	Refuse Derived Fuel
RRF	Resource Recovery Facility
SIDA	Swedish International Development Cooperation Agency
SWLF	Solid Waste Landfill
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TPD	Tonnes per day
TS	Total Solids
USA	United States of America
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organisation

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Land filling is an important component of integrated waste management for safe disposal of the fractions of municipal solid waste (MSW) that cannot be reduced, recycled, composted, combusted or processed. About three-quarters of the countries and territories around the world use 'open dumping' method of disposal of MSW (Rushbrook, 2001). It is a primitive stage of landfill development at which solid wastes are disposed of in a manner that does not protect the environment, susceptible to open burning, and exposed to disease vectors and scavengers. Lack of adequate waste treatment and disposal infrastructure, large volumes of waste involved in metropolitan cities, proximity of disposal sites to the water bodies and ever-burgeoning residential areas even in the proximity of waste disposal sites has given rise to significant environmental deterioration and health impairment in most of the cities (Joshi and Nachiappan, 2007). In many developing countries, solid waste disposal by open dumping is still under practice for reasons such as:

- ignorance of the health risks associated with dumping of wastes
- acceptance of the status quo due to lack of financial resources to do anything better
- lack of political determination to protect and improve public health and the environment
- by traditions thus it is the oldest known way to handle MSW, just to fill a hole in the ground

It thrives because of the false belief that it is the easiest and cheapest disposal method to use in those countries with difficulties in economy or where there is insufficient political will to allocate adequate public resources to improve the prevailing disposal practices. Each municipality operates one or more open dumpsites situated close to the towns and are widely regarded as uncontrolled and unsafe operations. The dumpsites are often poorly sited and operated by inexperienced or disinterested staff. Only a handful of these sites have access to bulldozers. Thus it shows a situation of dumpsites necessitating immediate closure or rehabilitation.

Many dumpsites existing in the cities in developing countries pose a threat for human health. All of them also have a common challenge of managing the old dumpsites in a scientific manner. Historically, open dumps were commonly located on the fringe of urban development and as the cities developed, the urban fringe moved beyond the open dumps bringing residential and commercial development within their close proximity of the open dump. This brought about a conflict in land use, with dumps being considered incompatible with these uses raising community and regulatory concerns calling for its rehabilitation. There also exist cases where dumpsites close to national borders cause conflicts between two nations. Considering the difficulty in acquiring lands for the new waste disposal sites and obtaining consent from the neighboring communities for their operation, the municipalities are increasingly going in for reclamation/use of the existing disposal sites. This is carried out by best possible management of the waste already stored at site, waste processing and scientific landfilling within the existing sites for management of incoming MSW stream. This would help to some extent overcome the environmental impact of such improper disposal practices and may provide a solution to the crisis in solid waste management due to exhaustion of available space for landfilling. Sound examples of scientific management of the disposal site coupled with rehabilitation of existing dumps will go a long way in alleviating the apprehensions among the neighborhoods of negative impact on health and environment.

1.2 Waste decomposition in dumpsites and their impacts

The state of dumpsites in Asian countries is all similar: indiscriminately dumped, seemingly unplanned heaps of uncovered wastes, most of the times open burning (Figure 1.1); pools of leachate (Figure 1.2); rat and fly infestations, domestic animals roaming freely (Figure 1.3); and families of scavengers picking through the wastes (Figure 1.4). Open dumpsites do not have the necessary facilities and measures to control and safely manage the liquid and gaseous by -products of waste decomposition.

Figure 1.1
Dumpsites - a burning problem

Figure 1.2
Dumpsites - potential source of water pollution

Figure 1.3
Dumpsites - Scavenging

Figure 1.4
Dumpsites – animal roaming

The biodegradable components of waste (food and yard wastes) generally undergo anaerobic degradation in a dumpsite/landfill environment. The decomposition involves multistage dynamic processes, depending on the creation of a suitable environment subject to placement of wastes occurred at different times, heterogeneous nature of the wastes with different rates of biodegradability and the spatial variability in the physical and chemical environment of the waste materials.

Leachate is a liquid produced when the waste undergoes decomposition, and when water (due to rainfall, surface drainage, groundwater, etc.) percolates through solid waste undergoing decomposition. It is a liquid that contains dissolved and suspended materials that, if not properly controlled and treated, may pass through the underlying soil and contaminate sources of drinking water, as well as surface water. The composition of leachate depends on the stage of degradation and the type of wastes within the disposal facility. In the first few years, leachate contains readily biodegradable organic matter, resulting in an acidic pH and high biochemical oxygen demand (BOD_5). Leachate quality may vary from time to time and site to site due to variables such as waste composition, temperature, moisture content, climatic changes etc. Esakku et. al. (2007) has compared leachate quality of two large dumpsites in Chennai, India and four smaller dumpsites from Sri Lanka. According to them, the smaller dumpsites pose higher pollution potential in terms of leachate characteristics. TDS varied from 2000 to 6100 mg/L and 1200 to 8100mg/L in leachates from the Chennai dumpsites. BOD_5 and COD varied from 25 to 58 mg/L and 760 to 1198 mg/L, respectively. The COD of samples from different sites in Sri Lanka ranged from 1000 to 20000 mg/L. The BOD_5 also showed similar variations that ranged from 1000 to 4000 mg/L.

The decomposition of the waste also brings about the generation of gases, mainly methane (about 50-65%) and carbon dioxide (about 35-45%). As methane is formed, it builds up pressure and then begins to move through the soil, following the path of least resistance. Methane is lighter than air and is highly flammable. If it enters a closed building and the concentration builds up to about 5 to 15% in the air, a spark or a flame is likely to cause a serious explosion, accidents causing human loss. Aside from being a flammable gas, methane released to the atmosphere greatly contributes to global warming as it has approximately 21 times the global warming potential of carbon dioxide. Estimates say that about 5-15% of the methane released to atmosphere is related to waste dumping and waste landfilled.

If open burning of solid waste is practiced (usually, to reduce volume), it results in the emission of toxic substances to the air from the burning of plastics and other materials. The toxic fumes can cause chronic respiratory and other diseases, and it will increase the concentration of air pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), heavy metals (mercury, lead, chromium, cadmium, etc.), dioxins and furans, and particulate matter.

Open dumpsites do not have the necessary facilities and measures to control and safely manage liquid and gaseous by-products of waste decomposition and open burning. The health and environmental impacts of open dumpsite are aggravated due to:

- Unplanned siting.
- Haphazard operations as there are no general operational guidelines governing proper operation of the facility and many operators of these dumpsites lack equipment as well as the necessary expertise.
- Poor control over waste inputs, either in quantity or composition (or both)
- Random disposal of waste fractions at the dumpsite
- No control over emissions of pollutants released due to waste decomposition and burning of waste.

The growing concerns about public health, environmental quality and the risks associated with the existing and newly designed MSW landfills are making it nearly impossible to site new landfills in many parts of the world (Lee *et al*, 1989a). This calls for a new approach involving the following steps for sustainable management of landfills:

- Practice of waste minimization and recycling to conserve the remaining space in currently used landfills.
- Landfill mining operations to free new landfilling space.
- Integrating the concepts of dumpsite rehabilitation and landfill bioreactor system combined with landfill mining to enable responsible and protective management of municipal solid waste without locating new landfills.

Public health and environmental quality concerns along with escalating costs of monitoring and remediation would provide the impetus needed to develop and implement this sustainable approach to the management of solid waste and landfills.

If an open dumpsite is close to a developed area, there is generally more pressure to implement more acceptable or stringent closure and post-closure measures. Owners and operators of waste disposal facilities, especially financially-constrained local government units, should determine what is most appropriate based on several other factors indicated in Figure 1.5 rather than solely on initial costs. These factors include its technical feasibility, financial viability and environmental soundness compliance to the legal requirements as well as acceptability to the society. The following chapters of this manual will present a detailed analysis of the techno economic issues related to dumpsite closure and rehabilitation.

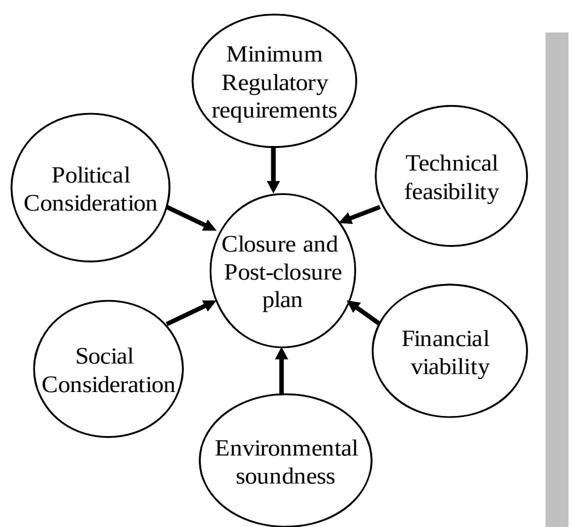


Figure 1.5
Considerations in the closure and rehabilitation of dumpsites

CHAPTER 2

DUMPSITES TO SUSTAINABLE LANDFILLS

2.1 THE APPROACH

At present, there are only limited resources for upgrading or replacing these dumpsites and, equally, limited funds and technical competence to operate and maintain land disposal sites. The attainment of highly complex landfill design and construction as practiced in the developed world may not be possible immediately. Under such circumstances, the improvement of land disposal practices may be achieved by a step-by-step approach (Rushbrook, 1999, 2001). The approach involves four steps as depicted in Figure 2.1 that shows the move from open dumps to sustainable landfills.

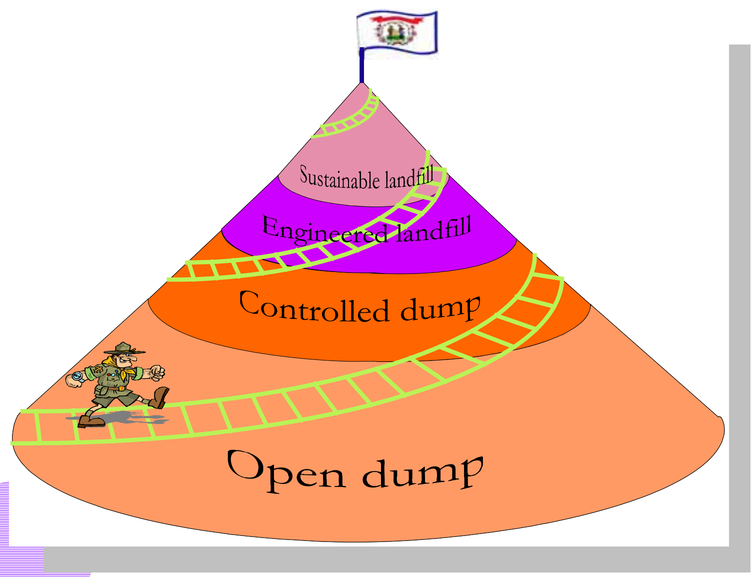


Figure 2.1
Phased approach to dumpsite rehabilitation

Such a phased approach has been attempted in South Africa (Ball and Bredenhann, 2003). Marques (2000) has suggested setting up of numerous sorting facilities and machines for upgrading the waste components and to improve the surface after closure of the dump to make it a beautiful waste management park. The steps to be taken may vary depending on local circumstances but all changes introduced should represent a progressive improvement over open dumping. It is best to identify those parts of the present land disposal operation that are unsafe or unsanitary and adopt ways to improve those using local materials and resources.

The general philosophy of the phased approach in addressing the challenge is to ensure sustainability and is internationally accepted as the best practicable environmental option approach to move from open dumpsites to sustainable landfills (Table 2.1) This approach assesses alternatives and aims to provide the most benefit or least damage to the environment as a whole, at an acceptable cost in the short and long term. "Attainability and Sustainability" are the key parameters to be focused on when setting standards for the upgradation of the dumpsites.

The first and the foremost challenge will be to decide whether the Open dumpsite should be closed and/or remediated or rehabilitated based on the environmental risks posed by it. This may involve technical investigations and rapid risk assessments (Chapter 3), including consultation with the interested and affected parties, especially the adjacent communities. Features of the dumps such as the depth and nature of waste, degree of compaction, variability of wastes within the site, the size of the dumps and the areal extent of the dumps need to be assessed. If there are a number of dumps that need to be rehabilitated and only limited resources are available, higher priority may be assigned to dumpsites with high health risk, maximum environmental impacts and public concerns and minimum rehabilitation costs. The issues of concern include operational history of the site, the rehabilitation process and after use issues and associated health risks, environmental issues and local impacts such as water and air pollution, hydro geological features, noise, dust and visual impacts, wetlands protection, and real or perceived negative neighborhood image/property value and availability of funding.

Table 2.1. General characteristics of land disposal facilities

Criteria	Open Dump	Controlled Dump	Sanitary Landfill
Siting of facility	• Unplanned and often improperly sited	• Hydrogeologic conditions considered.	• Environmental, Social and Economic factors
Capacity	• Site capacity is not known	• Planned capacity	• Planned capacity
Cell planning	• No cell planning and the waste is indiscriminately dumped • The working face/area is not controlled	• There is no cell planning, but the working face/area is minimized • Disposal is only at designated areas	• Developed cell by cell • Working face/area is confined to the smallest area practical • Disposal only at designated cells
Site Preparation	• Little or no site preparation, usually a wetland / swamp areas are used.	• Grading of the bottom of the disposal site • Drainage and surface water control along periphery of the site	• Extensive site preparation and bottom lining
Leachate management	• No leachate management	• Partial leachate collection and simple treatment	• Full leachate collection and advanced treatment • Leachate quality control programme
Gas management	• No gas management	• Partial or no gas management	• Full gas management • Gas emission control / warning systems
Application of soil cover	• No covering of waste	• Covering of waste implemented regularly but not necessarily daily	• Daily, intermediate and final soil cover applied
Compaction of waste	• No compaction of waste	• Compaction in some cases	• Waste compaction
Access road maintenance	• No proper maintenance of access road	• Limited maintenance of access road	• Full development and maintenance of access road
Fencing	• No fence	• With fencing	• Secure fencing with gate
Waste input control	• No control over quantity and /or composition of incoming waste	• Partial or no control of waste quantity, but waste accepted for disposal is limited to MSW	• Full control over quantity and composition of incoming waste • Special provisions for special types of wastes
Record keeping	• No record keeping	• Basic record keeping	• Complete record of waste volumes, types, sources and site activities/events
Waste picking	• Waste picking by scavengers	• Controlled waste picking and trading	• No on site waste picking and trading
Closure	• No proper closure of site after cease of operations	• Closure activities limited to covering with loose or partially compacted soil and replanting of vegetation	• Full closure and post-closure management
Cost	• Low initial cost, high long term cost	• Low to moderate initial cost, high long term cost	• Increased initial, operational and maintenance costs, moderate long term cost
Environmental and health impacts	• High potential for fires and adverse environmental and health impacts	• Lesser risk of adverse environmental and health impacts compared to an open dumpsites	• Minimum risk of adverse environmental and health impacts

Source : UNEP, 2005

When the decision is to rehabilitate or upgrade the site, the first step should be to move from open dumping to "controlled dumping" which can be achieved in most middle and low-income countries in the short term without much investment. This will significantly improve the site and reduce its adverse impacts and associated nuisance. This involves reducing nuisances such as odors, dust, vermin, and birds. The principle of landfill mining may be used as the driver to convert this challenging task into an opportunity. The possible outcome would include recovery of space for future landfills, soil fraction for growing non-edible crops as well as landfill cover material and the plastics for making refuse derived fuel. A natural remediation technique such as phytoremediation using higher vascular plants, though slow, is also worth considering.

2.2 Open Dumping

Open dumping is the most common method of MSW disposal in many middle and lower-income countries and such practices must be brought to an end. Characteristics of a typical dumpsite in these countries are listed in Box 2.1.

Box 2.1 Characteristics of open dumpsites

- No planning
- No one on site who can exercise authority
- No access control or control over the type of waste entering the site
- Scavenging by the rag pickers
- Water logging and leaching during monsoon causing water pollution
- Dust nuisance due to vehicular movement
- Blowing of light materials like plastics, paper etc., due to winds
- Trespassing and open defecation by the public
- No control of waste deposition
- Odour and fly nuisance
- No confinement of the waste body
- Uncontrolled burning of waste emanating smoke and causing air pollution

It is also possible that no proper siting or site investigation and no engineering design are done for the site. It will therefore have no groundwater protection and drainage controls. Thus, the first task will be to decide if the site should be closed and/or remediated or rehabilitated. To determine whether to rehabilitate and close, or to remediate, upgrade and operate a dumpsite, the environmental risks posed by the site must be assessed. These may involve technical investigations and Environmental Impact Assessments (EIAs), in consultation with the interested and affected parties, specifically in the adjacent communities.

Technical investigations assess the siting of the dumpsite and identify any flaws e.g., sites situated in floodplains, watercourses or groundwater; or sites that adversely affect the environment and, because of insufficient buffer zones, adversely affect the quality of life of adjacent residents. The key steps towards upgrading the dumping sites may include evaluation of some criteria to assess the risk of the current practices and to prepare an action programme for the dump rehabilitation (Box 2.2).

Box 2.2 Criteria for upgrading dumpsites

- Characteristics of the dumps, such as the depth and characteristics of solid waste and degree of compaction that took place, variability of wastes within the site, the size of the dumps as defined by the total amount of solid waste disposed of and the areal extent of the dumps
- Environmental and health impacts of the existing dumps and definition of current contamination
- Potential for "mining" decomposed organic materials (compost) from the existing dumps
- Potential of using the compost mined or developed from the land dumps as the daily cover material
- Occupational health of landfill scavengers and scope for assimilating these scavengers into the onsite activities during the upgradation of dumps
- Number of people and especially any sensitive populations that could be influenced by the release of pollutants from the landfill and the duration of exposure

The investigations should also consider the integrity and effectiveness of landfill design and the need for remedial design. They should also assess the operation in terms of standards and resource constraints. Finally, whenever a site has a limited life, this promotes the closure alternative. However, closure can only be considered if a replacement site is available.

2.3 Controlled dumping

The controlled dumpsite is still an unacceptable operation, as it does not comply with the fundamental landfill principles of waste compaction and covering. However, it is a step higher than the open dumpsite as there are certain "Basic Control Measures" (Box 2.3) in place.

Box 2.3 Basic control measures for controlled dumping

- A person in authority is on site
- Control of vehicle access to the site
- Control over the types of waste entering the site
- Control over where vehicles may drive and deposit waste on the site
- Waste will be deposited in a single controlled area where basic waste handling techniques will ensure a controlled and consolidated waste body
- Uncontrolled waste burning will be eliminated
- There will also be preliminary drainage control measures
- Control will be exercised over salvaging operations
- Foraging animals will be driven out of the site

Conversion of an open dump into a controlled dump means that disposal will be on a site previously used for open dumping. Thus, preparation of the area will consist of leveling and compacting existing garbage heaps and construction of drainage canals/ ditches, among others. Prescribed operational procedures include limiting the working face area, application of daily cover and miscellaneous provisions such as installation of litter barrier and others. The facility is also monitored for incoming waste volumes, water quality, condition of drainage systems and others.

While the World Health Organisation (WHO) suggests one year for this progressive upgrade steps (Rushbrook, 2001), it may vary depending on the original status and local conditions. Success depends mainly on the commitment of the concerned authorities and capacity building in the responsible organization through training, to ensure sustainability.

2.4 Engineered Landfill

An engineered landfill is a disposal site where, through planning before construction or through modifications at an existing site, there is a gradual and obvious adoption of engineering techniques (Box 2.4).

It is based on the concept of isolating the landfilled wastes from the environment until the wastes are stabilized and rendered innocuous as much as possible through the biological, chemical and physical processes of nature. Essentially, the landfill design should incorporate the components enumerated in Box 2.5 and depicted in Figure 2.2.

Box 2.4 Engineered landfill techniques

- Control and avoidance of surface water entering the deposited wastes by installing a well designed and constructed surface drainage system
- Extraction and spreading of soil materials to cover wastes
- Spreading and compacting wastes into smaller layers
- Collection and removal of leachate away from wastes into lagoons or similar structures.
- Passive venting of landfill gas out of the wastes
- Improvements in the isolation of wastes from the surrounding geology

Box 2.5 Components of engineered landfill

- **Liner system** at the base and sides of the landfill - prevents migration of leachate or gas to the surrounding environment;
- **Leachate collection and treatment system** - collects and extracts leachate from within and from the base of the landfill and treated to meet regulatory requirements;
- F**inal cover** of the landfill - enhances surface drainage, prevents infiltration of water and supports surface vegetation;
- **Surface water drainage system** - collects and removes all surface runoff from the landfill site;
- **Environmental monitoring system** - periodically collects and analyses air, surface water, soil and ground water samples around the landfill site;
- **Organized and well qualified work force and detailed record keeping system; and**
- **Landfill closure and post closure monitoring.**

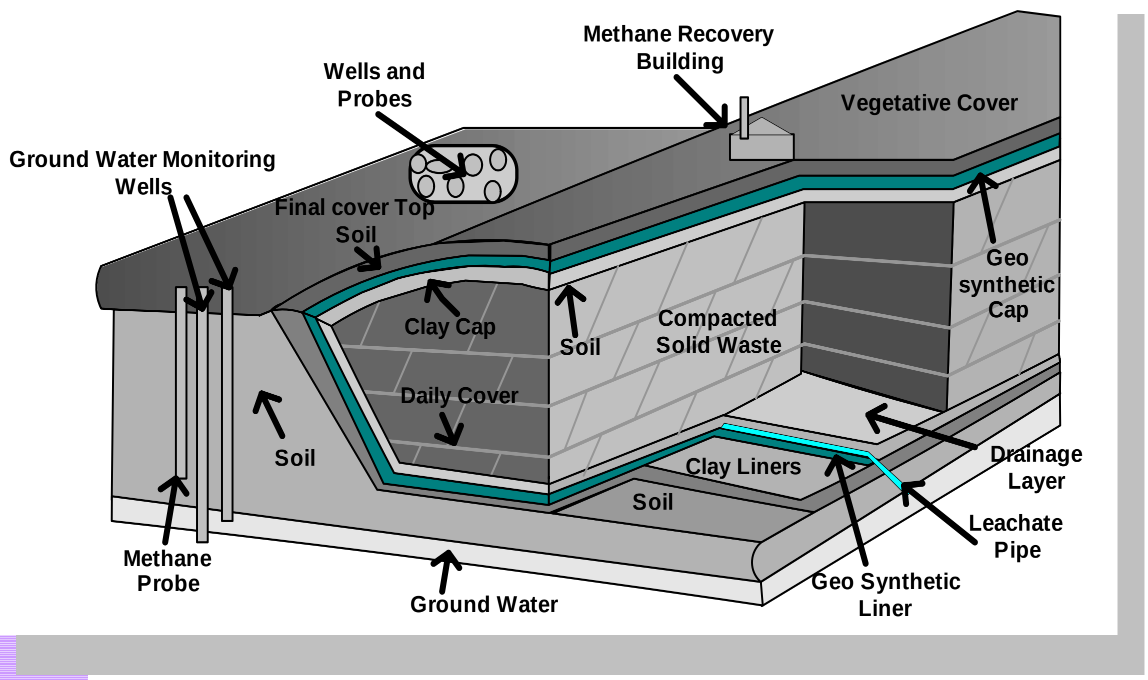


Figure 2.2

Cross section of a typical engineered landfill

Movement from open dumping to sanitary landfills may be a long-term goal since sufficient physical and financial resources are only likely to be available in a limited number of places over the next few years to reach this standard of waste disposal.

The development of these disposal facilities requires thorough planning and design, from its inception to its planned after use. Siting, design, construction and operation requirements are much more broad and stringent than other modes of land disposal. Sanitary landfills have the least impact to public health and the environment as compared to open dumpsites or controlled disposal facilities.

Reliance on heavy equipment such as landfill compactors to achieve high density may not be critical if the wastes are already dense with less bulky material. In areas where the supply of fuel or electricity may be interrupted, gravity and natural systems should be preferred for leachate management over mechanical systems. The principle of 'keep it simple' and 'make it sustainable' should be adopted rather than a 'high tech' solution.

2.5 Sustainable Landfill

Waste disposal sites that are planned, designed and constructed according to good engineering practice, and operated so that they cause minimum environmental impacts are called sanitary landfills. Until recent years, the driving principle of landfill management has been to prevent saturation of the waste to minimize the likelihood of leachate leaking into the surrounding ground as in an Engineered Landfill. This has resulted in very slow rates of waste degradation, with projected stabilization times of the order of hundred years. Degradation can in principle be accelerated by circulating fluids through the waste in a controlled manner, and operating the engineered landfill as a bioreactor. This approach is more consistent with the aims of a sustainable waste management policy than the conventional "dry tomb" approach, which leaves landfilled wastes in a potentially polluting state for many generations.

In sustainable landfills, airspace, processes, control and/or use of products and residues are at an optimum and where minimal negative effects on the environment takes place. The goal is to treat the waste within a lifetime of man. This can be achieved when the waste within a landfill becomes stabilized and the stabilized waste is mined to make the space available for refilling. Landfill mining in a sustainable landfill should be attempted when the landfilled wastes are sufficiently stabilized. The attainment of this level depends to a large extent upon parameters that control the chemical and biological processes (e.g., moisture content, temperature, microflora, and compaction rate) occurring in the landfill waste (Zurbrugg, 1999).

Two methods of landfill disposal, often called the *anaerobic bioreactor* and the *aerobic biocell,* are attempts in this regard (Reinhart and Timothy, 1998). The anaerobic bioreactor is similar in design to an engineered landfill and the basic difference is in operational practices, which involves leachate recirculation to enhance waste stabilization. It has a leachate collection and recirculation system, geomembrane liners, final cover, and gas collection system. In this type of system, the gas that is predominantly produced is methane, which can be collected and purified for sale and/or used. The level of methane production will be related to the level of organic waste present in the landfill. On the other hand, the aerobic biocell is set up just like the anaerobic except for the presence of an air circulation system. Unlike the anaerobic bioreactor, the ultimate objective is to maximize the speed of decomposition of the contents. Air is percolated through the landfill to encourage aerobic decomposition and the accompanying preferential production of carbon dioxide instead of methane. Since methane production is not the aim of this landfill, the level of organic waste will not affect its performance as much as the anaerobic system.

Environmental Control Systems, Inc. (2001) of South Carolina, provides a method for treating biodegradable waste material in a sustainable landfill by aerobic degradation (Figure 2.3). The purpose of this approach is to accelerate the natural degradation of the waste, as aerobic processes can degrade wastes up to 30 times faster than under anaerobic conditions. In the end, the "stabilized" waste mass has limited methane and odour production, produces less harmful leachate that can impact groundwater, and settles to the point whereby the landfill "recovers" valuable landfill airspace. In addition, the waste is in a safer condition to recycle, paving the way to "reusable" or "sustainable" landfills and lowering life-cycle landfill costs.

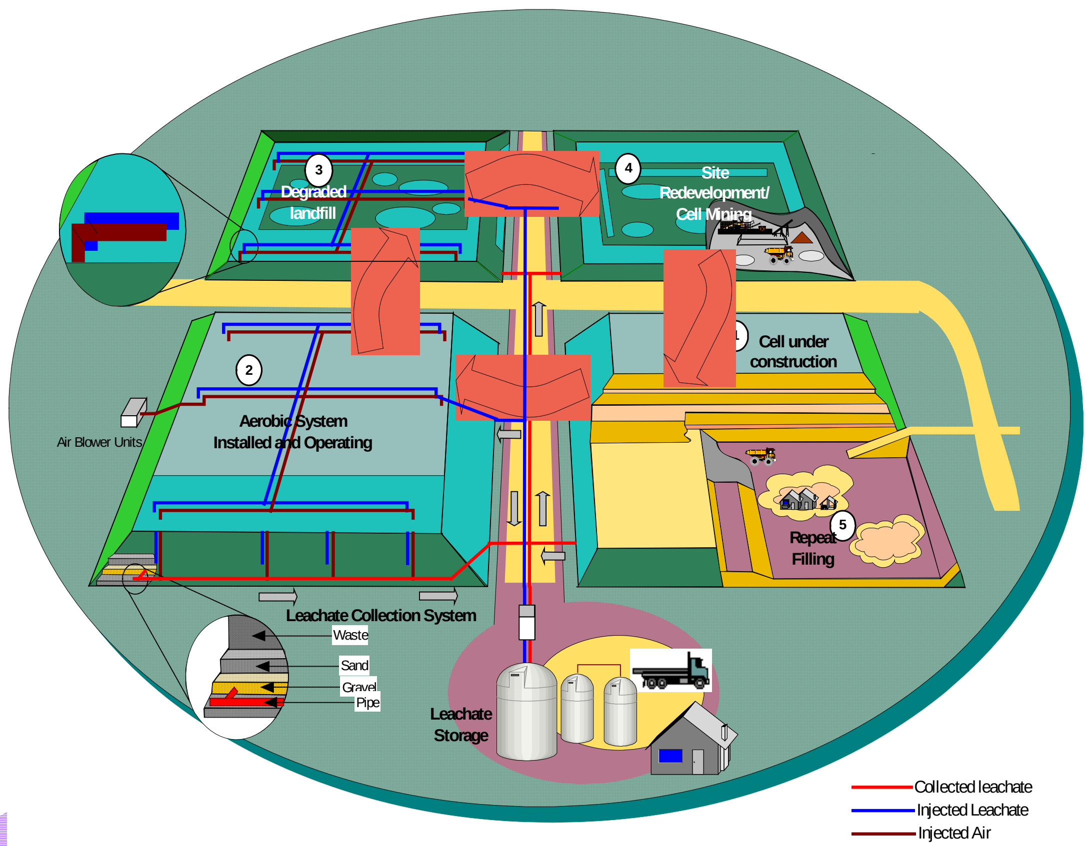


Figure 2.3

Schematic of a sustainable landfill

2.6 Integrated Approach

The concerted investigations from various Asian institutions have revealed that the sustainable landfill management in Asia could be achieved by an integrated approach as illustrated in Figure 2.4 (Kurian et. al. 2003). Dumpsite rehabilitation would be a paramount option to rehabilitate existing open dumps through landfill mining where the resource recovery might serve as a source of energy, recycle and reuse of metals, plastic and glass ware, use of compost as fertilizer for agriculture and as a cover material for future landfills. Since land close to the origin of the domestic waste is hard to find, dumpsite rehabilitation might benefit in regaining a suitable site for an engineered landfill.

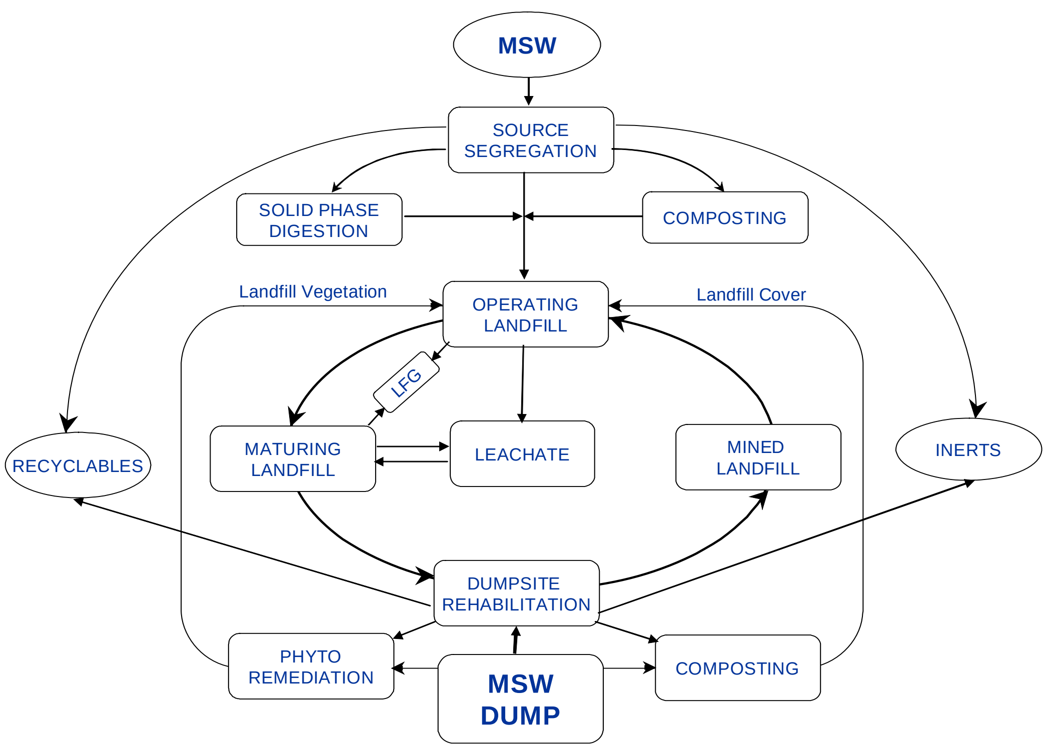


Figure 2.4

Integrated approach to sustainable landfill management

Pre-treatment of municipal solid waste prior to landfill through either aerobic or anaerobic, or a combination of both may become necessary to reduce the total amount of waste to be disposed off. This will also diminish the leachate treatment, gas management, geotechnical problem of landfill settlements and after care period.

The effects of pretreatment, compaction, and appropriate cover design would greatly minimize the pollution load to the environment. However, better understanding of the local climatic effect on enhanced degradation would help accomplish better landfill leachate management. Focus has to be given to the interaction of design and flexible operation, which needs trained and experienced staff. As environmental burden cannot be completely reduced, biologically enhanced methane oxidation and combined biological and low cost chemical-physical treatment of landfill leachate is a final practice of open-ended aftercare. A natural remediation technique such as phytoremediation using plants, though slow, is also worth considering.

CHAPTER 3

A DECISION MAKING TOOL

3.1. Dumpsite Rehabilitation and Environmental Risks

Reclamation and Rehabilitation of dumpsites as tools for sustainable landfilling have been in vogue throughout the world for the last 50 years (Cossu *et al*., 1996, Hogland *et al*., 1996). The critical questions to be answered include:

- Should the dump be closed or converted?
- If closed, is the site to be remediated?
- What standards are achievable at the dumpsite?

The first task would be to decide if the site should be closed, remediated or rehabilitated. To determine whether to rehabilitate and close or remediate, upgrade and operate a dumpsite, the environmental risks posed by the site must be assessed. These may involve technical investigations and environmental impact assessments (EIAs) including consultation with the interested and affected parties, specifically the adjacent communities.

The perception of risk is central to the fear, which the public frequently associates with the waste storage/disposal facility. Co-disposal of wastes other than municipal solid wastes, such as medical and toxic and hazardous wastes, in the site increases the risks to public health and the environment.

Typically, risk assessment process is a set of logical, systemic, and well-defined activities that provide the decision maker with a sound identification, measurement, quantification and evaluation of the risk associated with certain natural phenomena or man-made actions. The estimation of the potential adverse impacts of the waste disposal facilities on public health and the environment requires evaluation of the following:

- mass rate of release of both waterborne and airborne pollutants.
- areal extent of contamination, and persistence and transformation of the pollutants and their transformation products.
- concentrations and gradients of those pollutants that adversely impact air, water and land resources.
- number of people and especially sensitive populations that could be influenced by the release of pollutants from the site.
- total period of time over which pollutant release will occur.
- duration of exposure.
- synergistic and antagonistic impacts of other pollutant releases or adverse health conditions that might cause an exposed population to be more susceptible to pollutants derived from the site.
- characteristics of the site such as the depth of solid waste and degree of compaction.
- characteristics of the wastes accepted by the site owner/operator during the landfill's active life.
- size of the site as defined by the total amount of solid waste disposed of and the areal extent.
- Potential psychological effects on public health

Although one of the objectives of scientific risk assessment is objectivity, it is still subjective due to the non-availability of specific data on the dose response relationship for the chemicals of concern and the number of assumptions and interpretations involved in the process. In the face of uncertainty, it is fit to have a simple quantification tool based on expert judgment to analyse the risk conditions.

Saxena and Bhardwaj (2003) have reported such an approach to assess the hazard potential rating prior to developing an upgradation plan for existing MSW dumpsite at Panki landfill site, Kanpur, India. Kumar and Alappat (2003) have developed a Leachate Pollution Index which has many applications including ranking of landfill sites, resource allocation for landfill remediation, trend analyses, enforcement of standards, scientific research and public information. A risk based approach to solid waste management using a Landfill Location Criteria Calculator (LLCC), has been reported by Btenya et al (2005). LLCC allows communities to identify the risk factors and ultimately to minimize the cost of effective landfill management.

The rapid risk based decision making tool presented in this chapter is an attempt to provide guidance to Government and other implementing authorities for quick decision making for prioritizing actions related to dumpsite rehabilitation. Detailed investigations and regulatory approval may be required as per the respective national or local legislations. The attributes, their weightage and sensitivity may be refined to suit local conditions.

3.2 Methodology

The first step in the assessment of risk should be a site survey to gather specific information such as its operating history, types of wastes disposed its dimensions, topography and physical characteristics (Salerni, 1995). The next step for site investigation involves planning for preliminary excavation and obtaining the necessary regulatory approvals. At this point, a work plan must be developed which includes the number of pits and/or trenches to be dug; equipments and material handling procedure; labour requirements and their safety issues; creation of a work zone with clearly marked boundaries; and necessary analytical testing, measurements and collection of data.

Technical investigations assess the siting of the dumpsite and identify any flaws e.g., sites situated in floodplains, watercourses or groundwater; or sites that adversely affect the environment and, because of insufficient buffer zones, adversely affect the quality of life of adjacent residents. Characteristics of the dumps, such as the depth and characteristics of solid waste and degree of compaction that took place, variability of wastes within the site, the size of the dumps as defined by the total amount of solid waste disposed of and the areal extent of the dumps needs to be assessed. The specific steps involved in the development of the risk based decision-making tool are:

(i) Selection of risk indicating attributes for evaluation of the dumpsites
(ii) Apportionment of a total score of 1000 among the attributes based on their importance assigned by a panel of experts
(iii) Analysing the sensitivity of the attribute based on a Sensitivity Index and
(iv) Validating the approach to selected dumpsites by application of measured values of attributes.

In the following an example of how a risk assessment can be carried out is given in the form of a case study.

Risk indicative attributes were selected based on the literature, data obtained through observation of activities and investigations in and around a few dumpsites, consultation with experts on the contribution of the attributes to pollution, health risks and social impacts. The selection of the attributes was done based on the inputs of an expert panel consisting of academics (45%), municipal officers (18%), regulators (23%) and consultants (14%). Questionnaires were sent to experts in solid waste management in Asia. This questionnaire contained a total of 75 selected parameters under three classes, namely, site specific criteria, characteristics related to waste at dumpsite and those related to quality of leachate from dumpsite. The panel members were requested to select the parameters to be considered for developing the tool and to allot relative importance in terms of significance numbers ranging from 1 to 10. The attributes were then grouped into defined categories and ranked following the Delphi approach (Dalkey, 1968 cited in Brown, 1970).

The top ranking 27 parameters with scores over 65% were short-listed and weightage of attributes (Wi) were assigned based on the pair wise comparison method (Canter, 1996) such that the total weightage was 1000. Each attribute was measured in terms of a sensitivity index (Si) on scale of 0 to 1 to facilitate computation of cumulative scores called Risk Index (RI) that can be used for classification of dumpsites for closure or rehabilitation. While "0" indicated no or very less potential hazard. "1" indicated the highest potential hazard. Allotment of sensitivity indices for the selected parameters was made following earlier studies (Saxena and Bhardwaj 2003; CPCB 2005; MSW 2000; MoEF 1989).

The RI of the site was calculated using the following formula

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

where, W_i - weightage of the i^{th} variable ranging from 0 - 1000

S_i - Sensitive index of the i^{th} variable ranging from 0 - 1

RI - Risk Index variable from 0 - 1000

The site with higher score indicated more risks to human health and warranted immediate remedial measures at the site. The priority then decreased with decrease in the total score for the dumpsites. The dumpsite with the least score indicated low sensitivity and insignificant environmental impacts.

3.3. The Tool

Table 3.1 summarizes the tool that can be used for decision making for prioritization of dumpsite rehabilitation. The top ranking options focused mostly on site specific issues with a total of 20 attributes assigned with a total weightage of 711. Four waste related attributes with a total weightage of 221 and three leachate related attributes with a total weightage of 68 were also included in the selected attributes. Hazardous content of the waste obtained the maximum weightage of 71 out of 1000. The least weightage (3 out of 1000) was assigned to the methane content in the ambient air at the dumpsite.

Table 3.1. Tool for Rapid Risk Assessment of Dumpsites

Sl. 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 (1×10^{-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	$< 10^4$	$10^4 – 10^5$	$10^5 – 10^6$	$> 10^6$
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 proness (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

Table 3.1. Tool for Rapid Risk Assessment of Dumpsites *(Contd...)*

Sl. No.	Attribute	Attribute Weightage	Sensitivity Index			
			0.0 – 0.25	0.25 – 0.5	0.5 – 0.75	0.75 – 1.0
18.	Distance from the city (km)	7	> 20	10 – 20	5 – 10	< 5
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

The hazard potential of the site can be evaluated based on the overall score as detailed in Table 3.2. The classification has been done in line with the criteria recommended by Ministry of Environment and Forests, Government of India, for classification of risk potential of abandoned hazardous waste dumps (MoEF, 1989). Suggestions for further action for each category are also presented.

Table 3.2. Criteria for Hazard Evaluation Based on the Risk Index

Sl. No.	Risk Index	Hazard Potential	Recommended Action
1.	750-1000	Very High	Close the dump with no more land filling in the area. Take Remedial action to mitigate the impacts
2.	600 – 749	High	Close the dump with no more land filling in the area. Remediation is optional.
3.	450 – 599	Moderate	Immediate Rehabilitation of the dumpsite into Sustainable Landfill
4.	300 – 449	Low	Rehabilitate the dumpsite into Sustainable Landfill in a phased manner
5.	< 300	Very Low	Potential Site for future Landfill

3.3.1 Validation

The results of the validation exercise of the tool done for the Perungudi (PDG) and Kodungaiyur (KDG) dumpsites in Chennai, India presented in Table 3.3 show that the sites scored a RI of 569 and 579, respectively. The findings indicate that PDG and KDG have moderate hazard potential and both need to be rehabilitated immediately.

The hazard potential obtained for PDG and KDG following the method of Saxena and Bhardwaj (2003) was 505 and 491, respectively. The Risk Index of 569 and 579 obtained presently for PDG and KDG differs significantly as compared to those obtained employing the methodology suggested by Saxena and Bhardwaj (2003) for developing hazard potential. The variations can be attributed to the fact that 50% of the criteria used presently are different from those used by Saxena and Bhardwaj (2003). Variations not withstanding, the present approach has added advantages. For instance, the high values of Risk Index are clear indication of the grevity of environmental risk presented by the dumpsite. Further, the approach is easier to carryout.

Table 3.3. Risk Index work sheet for Perungudi and Kodungaiyur Dumpsites

Sl. No.	Attribute	Attribute Weightage	Perungudi Dumping Ground (PDG)			Kodungaiyur Dumping Ground (KDG)		
			Attribute measurement	Sensitivity Index	Score	Attribute measurement	Sensitivity Index	Score
	I – Site specific criteria							
1.	Distance from nearest water supply source (m)	69	< 1000	0.875	60.375	< 1000	0.750	51.750
2.	Depth of filling of waste (m)	64	3	0.250	16.000	3	0.250	16.000
3.	Area of the dumpsite (ha)	61	20	0.750	45.750	55	1.000	61.000
4.	Groundwater depth (m)	54	2-10	0.900	48.600	4-6	0.900	48.600
5.	Permeability of soil (1×10^{-6} cm/s)	54	3.2×10^{-7}	0.325	17.550	8×10^{-7}	0.450	24.300
6.	Groundwater quality	50	NP*	0.875	43.750	NP*	1.000	50.000
7.	Distance to critical habitats such as wetlands and reserved forest (km)	46	< 10	0.750	34.500	< 4	1.000	46.000
8.	Distance to the nearest airport (km)	46	10	0.500	23.000	50	0.125	5.750
9.	Distance from surface water body (m)	41	< 1000	0.625	25.625	3000	0.375	15.380
10.	Type of underlying soil (% clay)	41	> 50	0.100	4.100	> 50	0.100	4.100
11.	Life of the site for future use (years)	36	15	0.625	22.500	15	0.625	22.500
12.	Type of waste (MSW/HW)	30	MSW	0.100	3.000	MSW	0.100	3.000

*NP – non potability

Table 3.3. Risk Index work sheet for Perungudi and Kodungaiyur Dumpsites *(Contd...)*

Sl. No.	Attribute	Attribute Weigh-tage	Perungudi Dumping Ground (PDG)			Kodungaiyur Dumping Ground (KDG)		
			Attribute measurement	Sensitivity Index	Score	Attribute measurement	Sensitivity Index	Score
13.	Total quantity of waste at site (t)	30	15 x 10^6	0.750	22.500	12 x 10^6	0.750	22.500
14.	Quantity of wastes disposed (t/day)	24	2200	1.000	24.000	1800	0.750	18.000
15.	Distance to the nearest village in the predominant wind (m)	21	< 1000	0.375	7.875	< 1000	0.375	7.880
16.	Flood proness (flood period in years)	16	> 100	0.100	1.600	> 100	0.100	1.600
17.	Annual rainfall at site (cm/y)	11	14.56	0.200	2.200	14.56	0.200	2.200
18.	Distance from the city (km)	7	10	0.500	3.500	10	0.500	3.500
19.	Public acceptance	7	Accepts dump rehabilitation	0.500	3.500	Accepts dump rehabilitation	0.500	3.500
20.	Ambient air quality - CH_4 (%)	3	< 0.01	0.100	0.300	< 0.01	0.100	0.300
	II – Related to Characteristics of Waste at Dumpsite							
21.	Hazardous contents in waste (%)	71	< 10	0.100	7.100	< 10	0.100	7.100
22.	Biodegradable fraction of waste at site (%)	66	40	0.583	38.478	40	0.583	38.478
23.	Age of filling (years)	58	18	0.775	44.950	18	0.775	44.950
24.	Moisture of waste at site (%)	26	35	0.681	17.706	24	0.500	13.000
	III – Related to Leachate Quality							
25.	BOD of leachate (mg/L)	36	12-86	0.500	18.000	< 300	1.000	36.000
26.	COD of leachate (mg/L)	19	200-1100	1.000	19.000	70-2000	1.000	19.000
27.	TDS of leachate (mg/L)	13	1000-7000	1.000	13.000	1000-8000	1.000	13.000
	Risk Index				**569**			**579**

3.4 Risk Potential of Open Dumps in Tamil Nadu

There are 152 municipalities in Tamilnadu, India, with an approximate population of 10.5 million. Solid wastes generated in these municipalities are simply dumped onto low lying areas. Data on 27 attributes were obtained for 36 municipal dumpsites in Tamilnadu using a structured format. These data were verified from each municipality by direct visit to the dump sites and from the respective Regional Executive Engineers. The dumpsites were then grouped according to the risk score as presented in Table 3.4. Around 60% of the dumpsites were near critical habitats or surface water. The age of filling was greater than 30 years for all the open dumps and the life of these sites for future use is less than 1 year. Annual rainfall at these sites varied from 125 to 250 cm. The depth of groundwater varied between 3 and 10 m. In 50 % of the municipalities, the groundwater samples from wells located near the dumping grounds indicated non potability. In most of the sites, the percentage of clay was very low, indicating potential for soil contamination by the leachate. The quantity of the waste at the dumpsites was in the range of 10,000 to 1 million tonnes. The quantity of the waste disposed at most of the sites is less than 200 tonnes per day (except Tirupur) of which biodegradable fraction was 60% (Figure 3.1). The Risk scores of dumpsites are presented in Figure 3.2. While 18 sites indicated moderate risk, 19 were in the low risk potential group. Athipattu dumpsite located in Ambattur municipality scored the highest value of 625 out of 1000.

Table 3.4. Attribute characterization of dumpsites in Tamil Nadu

Sl.No.	Details	ATHIPET	SATHANKADU	OMAKULAMADU	THIRUVALLUR	PALLIKARANAI	PALAVELI	PALLAVARAM	TAMBARAM	PAMMAL	BHARATHIYAR	MARAIMALAI NAGAR	KARUR
1	Distance from the nearest w.s.s (m)	500	12000	5000	10000	10000	750	64000	6000	8000	8000	3000	6000
2	Depth of filling waste (m)	3	2.5	0.9	4.5	2	3	2	3.6	1.5	2	0.6	2
3	Area of the dump site (Ha)	2.83	4.85	0.7	0.77	6.07	0.692	1.21	1.82115	0.8094	1.21	2.22585	6.07
4	Ground water depth (m)	4.5	3	4.5	6	0.9	6	2	6	6	6	15	2.1
5	Permeability of soil (10^{-6} cm/sec)	Sandysoil	Clay	Silty Sand	Loose Soil	Gravel	Gravel	Silty Clay	Clay Soil	Silty Clay	Black cotton soil	Hard rock	Gravel
6	Ground water quality	Non-Potable	Non-Potable	Potable	Potable	Potable	Potable	Potable	Potable	Potable	Potable	Potable	Potable
7	Distance to critical habitats such as wet lands and reserved forest (km)	10	6	1	2	30	0.5	35	1	30	40	0.5	7
8	Distance to the nearest airport (km)	25	25	35	50	10	40	5	10	3	100	25	85
9	Distance from the surface water body such as river / lakes / ponds (m)	500	300	2500	10000	10000	750	500	500	5000	10000	3000	7000
10	Type of underlying soil (% clay)	Loose soil 10	75	80	Sand	10	5	70	90	70	30	20	20
11	Life of the site for future use (years)	5	1	5	2	15	1	1	5 months	15	5	25	25
12	Type of waste (MSW/HW)	80MSW, 2HW	95 MSW, 5HW	60MSW, 10HW	MSW	MSW	MSW	MSW	MSW	98MSW, 2HW	MSW	MSW	95MSW, 5HW
13	Total quantity of waste at site (T)	73500	121250	2205	12096	42492	28266	8470	22945	4200	8470	4683	42490
14	Quantity of waste disposed (t/day)	200	110	35	16	72	29.5	65	100	30	13	8	46
15	Distance to the nearest village in the predominant wind (m)	50	3000	2000	3000	3000	2000	500	500	3000	12000	5000	500
16	Flood proness (flood period in years)	5	1	3	6	5	10	5	5	5	3	15	50
17	Annual rainfall at site (cm/y)	201.6	184.2	170.6	201.6	193.4	145.3	112.4	193.4	145.3	190.2	193.4	110.3
18	Distance from the city (km)	0.05	3	2	5.5	3	0.5	0.5	3	18	0.5	7	7
19	Public acceptance	Dump closure	rehabilitation	dump closure	rehabilitation	dump closure	no public concern	dump closure	rehabilitation	no public concern	no public concern	no public concern	no public concern
20	Ambient air quality– CH_4 (%)	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1
21	Hazardous contents in waste (%)	15	10	10	12	10	5	10	5	12	1	1	10
22	Biodegradable fraction of waste at site(%)	45	60	70	60	65	60	65	60	40	30	75	10
23	Age of filling (years)	10	35	25	60	8	75	40	40	15	30	1	1
24	moisture of waste at site (%)	15	20	30	20	25	10	30	20	20	10	10	10
25	BOD of leachate (mg/L)	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
26	COD of leachate (mg/L)	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500
27	TDS of leachate (mg/L)	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000

Table 3.4. Attribute characterization of dumpsites in Tamil Nadu (Contd…)

Sl.No.	Details	ANIMOOR	BETHALEGAM	VELAPADI	VENDIPALAYAM	DHARAPURAM	MURUGABHAVANAM	SURAKOTTAI	KOVIL;PATTY	VALAMPURIVILAI	PARAIPATTI	MADURANTAGAM	GOBI
1	Distance from the nearest w.s.s (m)	22000	500	12000	250	21000	14000	1000	150	12500	12000	4000	6000
2	Depth of filling waste ,m	0.5	1	2	1	1.4	2.5	1.5	1	2.5	2	0.75	1
3	Area of the dump site (Ha)	4.46	1.27	0.704	7.68	1.82	4.95	0.40	1.54	6.27	2.17	3	0.6
4	Ground water depth (m)	200	15	6	10	4.5	90	3	100	30	100	6	33
5	Permeability of soil (10^{-6} cm/sec)	Red Gravel	Loose soil	Hard Soil	Red Gravel	Gravel	Hard Morrum	Hard Morrum	Gravel	Gravel	Clay	10	10
6	Ground water quality	Potable	Potable	Potable	Non Potable	Potable	Non Potable	Non Potable	Non Potable	Non Potable	Non Potable	Potable	Non Potable
7	Distance to critical habitats such as wet lands and reserved forest (km)	20	0.1	1	0.1	5	10	5	10	40	80	30	500
8	Distance to the nearest airport (km)	1200	200	150	70	70	80	120	60	100	75	75	89
9	Distance from the surface water body such as river / lakes / ponds (m)	20000	500	600	500	8000	1500	1000	2000	10000	3000	3000	450
10	Type of underlying soil (% clay)	2	30	1	1	1	30	30	10	10	5	2	15
11	Life of the site for future use (years)	25	22	1	1	1	2	1	1	1	5	1	1
12	Type of waste (MSW/HW)	92MSW, 8HW	75MSW, 3HW	97MSW, 3HW	MSW	MSW	97MSW, 3HW	98MSW, 2MW	58MSW, 12HW	95MSW, 5HW	98MSW, 2HW	99MSW, 1HW	92MSW, 8HW
13	Total quantity of waste at site (T)	7805	4445	4928	26880	8918	42437.5	2124.68	5390	54863	15190	12973	2345
14	Quantity of waste disposed (t/day)	34	29	15	120	30	95	15	27	70	40	9	26
15	Distance to the nearest village in the predominant wind (m)	500	100	2000	100	10000	5000	20000	1000	20000	60000	12000	2000
16	Flood proness (flood period in years)	20	30	5	50	10	10	100	60	75	15	5	30
17	Annual rainfall at site (cm/y)	120.2	139.6	150.8	119	130	130.9	125	92.7	100	158.2	145	134
18	Distance from the city (km)	8	1	5	5	0.05	1.5	2	5	0.5	3	25	1
19	Public acceptance	dump closure	rehabilitation	no public concern	rehabilitat ion	dump closure	no public concern	rehabilitation	dump closure	dump closure	dump closure and remediation	No public concern	Rehabi-litation
20	Ambient air quality– CH_4 (%)	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1
21	Hazardous contents in waste (%)	3	3	10	10	8	25	3	12	5	2	2	8
22	Biodegradable fraction of waste at site(%)	65	65	30	60	75	55	50	58	40	45	20	74
23	Age of filling (years)	2	75	40	50	50	30	40	40	40	10	25	48
24	moisture of waste at site (%)	10	2	10	20	20	25	10	10	10	10	10	20
25	BOD of leachate (mg/L)	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
26	COD of leachate (mg/L)	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500
27	TDS of leachate (mg/L)	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000

Table 3.4. Attribute characterization of dumpsites in Tamil Nadu (Contd…)

Sl.No.	Details	SIVAGANGAI	THIRUPPUR	THANJAVUR	MYLADUTHURAI	THIRUVARUR	THIRUTHURAIPOONDI	KOOTHANALLUR	PUDUKOTTAI	ARATHANGI	THURAIYUR	KAMMAIYANPETTAI	PACHAYANKUPPAM
1	Distance from the nearest w.s.s (m)	6000	100	1000	1000	150	4000	4000	1000	1000	4000	8000	7000
2	Depth of filling waste ,m	0.5	20	2	2	1.2	1.5	2	1	4	2.1	3	0.9
3	Area of the dump site (Ha)	1.2	1.25	8.2	2.6	4.85	2	1.78	5.26	3.07	3.03	2.46	0.82
4	Ground water depth (m)	30	152	12	3.5	11	6	6	6	24	18	3	4.5
5	Permeability of soil (10^{-6} cm/sec)	10	Gravel	10	Clay	Clay	Clay	sandy soil	Red gravel	0.75	Clay	Clay	sandy soil
6	Ground water quality	Non Potable	Potable	Potable	Potable	Potable	Non Potable	Potable	Non Potable	Non Potable	Non Potable	Non Potable	Non Potable
7	Distance to critical habitats such as wet lands and reserved forest (km)	30	60	30	35	30	20	500	1	30	1	200	210
8	Distance to the nearest airport (km)	40	15	50	115	120	130	110	70	90	45	27	34
9	Distance from the surface water body such as river / lakes / ponds (m)	10000	55	2	1	150	10	50	1	6000	4000	100	3000
10	Type of underlying soil (% clay)	15		30	50	30	50	15	10	15	30	50	5
11	Life of the site for future use (years)	5	1	1	1	1	1	15	1	1	1	1	1
12	Type of waste (MSW/HW)	100	99	100%MSW	100%MSW	100%MSW	90MSW,10HW	90MSW, 10HW	100%MSW	95MSW, 5HW	100%MSW	100%MSW	100%MSW
13	Total quantity of waste at site (T)	2125	250000	58072	18413	20396	19623	35612	52609	43058	22308	25877	2613
14	Quantity of waste disposed (t/day)	22.5	400	192	55	48	7.5	50	27	10	9.5	3	1
15	Distance to the nearest village in the predominant wind (m)	0.5	3	50	2	1	1	3000	1000	2000	1000	4000	1000
16	Flood proness (flood period in years)	30	30	30	30	10	30	10	10	1	35	30	30
17	Annual rainfall at site (cm/y)	129	175	130	130	184	184	184	131	131	135	190	190
18	Distance from the city (km)	1	1	3	1	2	2	20	2.5	3	4	1.9	1.7
19	Public acceptance	dump closure	Dumpsite rehabilitation	No public concern	No public concern	No public concern	No public concern	No public concern	No public concern	No public concern	No public concern	No public concern	No public concern
20	Ambient air quality– CH_4 (%)	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1
21	Hazardous contents in waste (%)	10	0.5	2	2	5	10	1	2	5	2	40	40
22	Biodegradable fraction of waste at site(%)	50	34	82	85	80	80	60	80	80	80	60	60
23	Age of filling (years)	5		40	30	40	30	15	30	20	30	30	15
24	moisture of waste at site (%)	10	35	20	25	20	20	25	20	10	15	25	20
25	BOD of leachate (mg/L)	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
26	COD of leachate (mg/L)	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500
27	TDS of leachate (mg/L)	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000	>4000

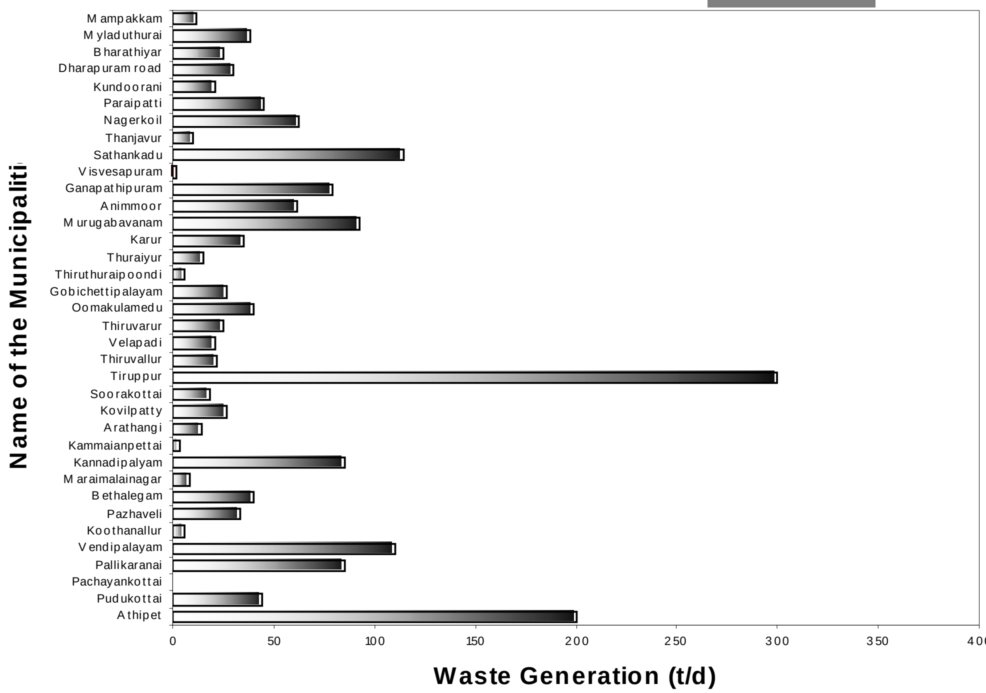


Figure 3.1

MSW generation (t/d) in selected municipalities from Tamil Nadu

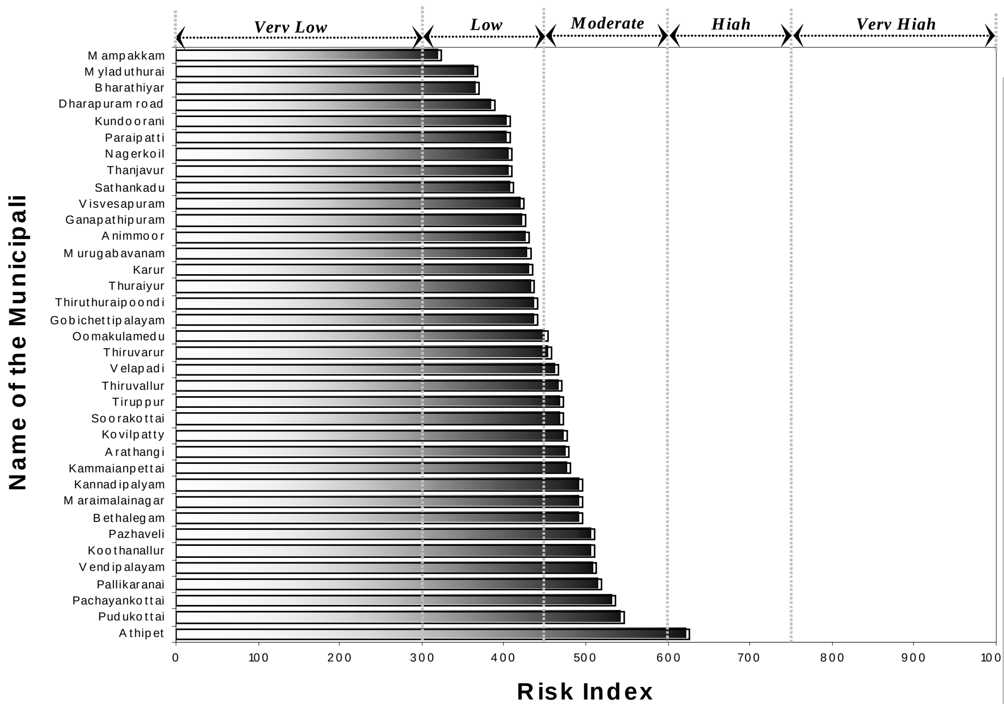


Figure 3.2

Risk Index for selected open dumps in Tamil Nadu

CHAPTER 4

PLANNING FOR DUMPSITE CLOSURE AND REHABILITATION

4.1 Dumpsite Closure

In order to abandon the practice of open dumping, the municipality may either close its open dumps when a replacement upgraded landfill site is ready to accept wastes, or alternatively it may convert its open dumps to operate as upgraded landfills. This latter option will only be possible if:

- The dump is in an area where groundwater and surface water pollution is not critical
- There is sufficient remaining void space to justify the cost and effort of conversion

Dumpsites that have higher risks or exhausted their volumetric capacity to hold waste are suitable candidates for closure. An open dumpsite should not be converted to a more controlled operation if its estimated remaining lifetime is less than one year. Instead, efforts should be directed towards identifying a new temporary, better-controlled disposal operation or the development of a larger engineered landfill with an estimated lifetime of more than ten years.

The basic requirements for closing an open dumpsite include providing final soil cover, vegetation layer, drainage control system, leachate and gas management systems, monitoring systems and site security (aftercare programme). The closure of dumpsites typically requires re-gradation of site slopes, capping of landfill with impermeable cover, placement of leachate collection and treatment systems, installation of landfill gas collection and flaring system and aesthetic landscaping of the closed dumpsite. If landfill gas volumes are significant, then a landfill gas utilization project by way of power generation/direct supply to neighborhood community for use as fuel may be installed. As appropriate, waste materials may be moved or relocated to higher portions of the site or placed in appropriate areas to help sloping of the closed site. It is important to promote surface water drainage from landfill areas in order to prevent it from infiltration and further percolation through the garbage and the soil underneath, thus creating ground and surface water degradation. From an environmental point of view, the sites may still have potential for ground water contamination.

4.2 Dumpsite Rehabilitation

Rehabilitation actions will be aimed at both reduction and stabilisation of the risks associated with the accumulated waste, i.e. leachate control, landfill gas removal, and nuisance reduction (odour, wind scatter, birds, scavengers, pests, etc.). The general transition to dumpsite closure will include the following works: shaping the main capping, topsoil application, grass sowing (and possibly bush planting), gas collection and removal, and leachate management. Vegetation must be selected so that it doesn't destroy the cap and it should fit into the surrounding natural landscape.

If a dump is to be converted into a landfill, operational practices should be the same as those for a new sanitary landfill site. The available disposal area should be able to accommodate wastes from the service area. The present open dumpsite is not within or approximate to sensitive receptors such as: built-up areas, groundwater reservoir or watershed areas, geological hazards such as active faults, erosion prone areas, and flood-prone areas.

The scope of a Dumpsite Rehabilitation will be determined by whether its goal is one or a combination of the following:

- Reduce dumpsite footprint and cover
- Recover dumpsite space for continued operation
- Dumpsite upgrading or installation of liner and relocation of the entire dumpsite

It involves three distinct stages of remedial activity:

- planning and designing of the remedial works
- undertaking a one-time physical improvements at the site
- changing subsequent operations at the site.

Providing for a more sanitary and environment friendly method of waste disposal for a community poses significant challenges to local government units, particularly to its leaders. It will require them to come up with a plan that will identify workable alternatives, strategies and programmes to solve the problem and identification of the steps necessary to carry out the plan, and the corresponding timetable/schedule for the activities identified in the plan as well as the allocation of resources to carry out the plan.

4.3 Dumpsite assessment and closure plan

Before the dumpsite stops receiving wastes, it is important that a final closure plan is prepared, approved, and available for implementation. The main components of the plan include, but are not limited, to the following:

- Stabilization of critical slopes
- Final cover
- Drainage control systems
- Leachate and gas management systems
- Fire control
- Prevention of illegal dumping
- Resettlement action plan
- Security

Extinguishing fires, eliminating vermin and reducing ground water and surface water pollution are critical issues. At those open dumps in ravines, where waste has been tipped over a steep cliff into a valley below, the main problem may be to stabilize the loose and dangerously steep slopes of waste.

Before any closure plan is developed, a site assessment/investigation is to be conducted to assess the existing conditions. This is a necessary step as knowledge of the actual conditions of the site, the operational procedures practiced during its operation, and other issues relative to the site, are studied. Site investigation may also help identify the extent of potential contamination and the likely pathways of contaminants. Site investigation may include activities such as:

- Review of data such as the geology of the site, depth of groundwater, volume and types of wastes disposed, reports, studies, historical records concerning the dumpsite (operations, unusual events such as fires, dumping of hazardous wastes, etc.)
- Review of available maps (map of the dumpsite and its surroundings, topographical, geological, hydrogeological, etc.)
- Interview with those directly involved with the operation of the dumpsite, waste pickers, and residents near site
- Inventory of existing settlements, structures, surface water bodies, water wells, etc.
- Identification of existing land uses around the area and points of leachate seepage and ponding within and beyond the disposal facility
- Conduct of topographic survey of the dumpsite, extending some distance from its boundaries
- Conduct of geotechnical investigation to determine stability of slopes
- Identification of sources of soil or other cover material for the site
- Determination of depths of the dumped wastes
- Determination of gas leakage within and on the areas surrounding the dumpsite
- Conduct of leachate and gas sampling (if practical)
- Conduct of water quality sampling of surface waters, water wells, groundwater (if practical)

Data on the nature and extent of the contamination present at the site are needed to:

- Establish the overall approach to the operation in terms of the unit operations (on/off-site disposal, recycling/replacement needs) likely to be involved
- Determine the scale and likely duration of the operation
- Determine the disposal (or treatment) requirements of the excavated material
- Establish monitoring, health and environmental protection requirements.

Data on the geotechnical and hydrological properties of the site are required in order to:

- Establish the physical capacity of the site to accommodate the excavation and disposal operation, and the engineering measures (physical support to excavation, hydraulic or physical barriers to groundwater movement, drainage for surface water flow) likely to the required level
- Determine the engineering requirements (grading, leveling, lining, gas and leachate controls) associated with the establishment of on-site disposal facilities
- Identify any constraints on the excavation and disposal operation stemming from the presence, or behavior, of surface and groundwater bodies
- Determine the physical handling properties of the contaminated material, and any difficulties these may present for materials handling operations or for final disposal
- Assess any long-term risks associated with on-site disposal
- Design and equip all necessary long-term monitoring measures associated with on-site disposal facilities

Extreme care should be taken in carrying out the surveys since open dumps can present a range of health and safety hazards to humans. These include unstable slopes, hidden voids, sharps objects, hazardous chemicals, and attack from rodents or mosquitoes, hidden bodies of water and risk of injury from falling waste.

If the dump cover is poor or sporadic, a walk over of the dump area may provide some information on the types of wastes. Trenches and/or soil borings are generally used to retrieve waste samples for characterization. Trenches generally produce more usable information since a larger, continuous area is exposed. Trenching allows more whole items to be recovered giving a better indication of the types and condition of the waste materials, the consistency of the soil cover and evidence of soil/waste layering. Soil borings, while being less intrusive, only retrieve a small portion of the wastes for examination. While soil borings alone may fail to fully characterize a dump, they have the advantage of producing less odor, covering a larger area in less time and can be located closer to buildings without endangering the integrity of the buildings.

Observations of dump materials include listing the presence of liquids, semi-solids, ash, cinders and chemical solids such as paint and resin solids. Any evidence of decomposition, visual contamination, odors, perched water, leachate, moisture or hazardous substances should be noted. Lists of items encountered, the relative amounts of wastes and soil, and conclusions as to the relative amounts of household, municipal, industrial and demolition materials are important in characterizing dumps. Video tapes and photographs of trenches and excavated wastes are extremely useful in documenting waste materials. It is recommended that vertical profile logs be prepared.

Once determinations have been made as to the nature of the materials, health and safety issues, and possible impacts to the environment and the proper regulatory agencies have been contacted, the wastes should be stockpiled separately from non-impacted soils. Wastes should be sorted based on physical appearance, including texture and consistency, on field screening response, and incidental odors. Waste/soil segregation is dependent on waste management options. At a minimum, separate waste piles should be made for soil, recyclables, asphalt, demolition materials, scrap metal, general municipal solid waste and suspect hazardous wastes, including landfillable materials, containerized chemical wastes, contaminated soils and special wastes. Suspect hazardous wastes and contaminated media should be separated from all other wastes.

Uncontainerized bulk solids which are potentially hazardous wastes, need to at a minimum be stockpiled separately on-site in and under plastic sheeting, until fully characterized. Precautions may need to be taken to prevent surface water run-on.

Soils mixed with or located beneath waste materials are commonly sampled for chemical and physical analyses in order to identify contaminants leaching or oozing from the wastes in order to predict future ground water contamination and soil gas generation. In addition, a soil sample is to be collected to evaluate background concentrations/character of the naturally occurring parameters of concern. Analysis of stockpiled soils will be dependent on site target compounds as determined from site history and preliminary investigations. Soils covering the dump are commonly sampled to determine the permeability, organic carbon content and moisture content in order to estimate the rate of leaching and generation and venting of methane gas.

Gas surveys are necessary at most dumps. This should be completed at least three to four times per year to monitor changes in the gas concentrations and types of gases that occur with changes in moisture, temperature and frost. At a minimum, the meter chosen needs to be tested for methane. Meters that provide readings as a percent by volume are preferred to those which measure as a percent of the lower explosive limit. A portable gas chromatography instrument may be used or samples may be collected and sent to a laboratory for analysis.

Ground water monitoring is very important in characterizing dumps given the variety of wastes and the lack of information available about the types of wastes buried in most abandoned dumps. Ground water monitoring is necessary at all abandoned dumps where wastes remain on the property; all dumps where hazardous wastes were removed and all dumps containing a significant amount of wastes.

4.3.1 Stabilization of Critical Slopes

The absence of proper operational procedures in most open dumpsites often result in dangerously high heaps of garbage. A simple method for stabilization of the steep side slopes is to re-profile and re-grade them to a gentle slope of the order of 4 (horizontal) : 1(vertical). Such gentle slopes have adequate safety against sliding of components of the cover material over the waste Thus, it may be necessary to level the heaps of garbage in order to reduce the hazards posed by unstable slopes. The final surface of the fill should be graded to about 2 - 4%, while the side slopes should have a vertical to horizontal ratio less than 1:3.

The most attractive option of stabilizing the steep side slopes of the landfill was to strengthen them externally or internally without relocating the existing waste and without moving the toe of the slope. Steep slopes in soils are often stabilized by the techniques of anchoring or nailing (Hausmann (1990)).

4.3.2 Final Cover

The final soil cover (or cap) is applied to a completed disposal facility to act as a barrier in order to:

- Reduce infiltration of water into the disposal area
- Reduce gas migration
- Prevent burrowing animals from damaging the cover
- Prevent the emergence of insects/rodents from the compacted refuse
- Minimize the escape of odors
- Support vegetation

A uniform layer with a minimum depth of 0.60 m is recommended as final soil cover (Figure 4.1). It is usually composed of a layer of compacted soil with a depth of at least 0.45m and a topsoil of at least 0.5 m. The topsoil, which is usually not compacted, will serve as protection layer for the compacted soil cover, as well as support plant growth.

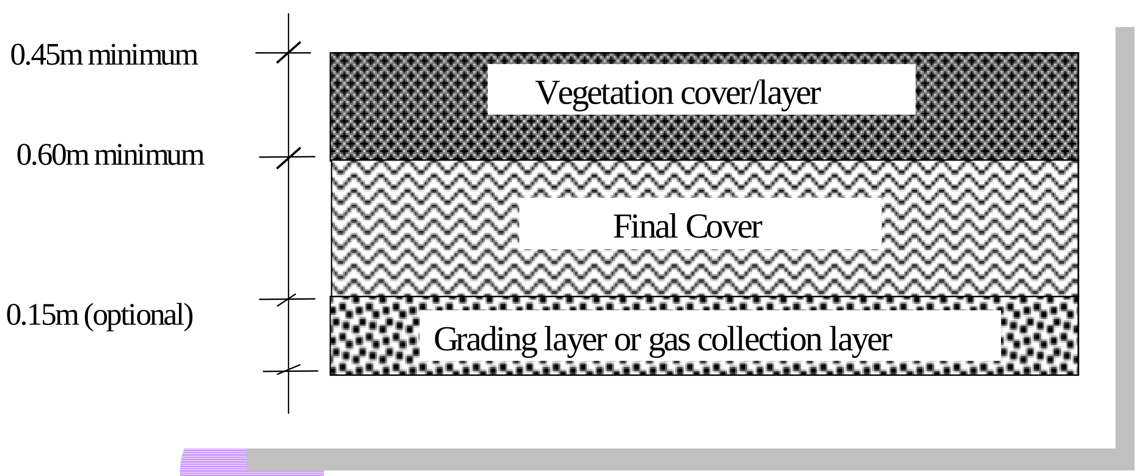


Figure 4.1

Recommended Final Soil Cover

Design Criteria to be considered for the Final Cover include

- Installation of some run-off control berms or terraces along the top of the landfill will be required, in areas with a higher potential for erosion. These berms will minimize long-term maintenance requirements.
- Installation of terraces on the side slopes of the landfill, if applicable, to minimize erosion and divert surface water runoff to the drainage ditches. The terraces must be designed and sloped to drain the storm water.
- Consideration must be given to the geotechnical stability of the final cover system to prevent failures, such as sliding. Conduct slope stability analysis, if applicable.
- Installation of storm water ditches to convey concentrated flows from the landfill top slope to the perimeter ditch system, if applicable.
- Control landfill gas migration using passive vent systems, if applicable (erosion control).
- Consideration must be given to selecting plant species that are not deeply rooted to prevent damage of the underlying infiltration layer.

A review of laboratory and field investigations performed over the last 20 to 30 years makes it obvious that alternative geosynthetic products (Table 4.1) manufactured under high-quality, closely-monitored conditions often afford better functionality and efficiency than the corresponding mineral components.

4.3.3 Drainage Control Systems

Run-on and runoff of surface waters can cause erosion and scouring of the final cover, as well as water ponding. Thus, to mitigate these effects, drainage control systems are installed in and along the periphery of the disposal area.

Table 4.1. Comparison of alternative geosynthetic products

Attribute	HDPE	LLDPE	PVC	EPDM	EIA-R	CSPE-R	FPP
General chemical exposure	Excellent	Good	Fair	Good	Excellent	Excellent (when cured)	Excellent
Hydrocarbon exposure	Good	Good	Fair	Good	Excellent	Good (when cured)	Good
Weathering (UV exposure)	Excellent	Fair	Poor	Excellent	Excellent	Excellent (when cured)	Excellent
Thermal stability	Poor	Poor	Good	Excellent	Good	Excellent	Good - excellent (when reinforced)
Tensile Performance	Good	Good	Good	Good	Excellent	Excellent	Good – excellent when reinforced
Uni-axial elongation performance	Excellent	Excellent	Good	Good	Fair	Good	Excellent
Multi-axial elongation performance	Poor	Excellent	Excellent	Good	Fair	Good	Excellent
Puncture performance	Fair	Excellent	Excellent	Good	Excellent	Good	Good
Installation damage resistance	Fair	Fair	Excellent	Excellent	Good	Good	Excellent
Seaming methods	Thermal excellent	Thermal excellent	Thermal or solvent bonding – good	Tape seams - good	Thermal excellent	Thermal or solvent building - good	Thermal- excellent
Repair in service	Good	Good	Good	Good	Good	Poor – requires adhesives	Excellent
Stress cracking	Fair	Good	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur
Flexibility in detailing	Fair	Excellent	Good	Good	Good	Good	Excellent

Source:

Note: HDPE - High density polyethylene; LLDPE - Linear low-density polyethylene;
PVC - Polyvinyl chloride; EPDM - Ethylene propylene diene monomer;
EIA-R - Ethylene interpolymer Alloy – Reinforced;
CSPE-R - Chlorosulphonated polyethylene – Reinforced;
FPP - Flexible polypropylene

When planning and designing the drainage control systems, the following are to be considered:

- Surface waters should be diverted away from the disposal site at the shortest distance practical;
- The path or route of the drainage system should convey the surface waters at adequate velocities to prevent stagnation or deposition;
- Hydraulic gradient should be sufficient to maximize removal of surface waters but at the same time not too steep as to cause scouring, and;
- The design of the drainage systems and the materials used should consider the effects of settlement.

4.3.4 Leachate Management Systems

Where economically and technically feasible, leachate pipes may be installed to collect the leachate for subsequent treatment. This will depend on several factors such as depth of the waste, topography of the area, underlying soil, and age of the deposited waste. Sources of leachate seepage at and around the surface of the disposal site should be determined before application of the final soil cover. For seepages on the surface, these may be intercepted by constructing canals/ditches to collect the leachate. The collected leachate should then be channeled towards a leachate retention basin/pond located downgradient of the site. To intercept leachate movement below ground, an interceptor trench, cutoff wall, and collection pipes may be constructed down gradient of the disposal site. These measures do not ensure that ground or surface water contamination near the site will not occur. They are only simple and inexpensive remedial measures that are intended to reduce as much as practical, the potential contamination that may occur. The collected leachate may be treated using biological or chemical methods. Biological methods involve letting the wastewater pass through a series of stabilization ponds or the use of vegetation to absorb or digest the pollutants, while chemical methods involve the use of chemicals to treat leachate.

4.3.5 Gas Management Systems

Landfill gas, such as methane and carbon dioxide, will continue to be generated as long as waste decomposition occurs. Thus, depending on the environmental sensitivity of the area, it may be necessary to collect the gas and vent it freely, flare it, or recover it for energy use. Vent pipes made of perforated polyvinyl chloride (PVC) or discarded oil drums welded together at the edges may be used for gas management.

4.3.6 Extinguishing Fires

If open burning of waste is practiced at the dumpsite, it is essential that the fire be thoroughly extinguished first before applying final cover or capping. Where the depth affected by burning is relatively shallow, the waste in the affected area is spread out to allow for complete combustion and after which, water may be applied prior to applying the final cover. Sand may also be applied instead of, or together with water. This operation must be carefully done thus when you enter water into the heap you change pressure in the heap and also the moisture content that change the biological activity which can lead to self ignition in the near future. Furthermore the water used will be polluted and might be a problem for the environment. The best is to use clay or sand and after some months the temperature goes down if the cover is well done. Foam can be used but it is expensive.

Burning garbage is a common practice at many open dumps. Fire could occur spontaneously, but more often, the fire is purposely set in an attempt to reduce the volume at a dump or destroy the food waste that attracts rodents and insects or to enable easy scavenging. Some dumps may still be smoldering underground much like peat or coal mine fires (Pyrolysis). Development activities, which disturb the surface of the dump, could introduce oxygen into a site and result in a surface outlet for the fire. If a fire erupts, it is very important to implement the contingency plan and CALL THE FIRE DEPARTMENT IMMEDIATELY.

If the depth affected by burning is relatively deep, it may be necessary to isolate the burning area by excavating trenches around it. These firebreaks /fire lanes must be carefully done so the situation does not become worse when more air comes into the walls of the landfill, The slopes should be covered with soil directly on that side that is not on fire. The waste is then spread or regularly agitated to allow for complete combustion. The ashes subsequently produced are then smothered with sand or soil.

4.3.7 Rehabilitation of scavengers

The informal scavengers/waste pickers at the disposal site should be relocated and an alternative livelihood provided for them. If there is a Materials Recovery Facility (MRF), these people can be formally hired since they are efficient in waste segregation. If organized waste picking is allowed at the new disposal site, a small space can also be allocated for these displaced families. Organized or managed waste picking may be allowed at controlled disposal sites with certain procedures in place.

4.4 Dumpsite closure – the Challenges

Planning the closure of a disposal site should be made many months (or years) before actual closure. The concerned local body should first identify an alternative site(s) where it will dispose off the waste it generates. The new disposal site may be developed or it can use the disposal sites of neighboring municipalities (where appropriate) and pay the tipping fees required. Whatever be the option, early planning is essential in order to have enough time to raise the necessary funds or look for sources of funds. Localization of a site and establishment of a new landfill can take 10 years or more.

A critical challenge in closing dumpsites is to provide a viable alternate facility or a collection system for waste disposal. The fence and gate to the site must be maintained or upgraded and the site locked to prohibit public access. The signs placed at the site should notify the public that the facility is closed, provide information on alternative disposal and specify appropriate provisions or penalties against trespassing or dumping.

For a short while after site closure, problems such as disposers or vandals tearing out gates, driving through fences, dumping wastes on access roads or in ditches near the disposal facility are common. If necessary, rats should be exterminated to prevent their migration to populated areas. The area should be posted with adequate poison warnings.

Closing a dump does not end the responsibility for it. When disposal facilities close, the owner and/or site operator are legally and financially accountable for post-closure maintenance. Laws should require that waste disposal sites, whether they are public or privately owned, have a post-closure maintenance plan and the mechanisms and means for financing the activities in the plan. It may also be appropriate to assign liabilities to large waste generators of specific types of wastes, such as commercial establishments and industries, who use the disposal site. Residential wastes, however, remain the liability of the local government where the waste was generated since these types of wastes are generally mixed upon collection and disposal.

In order to sustain post-closure maintenance and monitoring activities, owners and operators of waste disposal facilities should incorporate a financial assurance plan in order to provide sufficient funds for the said activities. In case a closed disposal site is sold and property ownership changes, the new owner must be made aware of the transfer of liability for post-closure maintenance. Some land buyers or developers may be interested in the property in the hope that they could develop the area for some financially beneficial use. Thus, the responsibility of the party who acquired the property should be explicitly defined in the land deed in order to ensure continuity of environmental controls over the former disposal area, in accordance with the approved closure and post-closure maintenance plan.

A primary concern of site closure is the slope of filled portions of the site to promote surface water runoff without causing ponding or severe erosion of the final cover. Final slopes of filled portions of the landfill site should be at least 2 percent in grade and should not exceed 8 percent. Terraces, drains or other measures should be used as appropriate to minimize soil erosion.

It may be difficult to properly close a landfill that continues to be used as an open dump site. To address these difficulties, rehabilitation processes involving the following elements are suggested.

- Fencing and Security
- Providing/Improving the access roads
- Sign and direction boards
- Monitoring of incoming vehicles and waste characteristics
- Providing a viable alternate facility for waste disposal.
- Prevention of open burning
- Control of stray animals
- Controlled scavenging
- Lay out planning and designation of areas for filling and Controlled tipping (Zoning)
- Provision of appropriate equipment and machinery
- Office and record keeping
- Environmental monitoring
- Protection of workers (Gloves, masks, Boots etc.)
- Drainage diversion
- Promotion of waste segregation at source
- Progressive rehabilitation including leachate and landfill gas management, compaction, daily cover and organised Landfill mining

The most significant aspects are to block access, stop open dumping, cover the dump with at least 60 cm of earth and vegetate the site. The requirements are relatively simple and inexpensive. Local officials should consider enacting appropriate ordinances prohibiting unauthorized disposal and local law enforcement officials should be enlisted as needed.

4.5 Planning for dumpsite rehabilitation

Rehabilitation may be defined as a set of activities for re-establishing the productivity and business value of rehabilitated land and for environmental improvements. The rehabilitation process is carried out after the closed dumpsites have been stabilised. The use of the rehabilitated land depends on the rehabilitation technology. The most appropriate directions for recultivating the closed dumpsite are forestry, recreation, and construction. The dumpsite recultivation is carried out in two phases, namely technical and biological. The technical phase involves the levelling of any dumpsite slopes by a bulldozer and then the transport of fertile soils to the site, and their subsequent spreading over the site, with the aim of establishing a re-cultivation layer. This is followed by the biological phase whereby, subsequently, one of the selected recultivation measures is implemented. If the dumpsite is over 1.5 m high, then its slopes have to be levelled and terraced if required (for high-rise dumpsites). The slope levelling process is undertaken by a bulldozer by waste downwards, from the upper to the lower edge, in a number of stages. When rehabilitating high landfills combined terracing and slope levelling is carried out. Terracing (5-7 m wide) is done for each 10-12 m of height of the landfill.

Upgrading from open to controlled dumping does not generally require significant capital investments as compared to upgrading from controlled dumping to sanitary landfilling. It may be a practical option for managing the large dump sites where the average waste height on is typically below 10 m where it is possible to plan partial closure of the site by shifting the waste into a suitable portion of the dumpsite and closing it with a average landfill height of about 25m. For a shallow dumpsite (average depth of waste 5m or less) which may be the case for a large number of cities in India (population 1.0 to 2.0 million), this approach is likely to release higher area and the footprint of a tall landfill that is required to accommodate the waste strewn over the site will be even smaller. This approach has been successfully used for planning rehabilitation of Deonar dumpsite at Mumbai ((Joshi and Nachiappan, 2007). Hence, it is imperative that the operation of controlled disposal facilities be properly implemented. Otherwise, they are bound to revert to or become just another open dumpsite.

As with the closure of open dumpsites, upgrading into controlled disposal will require planning. The construction documents developed for dumpsite rehabilitation include:

- Baseline layout of dumpsites prior to rehabilitation
- Site plan after rehabilitation
- Ground movement scheme
- Rehabilitation technology
- Explanatory note with a description of the waste mass
- Soils and top soils to be brought to the site for rehabilitation
- Materials and technologies used in the landfill gas management system
- Assortment of plants and fertilizers
- Cost estimates for the works

The first step in planning a dumpsite rehabilitation project should be a site survey to gather site-specific information such as its operating history, types of wastes present, dimensions, topography and physical characteristics (Salerni, 1995). The site assessment has to be conducted first in order to determine if the open dumpsite is convertible to a controlled dump. A desk study can gather a wide range of information about the site, including maps and photographs, and information about the geology of the site. Any known pollution or contamination of soil, water and air at or near the site, and details of the waste types and amounts dumped can also be obtained. The site investigation survey will, where physically and safely possible, confirm the depths of dumped wastes. Boreholes will detect any pollution by leachate.

The next step of site investigation involves planning for preliminary excavation and obtaining the necessary regulatory approvals. At this point, a work plan must be developed to include:

- The number of pits and/or trenches to be dug
- Equipment and material handling procedure
- Labor requirements and their safety
- Creation of a work zone with clearly marked boundaries
- Necessary analytical testing, measurements and data collection

Some relevant factors that need to be addressed while planning dumpsite rehabilitation employing the concept of landfill mining are given in Box 4.1.

Box 4.1 Planning for dumpsite rehabilitation

- Proper time to begin extracting material from the landfill, taking into consideration the odor that will be produced
- Methodology that should be adopted to conduct feasibility studies
- Methodology in taking representative samples
- Development of methods of analysis of the mined samples
- Materials that can be recovered through mining of dump sites/landfills
- Expected quality of the recovered materials in terms of purity
- Variation of degradation with time, wastes and space
- Environmental and health risks of landfill rehabilitation works
- Enhancement of waste stabilization and integration of landfill design and operation

This plan has to provide the blueprint for every activity to be conducted during site investigation. The primary activity of the site investigation is to characterize the wastes in the areas to be excavated. This is accomplished by digging test pits and/or trenches and analyzing to determine material volumes, soil to waste ratio, waste composition and its state of decomposition. A trench exposes a larger area and can give a better idea of what is buried but may unleash odors than digging a pit (Salerni, 1995). Once the site investigation is completed, the information gathered should be analyzed to determine whether the proposed goals could be met within the projected cost framework. The issues to be addressed in this analysis include slope stability, access roads, leachate management, fire control, soil cover, waste reception, fencing, scavenger control, use of mechanical equipments, limiting the working face and waste disposal operations.

4.5.1 Slope stability

Over-steepened waste slopes should be identified for regrading and the quantity of waste to be moved estimated. Unless there are compelling local geotechnical reasons, in parts of the site not in use, no waste side slope should be steeper than 1 in 3 (33% gradient) and top slopes should not be more than 1 in 20 (Rushbrook, 2001). The slope stabilization activities should seek to redistribute waste within the confines of the existing dumpsite and not extend the external boundaries of the fill.

4.5.2 Access road

Access to a disposal site from the highway is essential. The access road should permit the passing of two trucks travelling in either direction. Roadside waste piles should be removed and the road upgraded to a sufficient standard to permit the easy passage of trucks carrying waste to the site. The running surface should be firm and not easily disrupted by traversing trucks. A minimum standard for the road surface is compacted earth or similar material with a top dressing of road stone. A durable, asphalt surface would be preferred.

4.5.3 Dumpsite fire control

Where fires exist at an open dumpsite, a plan should be prepared to extinguish them as the rehabilitation work progresses across the site. The method to be used for extinguishing fires should be presented in the plan. The use of water to extinguish fires should be avoided. Isolation and rapid natural burnout or smothering with soil is preferred. Firefighting tools, equipment, protection clothes etc should be selected and placed at the landfill. Training of personnel should be planned also in cooperation with Firebrigade.

4.5.4 Leachate accumulation

If accumulated leachate is identified on the open dumpsite then a plan should be made to drain or pump the leachate into a prepared lagoon not liable to flooding or recirculated back into the waste. The source of the leachate should be determined and the remedial works defined to prevent leachate accumulations reoccurring in the future.

4.5.5 Soil cover

Compared to the benefits of a better-controlled operation and improved compaction of waste, soil cover is expensive and may not be that beneficial, especially if the dumpsite is located in a remote area. In a situation where dumpsite volume is limited, the use of soil cover implies less site volume will be available for waste disposal. In case a decision is made to use cover material then the daily quantity of cover material (at least 5 cm depth of daily cover, 25 cm intermediate cover and 50 cm final cover) required should be estimated. Clay soils can be used as cover material. The local availability of soil cover vary and therefore the expenses for the both daily and final cover can vary a lot between different locations.

4.5.6 Waste reception area

A reception area should be clearly defined to allow incoming vehicles to be stopped and checked by operating staff. The reception area should have an entrance gate or barrier to regulate the flow of vehicles to and from the disposal site and a gatehouse to store waste records and documents and provide landfill staff with protection from unfavorable weather conditions. The reception area should have sufficient space for at least two trucks to be parked and not interfere with the vehicle movements in and out of the site.

4.5.7 Fencing

The provision of perimeter fencing is desirable but may not be practicable to install around all rehabilitated open dumpsites. The purpose of simple fencing is to delineate the boundary of a site and to discourage unauthorised vehicular access and straying animals. Simple fencing will not deter scavengers from entering a site. As a minimum requirement all open dumpsites within 0.5 km of communities should be fenced. The perimeter at both sides of the site entrance should be fenced to a sufficient distance to prevent vehicles bypassing the official entry point to the site. The minimum form of fencing to control vehicular access and larger animals should be a stake-and-wire strand fence or an excavated perimeter ditch and bund planted with fast growing hedge-forming shrubs.

4.5.8 Scavenging Control

Scavenging is disruptive to controlled and safe land disposal operations. Ideally, it should not be allowed to take place, but when difficult economic circumstances prevail it is not easy to eradicate it from a disposal site. A policy to tolerate the presence of scavengers requires decisions on how best to accommodate their activities without interfering with the waste emplacement operations. A decision to eradicate scavenging will imply the need to install additional site security measures.

Where scavenging is tolerated, a minimum approach is to separate scavengers from the mechanical equipment emplacing waste. The usual approach is to set up a temporary scavenging area near the waste emplacement area where trucks can discharge their loads. After the scavengers have finished searching the waste it is bulldozed to the emplacement area. At larger sites, a permanent scavenging area such as a raised platform, could be established and the remaining residues transferred to a truck or container below for transport to the emplacement area. It is also common to arrange for families or groups of scavengers to be licensed to enter the dumpsite and collect one or more types of materials.

4.5.9 Mechanical equipment

The preparations for dumpsite rehabilitation should include a list of equipment to be provided to the improved site. Mechanical equipment serves three basic functions at a controlled land disposal site:

- Functions related to soil (excavation, handling, spreading and compaction)
- Functions related to wastes (spreading and compaction)
- Support functions (maintenance of on-site haul roads, water clearance and drainage ditches and removal of trapped trucks from the landfill working area)

The number and type of equipment required will vary depending on the quantity of waste received each day and the resources available to maintain and operate the equipment. The followng equipments are required for full operation of the disposal site:

- one bulldozer of sufficient size to handle the daily quantity of waste arriving at the site to spread and compact waste and soil cover
- one tractor and trailer to carry soil to the working area and undertake some support activities
- a supply of spare parts and consumable items for the mechanical equipment
- a supply of hand tools including shovels, brooms, wheelbarrows and rakes

Additional items that would improve further the operation of the dumpsite are:

- One water tank on a trailer with a pump to carry leachate and spray water on roads to control dust
- A mechanical shovel to excavate the soil cover if soil has to be brought from a borrow area.
- At small landfill sites or if the budget is low equipment with multiple function must be selected.

4.5.10 Area of exposed waste

All exposed and uncontrolled piles of waste should be compacted into layers. They may also be moved to other parts of the site if this facilitates the creation of the eventual final landform of the site. All uncovered areas of waste not expected to receive new deposits of waste, or at least not in the next few months, should be covered with an intermediate or final layer of soil material. The remaining area of exposed waste will form the initial working area for the emplacement of incoming waste. This area should not exceed 0.5 ha for sites receiving up to 250 tonnes per day and one hectare at sites receiving 250 to 500 tonnes per day. Two hectares may be appropriate at large sites receiving well over 500 tonnes per day.All these preparatory aspects of the planning and design of open dumpsite remedial works should be presented to the relevant technical and municipal authorities in a 'Rehabilitation plan'. Once the project is deemed feasible, an expanded work plan must be created to address the material, movement, manpower and machine requirements. The work plan may address issues listed in Box 4.2.

Box 4.2 Issues related to rehabilitation plan

- How much material has to be moved in a day to reach the project goals without exceeding the budget?
- Which part of the site will the equipments be placed?
- How will the materials be moved and stockpiled on site?
- How many workers will be needed to accomplish the tasks?
- What training do the workers require?
- What should be done with the wastes/recovered components after digging them up?
- What are the sampling and analysis protocols to determine the quality of excavated material?

Source : Salerni, 1995

Financial and economic analyses for producing the cost estimates of rehabilitation; the assessment of the financial and economic impacts of rehabilitation and forecasts of increases in the land price in adjacent areas subsequent to rehabilitation may also need to be prepared. Once this plan is finalized, the activities may be carried out based on the plan. A daily review of the work plan is necessary to make adjustments to suit site requirements.

4.5.11 Waste disposal operations

Waste disposal operations at the site should be in accordance to a waste disposal plan prepared during the rehabilitation planning stage. A waste disposal plan should be prepared to provide clear instructions on the elements listed in Box 4.3 related to site operation.

Box 4.3 Waste disposal plan

- Size and location of the first and subsequent sequence of areas to be filled with waste after the site has been rehabilitated, leading ultimately to the completion of the site and its final landform. Each waste emplacement area will have a unique reference number indicated on a scale drawing of the site
- Method of waste emplacement and soil covering to be used
- Structure, roles and responsibilities of the management and manual staff at the site
- Procedures for record keeping related to incoming vehicles, waste types and estimated quantities
- Procedures for record keeping related to on-site mechanical equipment, other routine maintenance and accident and defects reporting
- Traffic control at the site
- Fire prevention and smoking rules
- Maintenance and repair water drainage ditches
- Instructions for dealing with prohibited wastes that arrive at the site reception.

4.5.12 Waste reception

The site preferably it should have a weight bridge and all incoming loads should be registered for the following details or to be recorded for each load: date, time of arrival, vehicle identification number, vehicle owner, description of waste, estimated quantity of waste (weight or volume), and waste emplacement area used. The waste disposal site should have a sign at the main entrance providing the following details: name of site, opening days and hours, arrival instructions for drivers, no smoking markings and a short summary of the site's importance.

4.5.13 Waste placement

No vehicle driver should be allowed to choose where to deposit a waste load. The driver must be directed by the site entrance staff to the current waste emplacement area and discharge only at the location indicated by the traffic marshal. The installation of sufficient portable, temporary or permanent lighting should be considered if nighttime working at the dumpsite is planned.

4.5.14 Environmental monitoring

Box 4.4 lists the minimum environmental and health monitoring recommendations.

Box 4.4 Environmental and health factors

- Presence and distribution of surface discharges of leachate
- Quality of the receiving watercourse and diversity of ecological indicator invertebrate and fish species
- Presence of vegetation die-back or discoloration around the dumpsite that may indicate lateral gas migration
- Water quality in drinking water wells located within 500 m radius of the dumpsite
- Presence of vectors (e.g., rodents and insects) breeding in or near the dumpsite
- Landfill gas emissions

4.5.15 Staff training

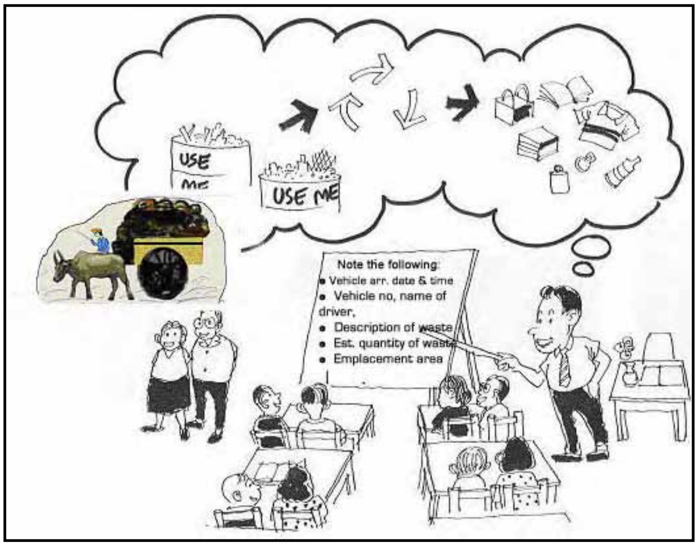
The minimum number of staff will vary depending on the quantity of waste received and the standard of disposal operation achieved (Box 4.5). If the staff are not trained or given clear, written job descriptions then it is not surprising that they show little interest or competence in operating an organised and well-run waste disposal operation. It is also for site personnel to understand that with training and defined job descriptions comes the responsibility to perform properly the tasks they are given. Status, pay, employment contracts and working conditions also influence the ability and willingness of individual staff members to accept and carry out the responsibilities placed upon them. These personnel issues must also be addressed during the planning stage.

Box 4.5 Staff requirements

- A site manager with sufficient delegated authority to manage daily site activities and access to physical and financial resources to overcome day-to-day operational problems
- A gatekeeper/office clerk
- Security guards (if necessary)
- Traffic marshal(s) for directing trucks to discharge waste at the working part of the disposal site
- Mechanical equipment drivers (minimum of two)
- Manual labourers (minimum of ten)
- Maintenance mechanic(s) if it is intended to establish a maintenance facility at the disposal site.

4.6 Post closure care and after use of a closed dumpsite

When disposal operations have ceased and final cover or capping has been applied to the waste, the dumpsite is considered as "closed". It is important to ensure that illegal dumping does not continue at any closed dumpsite. The long-term effects of settlement, gas emissions and leachate production, among others, will require aftercare measures for a closed dumpsite long after it has ceased operations. Thus, post-closure activities are important in ensuring the proper functioning of the final cover, drainage control systems, leachate management systems, and other environmental controls. Long-term monitoring of closed disposal sites is recommended to ensure that there is no release of contaminants from the disposal site that may significantly affect public health and the surrounding environment.



Closed dumps are not suited to buildings or permanent structures without extensive site engineering. Mindspace, a commercial complex over an area of 125 acres of land at Malad Dumpsite (20 ha) in North Western Mumbai is reported to be causing heavy damage to the equipment and materials due to the emissions from the dumpsite (Sahu, 2007).Vehicular traffic over closed landfills should be prohibited to protect the soil and vegetative covers. For at least two years after site closure, the site should be checked monthly to ensure vegetation reestablishment and to monitor any erosion or settling of the final cover. The closed dump should continue to be monitored on a less frequent basis for up to thirty years after site closure.

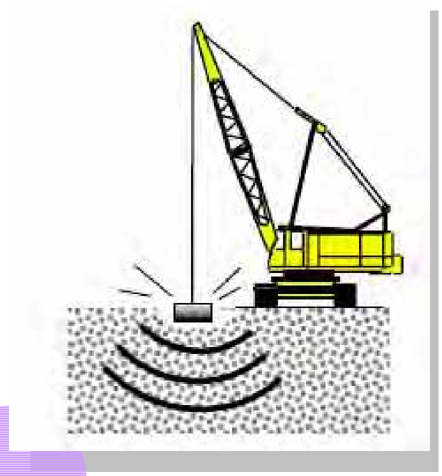
A closed dumpsite may later be used as a green area, recreation area, or for construction purposes. However, its planned after use will need to consider such factors as differential settlement, bearing capacity, gaseous emissions, and corrosion of metals. These factors often dictate the potential uses of the site, such as the kind of structures that can be erected over it, the kind of vegetation, and the types of materials that may be buried underneath it. Because open dumpsites are unplanned and haphazardly operated, the practical beneficial afteruse are often limited. Constructing a landfill on top of dump waste is not a preferred option. Construction of commercial and residential complexes over improperly closed dumps is known to affect human health and effect damage to sensitive equipment like computers and other electronic devices.

The typical problems related to after use of closed dumpsites are:

- As the waste is typically dumped in a haphazard manner, it would first need to be leveled. In case the height of the waste dumped is very high, its stability needs to be checked
- As the compaction of the waste is rarely done, stability of the waste with additional load due to new landfill on top has to be accounted for
- Movement of waste for leveling is costly and time consuming. Moreover, the activities have to be carried out in unhygienic conditions
- Waste has to be brought to stable slopes
- Settlement of waste over a period of time needs to be considered when designing and choosing the geotechnical material and leachate collection system
- Release of gas has to be considered to avoid bulging

As waste decomposes even under a capping, its volume decreases and the heap settles, leaving a dangerous vacant pocket near the top. The most attractive option of stabilizing steep side slopes of the landfill is to strengthen them externally or internally without relocating the existing waste. Another simple method for stabilization of the steep side slopes is to reprofile and regrade them to gentle slope of 4 (horizontal) : 1 (vertical).

Dynamic consolidation (also known as dynamic compaction) is a ground improvement technique (Figure 4.2) that involves dropping heavy weights (15ton - 20tons) on to the surface of the fill from a considerable height (15m - 20m) following a selected grid pattern to reduce void space, increase density and reduce long-term settlement of the fill (Vee, 1999). By increasing the density, it increases the storage capacity of the landfill. Beside, it also increases the bearing capacity. Reducing the long-term settlement, roads, parking bays and lighter structures can be designed on shallow foundations on closed landfills. A thick layer of soil masses could also be placed on top to make the compaction 5-10 m or more that later is taken away.



Source: Vee, 1999

Figure 4.2

Schematic of Dynamic consolidation

When excavation works begin at large open dumps to shape the steep sides to a one-in-three slope, the opening-up of the heap releases large quantities of methane. This may cause fires and smoke. Fire-brigade efforts to douse the flames with copious water will aggravate the problem and generate more uncollected methane by introducing water deep into the airless mass which one wants to keep dry apart from generating more leachate to pollute the groundwater. This vicious cycle of methane – fire – water dousing – more methane – and - leachate will persist daily unless there is a change in practices. It is possible to pump in oxygen into the dumpsite some weeks before start of excavation in order interrupt the methane production.

A proposed after use should be evaluated carefully from a technical and economic point of view. If more suitable land is available elsewhere that would not require the expensive construction techniques that may be required at a former disposal site, then it may be prudent to look for other sites. Selection of an end use for a closed disposal site is often dictated by availability of funds for a redevelopment project and the needs of the community. Any planned afteruse(s) of a closed or completed open dumpsite should take into account the planning considerations in the previous discussion.

4.7 Remediation

The objective of remediating an open dump is to minimize the environmental health and safety problems created by the dump. One option for the remediation of a closed site is to remove all dumped material to a replacement sanitary landfill. This is likely to be an expensive approach unless only a small volume of waste is involved. It will also use space in the new landfill. It may also be possible to use bio-remediation techniques. The main considerations in selecting a cleanup technology include the following:

- Types of contamination present
- Cleanup objectives and planned after use of the site
- Length of time needed to achieve cleanup objectives
- Post-treatment care needed
- Budget

Generally, the more intensive the cleanup approach, the more quickly the contamination will be mitigated and the more costly the effort. For most Local Bodies, financial constraints will most likely dictate the actions taken (or not taken). Typical approaches are Institutional controls and use of containment or cleanup technologies.

4.7.1 Institutional Controls

This means controlling or limiting the current and future use of, and access to, a site. Institutional controls can range from a security fence prohibiting access to certain portions of the site to deed restrictions imposed on the future use of the facility.

4.7.2 Containment Technologies

This means reducing the potential for migration of contaminants from the site to avoid exposing the public and the environment to the deleterious effects of such contaminants. ***Containment Technologies*** include engineered barriers such as caps and liners for landfills, slurry walls, and hydraulic containment. They reduce the potential for offsite migration of contaminants and possible subsequent exposure to people and the environment. Like institutional controls, containment technologies do not remove the contamination, but rather mitigate potential risk by limiting access to it. In determining whether containment is feasible, planners should consider:

Depth to groundwater - Planners should be prepared to prove to regulators that groundwater levels will not rise and contact contaminated soils.

Soil types - If contaminants are left in place, native soils will be an important consideration. Sandy or gravelly soils are highly porous, which enable contaminants to migrate easily. Clay and fine silty soils provide a much better barrier.

Surface water control - Planners should be prepared to prove to regulators that stormwater cannot infiltrate the floor slab and flush the contaminants downward.

Volatilization of organic contaminants - Regulators are likely to require that air monitors be placed to monitor the level of organics that may be escaping from the dump.

Containment technologies such as caps and liners will require regular maintenance, such as maintaining the vegetative cover and performing periodic inspections to ensure the long-term integrity of the cover system.

Sheet Piling - Steel or iron sheets are driven into the ground to form a subsurface barrier. Low-cost containment method used primarily for shallow aquifers. Not effective in the absence of a continuous aquitard. Can leak at the intersection of the sheets or through pile wall joints.

Landfill Capping - Landfill capping is by far the most common method of site remediation. Landfill caps are designed to do just what their name says, they 'cap' the landfill so that contaminants contained within are not released into the environment. They are most effective when the landfill or dump site in question has a viable liner system that is still functioning and where most of the waste is above the water table. In these situations, a cap functions to keep water from entering the waste matrix, thus reducing leachate contamination. Caps usually are formed of a combination of compacted clay and soil in combination with a semi-permeable membrane.

4.7.3 Cleanup Technologies

Cleanup Technologies may be required to remove or destroy onsite contamination if the types of contamination are not conducive to the use of institutional controls or containment technologies. Cleanup technologies fall broadly into two categories - ex situ and in situ, as described below. An ex situ technology treats contaminated materials after they have been removed and transported to another location; After treatment, if the remaining materials, or residuals can be returned to the site or moved to another location for storage or further treatment.

Excavation and *ex-situ*/treatment/disposal - Removes contaminated material to an approved landfill. Generation of fugitive emissions may be a problem during operations. The distance from the dumpsite to the nearest disposal facility will affect cost. Depth and composition of the media requiring excavation must be considered. Transportation of the soil through populated areas may affect community acceptability.

In-situ technologies treat contamination in place and are often innovative technologies. Examples of *in-situ* technologies include bioremediation, soil flushing, air sparging, and treatment walls. In some cases, *in-situ* technologies are feasible, cost-effective choices for the types of contamination that are likely at dump sites. Planners, however, do need to be aware that cleanup with *in-situ* technologies is likely to take longer than with *ex-situ* technologies. A cost-effective approach to cleaning up a dumpsite may be the partial treatment of contaminated soils or groundwater, followed by containment, storage, or further treatment off site.

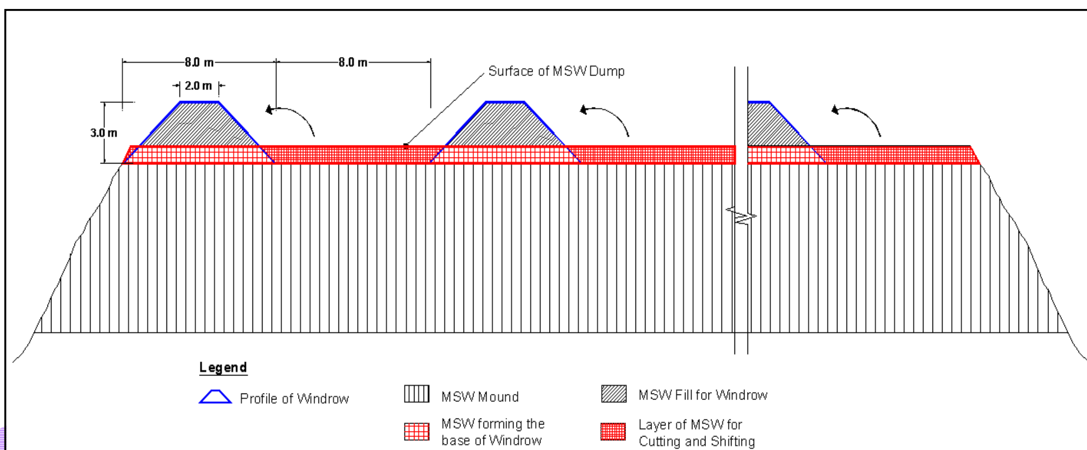
Natural Attenuation - Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface media can reduce contaminant concentrations to acceptable levels. Consideration of this option requires modeling and evaluation of contaminant degradation rates and pathways. Sampling and analyses must be conducted throughout the process to confirm that degradation is proceeding at sufficient rates to meet cleanup objectives. Intermediate degradation products may be more mobile and more toxic than original contaminants and the contaminants may migrate before they degrade. The site may have to be fenced and may not be available for reuse until the risk levels are reduced. Modeling contaminant degradation rates, and sampling and analysis to confirm modeled predictions extremely expensive.

Phytoremediation - a technology using green plants to remediate contaminated sites can be put to beneficial use during the management of open dumps. Features that make phytoremediation an attractive alternative include: low capital cost, relatively minor on-going maintenance costs, non-invasiveness, easy start-up, high public acceptance, pleasant appearance to the landscape and economic value addition through non edible product harvest. Selection of plant and the type of phytoremediation should be appropriate with the type of contaminants to be treated and the nature of the site. A good starting point for selection of appropriate plant species is to use the naturally occurring species at the sites. Although landfills only cover a limited surface, they often offer a large diversity of environmental niches for species.

Bioreactor Landfill - it is an *in-situ* technology in which air is injected under pressure into the dump to enhance the rate of biological degradation of contaminants by naturally occurring microbes. The moisture requirements will be supplied by leachate recirculation. Risk of fire/explosive is air mixture with methane.

4.7.3.1 Bioremediation by In-Situ Windrow Composting

Patel (2007) is of the opinion that "Bio mining" is a very simple, low-tech, low-cost, quick and eco-friendly method of remediating old open waste dumps to permanently achieve near-zero emission of landfill gases and leachate. This involves reclamation of old dump site by in-situ composting by formation of windrows at the top of the dump site and their systematic turning and sieving (Joshi and Nachiappan; 2007). The methodology is illustrated in Figure 4.3. The garbage at the dumpsite may be loosened by a tractor-cultivator in 15 cm layers and bulky waste removed manually. The rotted garbage (quite smelly) may be sprayed with a bio-sanitiser plus composting bioculture and formed into windrows which could be turned periodically till complete stabilization of the waste.



Source: Joshi and Nachiappan, 2007

Figure 4.3.
Schematic of in-situ windrow composting at dumpsites

This will not only remediate the dump, but will also increase the available post-closure area for a new scientific landfill or alternate use, as the cleared area at ground level will be three times more than a small plateau at 30 meters height above 1:3 side slopes after capping. Site clearance by bio-mining can commence at many points simultaneously if closure is very urgent. Considering that about 50 % of the waste could be recovered as soil conditioner/compost, the revenue stream from the operations is expected compensate for cost of landfill for rejects with effective cost of reclamation of about Rs.7 (US $ 0.2) per m^3 of waste. It is however noteworthy to consider the impact of frequent burning at dumpsites and *in-situ* degradation over the years, by which the waste may have very low compostable material and the windrow composting may not lead to any significant reduction in waste volumes. The quality of compost obtained from the dumped waste has to meet the standards for sale of the product as compost.

4.8 Cost of closure and Rehabilitation

Closure cost includes the capital and operational expenses. The capital expenses may include the cost of

- final cover material (if need to be imported into the site)
- drainage control systems
- fencing of the area
- leachate and gas management systems
- monitoring wells
- relocation of informal settlers
- planting and grading
- costs for treatment of hazardous waste collected

The operational expenses include the following:

- heavy equipment rental and maintenance costs
- manpower requirements – this includes laborers, utility men, and experts/consultants
- electrical Service – this will be required for the operation of pumps and lighting requirements of the area

Post-closure maintenance costs include the following:

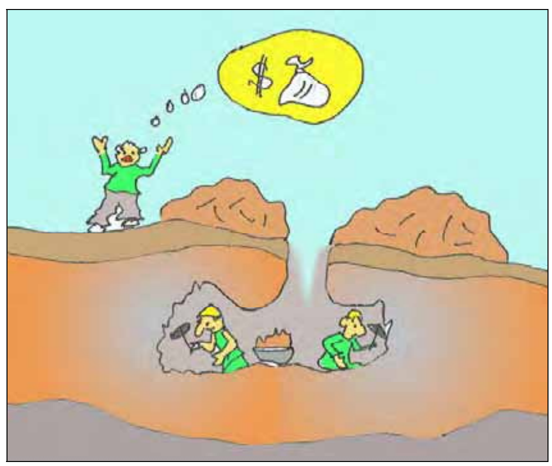
- Manpower requirement to: (a) secure the area; (b) conduct routine inspection; (c) conduct repair and preventive maintenance of site infrastructure such as the final cover, drainage control systems, and leachate and gas management systems, and; (d) conduct monitoring programmes for groundwater, surface water, leachate, and air quality.
- Repair and preventive maintenance costs, if there are damages to the cover, drainage control systems and other site facilities, repairs may need to be done. Preventive maintenance includes activities such as hauling of soil into the site to repair and seal cracks due to waste settlement, maintain grading of surface to facilitate surface runoff, and maintenance of leachate treatment ponds

Typical cost of landfill closure, without a bottom liner system, are in the range of Rs. 12.5 to 15 million per ha for sites exceeding in footprint area of 10 ha and volumetric capacity of 2 million m^3 (Joshi and Nachiappan; 2007). The closed landfill site, however, can give rise to significant CDM benefits if the site continues to receive fresh MSW for a period of one to two years during which the closure is planned and during this period the waste burning at the site is successfully eliminated. Typical CDM benefits at a conservative estimate from a site having 2 million m^3 of waste are estimated to be in the range of Rs. 60 to 100 million. About 40% cost of the closure can be off-set by CDM revenues for a typical dumpsite. These estimates do not include the revenues from the sale of landfill gas or the CDM benefit that may accrue due to fuel substitution.

CHAPTER 5

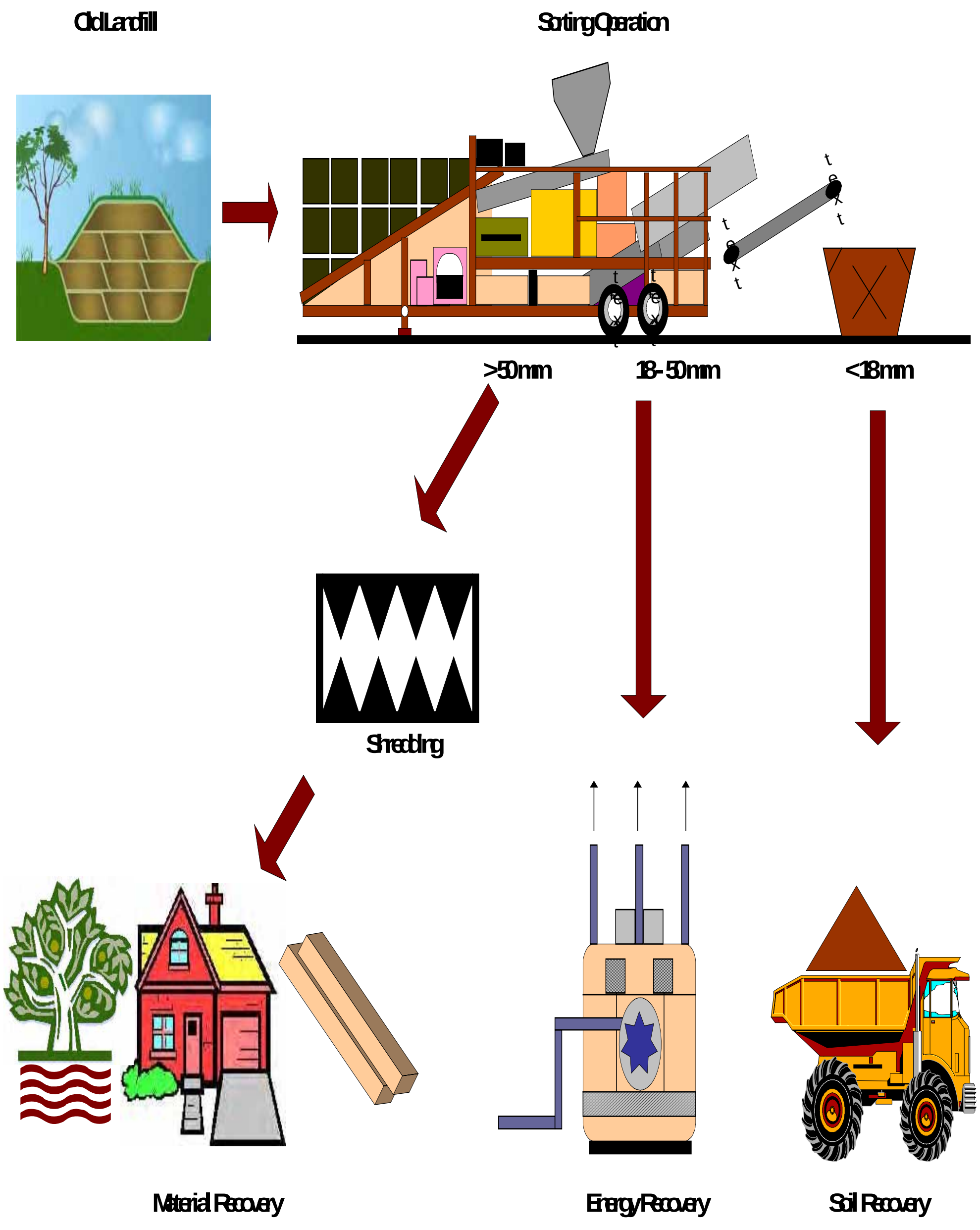
DUMPSITE MINING AND RECLAMATION

5.1 Dumpsite Reclamation Process



Dumpsite Reclamation or Mining is the process of excavating from operating or closed solid waste landfills, and sorting the unearthed materials for recycling, processing, or for other dispositions (Lee and Jones, 1990; Cossu et al, 1996; Hogland et al, 1998; Carius et al, 1999). It is the process whereby solid waste that has been previously land filled is excavated and processed (Strange, 1998). Typical landfill mining processes are presented in Figures 5.1 and 5.2.

Technically, dumpsite mining employs the method of open cast mining for sorting out the mixed material from the landfill according to their size by using a screening machine. The oversized materials are prescreened by another sorting machine which separates the larger objects like tyres and rocks from cardboards and other smaller unearthed materials. The objectives of landfill mining are summarized in Box 5.1. Several preparating activities (Table 5.1) are required prior to dumpsite reclamation.



Source: Carius et al, 1999

Figure 5.1 *Schematic of a dumpsite mining process*

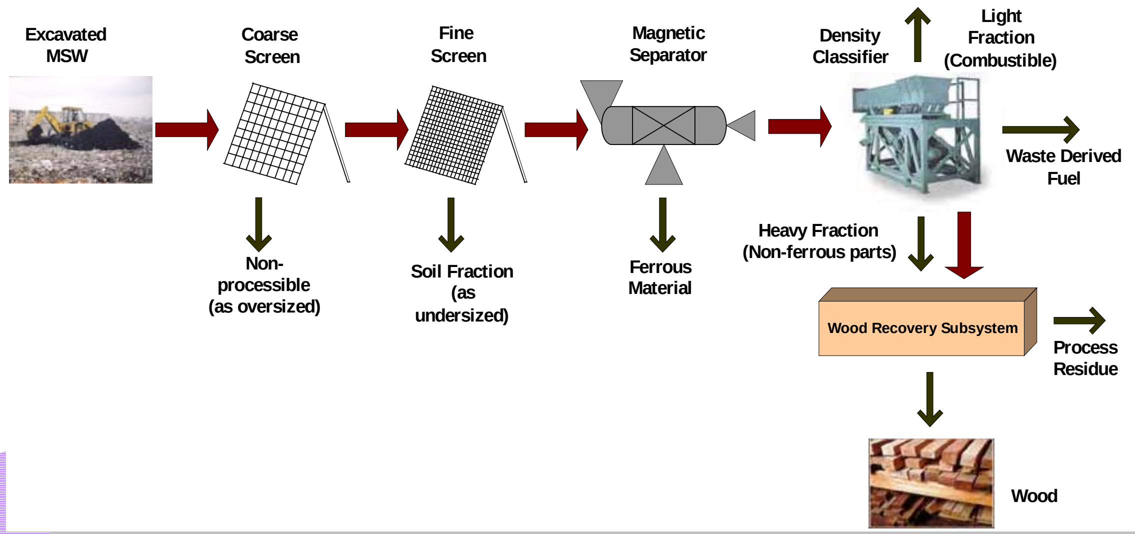


Figure 5.2
Process scheme for a dumpsite mining plant

Table 5.1. Site Preparation prior to dumpsite reclamation

Item	Provision
Site security	The whole site, for operational areas
Access and service areas	Internal access routes Materials handling areas (e.g. recycling, loading, weighting)
Division of site	Operational areas
Temporary storage areas	Contaminated solids Contaminated surface and groundwater Recycled material Replacement material
Environmental protection measures (air and land)	Wheel wash facilities, Water sprays, road sweepers Passive/active containment of working and storage areas Air monitoring, noise measurements
Environmental protection measures (water)	Temporary surface drainage, collection and treatment Groundwater controls (physical, hydraulic), collection and treatment of drainage from storage areas
Health and safety provision	Protective clothing and equipment Monitoring equipment Control of ignition sources Permit to work system Site security

Source

Dumpsite mining also provides the opportunity to remediate public health and environmental quality problems associated with the existing or closed facility (e.g. groundwater contamination). It will allow the placement of a lining system in unlined dumpsites and landfills so that future processing and solid waste management activities undertaken at the site might not present any unmanageable risk to public health and environmental quality (Lee and Jones, 1989a, b).

Box 5.1 Objectives of Dumpsite mining

- Conservation of landfill space.
- Reduction in landfill area.
- Elimination of potential contamination source.
- Rehabilitation of dump sites.
- Energy recovery from recovered wastes.
- Reuse of recovered materials.
- Reduction in waste management costs.
- Redevelopment of landfill sites.

Source : USEPA, 1997; Lee and Jones, 1990; Hogland et al., 1997

Dumpsite mining process typically involves a series of mechanical operations to recover one or all of the following:

- Wood for the production of wood chips
- Concrete, bricks and mortar material for road construction
- Metals such as iron, aluminum, copper etc., for recycling
- Compost/Soil
- Landfill space

The key to dumpsite mining operation is a set of conveyers and screens that sorts the solid wastes into three fractions: oversized material, intermediate-sized waste, and dirt/humus. The oversized materials consist of recyclable metallic goods, white goods, plastics and rubber. The intermediate-sized materials consist of partly decomposed organics, combustibles, recyclables and the fine fraction will mostly be stabilised soil. The main part of the process is the screening where the main separation is done for the oversized and the soil elements. Ferrous metals are generated from the main stream by employing a magnetic separator and the non-ferrous parts using an air classifier, which leaves behind the residue that could be combusted.

In dumpsite mining operations, an excavator removes the contents of the landfill cell. A front-end loader then organizes the excavated materials into manageable stockpiles and separates out bulky material. A trommel (a revolving cylindrical sieve) or vibrating screen separates soil (including the cover material) and solid wastes from the reclaimed waste. Trommel screens are more effective than vibrating screens for basic landfill mining (Murphy, 1993). The size and type of screen used depends on the end use of the recovered material. For example, if the reclaimed soil were to be used as landfill cover, a 6.25 mm screen is used for separation. A smaller mesh screen (2.5 mm) may be used to remove smaller pieces of metal, plastic, glass, and paper, if the reclaimed soil were meant for construction fill, or for another end use requiring fill material with a high fraction of soil content. The separation of dirt/ humus material from the intermediate-sized waste is made using a screen grid with 6.25 mm openings. The success of materials recovery is dependent on the composition of the waste, the effectiveness of the mining technology and the efficiency of the technology (Cossu et al, 1996). The recovery of various materials ranges from 50 to 90% of the waste (Strange, 1998). The average soil fraction in recovered municipal waste from landfill tends to be around 50-60%. However, it can vary between 20 and 80% as given in Table 5.2 depending on moisture content and decomposition rate (Hogland, 2002). The soil fraction could be used as cover or lining of new landfill. Strange (1998) suggested that a landfill needs to be 15 years old before a successful mining project can be performed. The success of a project depends on the composition of the decomposed waste.

The non-recyclable part of the intermediate-sized and oversized materials is typically reburied in the mined area of the landfill. If this portion is reburied without further processing, this landfill mining operation typically achieves about 70% volume reduction (Cossu et al, 1995, Hogland et al, 1995). Facility operators considering the establishment of a landfill mining and reclamation program must weigh the several benefits and drawbacks associated with this waste management approach.

Table 5.2. Soil to waste ratio in landfill mining

Landfill	Soil-to-waste ratio (%)
Edinburg, New York, USA	75:25
Horicon, New York , USA	65:35
Hague, New York , USA	50:50
Chester, New York USA	25:75
Coloni, New York, USA	20:80
Sandtown, Delaware, USA	46:54
Burghof, Germany	71:29*
Schoneiche, Germany	77:23*
Döbeln-Hohenlauft, Germany	62:38*, 21:79**
Schoneiche, Germany	20-80*, 30:70**
Dresden, Germany	74:26*, 19:81**
Sengenbühl, Germany	11:89*, 45:65**
Basslitz; Germany	50:50*, 34:66**
Cagliari, Italy	31:69*
Filborna, Sweden	65:35

* Screen gauge 40 mm ** Screen gauge 8-40 mm *Source: Hogland, 2002*
Screen gauge is 24 mm unless otherwise indicated

5.2 Benefits of Dumpsite Mining

Landfill Mining for Reclamation (LFMR) extends the life of the current landfill facility by removing recoverable materials and reducing waste volume through combustion and compaction. The potential benefits of landfill mining are summarized in Box 5.2.

Most potential economic benefits associated with dumpsite mining are indirect and may include any or all of the following:

- Increased disposal capacity
- Avoided or reduced costs of landfill closure and post closure care and monitoring

- Revenues from recyclable and reusable materials, e.g., ferrous metals, aluminum, plastics, and glasses. Combustible waste and reclaimed soil are sold as fuel and construction fill, or for other uses
- Land value of sites reclaimed for other uses

The major benefit from this approach is the extension of useful life of the existing landfills by many years besides avoiding the cost and time to locate, design, permit, and construction of a new landfill.

Box 5.2 Benefits of dumpsite mining

- Recovered materials, such as ferrous metals, aluminum, plastic, and glass, can be sold if markets exist for these materials
- Reclaimed soil can be used on site as daily cover material on other landfill cells, thus avoiding the cost of importing cover material. Also, a market might exist for reclaimed soil use in other applications, such as compost
- Combustible reclaimed waste can be mixed with fresh waste and burned to produce energy
- By reducing the size of the landfill "footprint" through cell reclamation, the facility operator may be able to either lower the cost of closing the landfill or make land available for other uses
- Hazardous wastes if uncovered during LFMR, especially at older landfills, could be managed in an environmentally sound manner.

Source : USEPA, 1997; Lee and Jones, 1990; Hogland et al, 1997

5.3 Limitations of Dumpsite Mining

One limitation of dumpsite mining is that it requires a lot of machinery and manpower. Other limitations include odor and air emissions at the reclamation site, increased traffic on roads between the dumpsite and resource recovery facility, extra mixing and handling of waste at the resource recovery facility, and the handling of additional inert materials. Reclamation activities shorten the useful life of equipment, such as excavators and loaders, because of the high density of waste being handled. Moreover, the high particulate content and abrasive nature of reclaimed waste can increase wear of equipment. Lack of knowledge about the nature of waste buried might be a limitation regarding safety issues.

Other safety issues include physical injury from rolling stock or rotating equipment; exposure to leachate, and hazardous material or pathogens during mining or processing; subsurface fires and landfill gas emissions. Health risks to the general public appear to be minimal.

Cell excavation may raise a number of potential problems related to the release of landfill gases such as methane and sulphur dioxide. Excavation of one dumpsite area can undermine the integrity of adjacent cells, which can sink or collapse into the excavated area. There is considerable concern about the personal hazards to workers as part of dumpsite mining because of the burial of hazardous materials in many dumpsites and the presence of explosive gases such as methane (Box 5.3).

Box 5.3 Limitations of landfill mining

- Poor quality of recovered materials
- Ineffectiveness of substituting recovered tin cans for scrap aluminum cans
- Low-value and limited applications of recovered plastic products
- Poor separation of plastics/glass, based on their base material
- Emission of landfill gas
- Health hazardous
- Bad logistics at the excavation and sorting area

5.4 Public health and environmental protection measures

Excavation and disposal operations at dumpsites may have adverse public health and environmental impacts (Table 5.3) during excavation, materials handling, off-site transfer or on-site disposal due to:

- Air pollution, through the emission of hazardous particulates, fibres and gases
- Surface and groundwater pollution through the discharge of contaminated solids, sludges and liquids
- Transfer of contaminant off-site due to inadequate vehicle decontamination or sheeting of vehicles
- Noise and vibration
- Odors
- Traffic movements and congestion

Table 5.3. Hazards which may be encountered during excavation of dumpsites

Origin of hazard	Type of hazard	Example
Presence of contamination	Toxicological	Installation of hazardous substances, e.g. asbestos fibre, metal oxides, hydrogen sulphide, carbon dioxide, volatile hydrocarbons etc. Ingestion of contaminated food Inhalation of contaminant combustion products through smoking Direct contact with toxic, carcinogenic (e.g. PAHs, henzene) or corrosive (e.g. chlorates, acids and alkalis0 substances
	Asphyxiation	In oxygen-depleted atmospheres
	Explosion/ combustion	Organic vapours, elemental white phosphorous, subterranean fires
Pond ground conditions	Physical	Collapse of sides of excavation at depth, in unconsolidated ground or due to poor drainage Unexpected mineshafts or underground workings, wind due to underground combustion Insecure footing of personnel e.g. due to slippery soils or soft ground.
Use of heavy equipment and plant	Physical	Overlapping: collision; cuts, grazes or more serious injuries

The severity of these effects depend on a number of factors including: the nature of the contamination; the scale and duration of the remedial operation: weather conditions; the proximity and sensitivity of potential targets such as neighbouring residential populations, surface or groundwater resources and ecologically significant habitats; and the extent to which mitigating measures are taken to eliminate or reduce the impacts. Mitigating measures for use in connection with excavation of dumpsites and landfills are indicated in Table 5.4

Mitigating measures should be consistent with both the magnitude of the risks involved, and the scale and extent of the operation. Where excavated material has a significant potential to affect public health or the environment, consideration should be given to the use of active containment of the operational area (e.g. mobile tents with controlled air movement). The use of temporary cover on a daily basis is likely to be required for friable contaminated materials undergoing on-site disposal.

Table 5.4. Mitigating measures in connection with dumpsite excavation

Impact	Mitigating measures
Air pollution	Restriction of operations of favorable weather conditions Fine water sprays, temporary containment of excavation, materials handling, and deposition area monitoring Temporary covering of exposed surfaces Careful selection and operation of plant and equipment (e.g. sheeting of vehicles, control over vehicle speeds on-site)
Contaminant transfer	Site zoning, restriction of operation to favorable weather conditions. Fine water sprays. Vehicle decontamination measures, temporary covers, Dust control on haul road and operational areas.
Surface and groundwater pollution	Temporary surface drainage. Use of physical/hydraulic measures to control local groundwater regime collection and treatment/authorized disposal of liquid effluent. Containment and monitoring of storage/residual contamination-site disposal areas
Noise and vibration	Carcial selection of location for noisy equipment on site. Restrictions on working hours Note: Compliance with prior consents under the control of pollution act 1974 and legal requirements on noise emissions from vehicles and plant
Traffic movements and congestion	Use of rail transport where available, Careful positioning of site entrance and internal access routes, Careful selection of external access routes Observance of planning, conditions regarding vehicle movements

5.4.1 Site services

For excavation operations lasting for periods longer than a couple of weeks or for particularly hazardous operations, power, water and drainage services will be needed to:

- Support office and sanitary accommodation for the workforce
- Support any on-site laboratory facilities
- Provide water for an environmental protection measures such as water sprays, wheel wash
- Provide foul water drainage for site accommodation, operational and storage areas

Special provision may have to be made for 'fixed' materials handling facilities such as weighbridge, rail sidings, wheel washers etc. Telephone links should be considered for health and safety reasons.

5.4.2 Storage

Areas for the temporary storage of excavated solid materials, recycled material and contaminated surface and groundwater may have to be accommodated on the site.

Areas designed for the storage of contaminated material should be located on untreated parts of the site. Some form of containment may be necessary to prevent contaminants leaching out of stockpiles and exacerbating ground conditions beneath. Temporary cover, such as tarpaulins, plastic sheeting etc. may be needed to reduce infiltration of rainwater into stockpiles or prevent the release of dust.

Storage areas for uncontaminated excavated material, clean recycled hardcore, or imported replacement fill, should be established on the treated or otherwise uncontaminated areas of the sites (keep out the sorted material separately so that they are not mixed again, storm water shall not flow between the heaps and add new contaminates to the materials).

5.4.3 Site Security

The security requirements of the site will vary depending on local conditions and existing provision. Appropriate measures should be taken at the site boundary to prevent unauthorized access, particularly by children, and in respect of individual operational areas where necessary. Access restraint, in the form of temporary fencing, visual markers etc., should be used around excavations greater than 1.2 m in depth which are left unattended for any period of time (See Box 2.2)

5.5 Plant and Equipment

A wide variety of plant and equipment may be required to undertake excavation and disposal operations (Table 5.5).

Table 5.5. Examples of plant and equipment needs for excavation and disposal

Unit operation/support activity	Example
Boundary definition	Temporary/permanent posts and linkage paint markers on permanent structures e.g. walls, buildings
Site preparation	Office and sanitary facilities Lifting, earth warming and compaction equipment for site preparation including: access and base preparation: surface drainage installation: storage area preparation: effluent treatment plant; on site disposal facility physical barriers and associated installation equipment for in-ground containment Lining materials for storage areas; on-site disposal area Equipment and materials for gas and leachate control systems for on-site disposal Health and safety clothing and equipment.
Excavation	Excavation and breaking plant
Materials handling	Lifting and loading plant, dumper and tipper trucks Concrete crusher and screening plant Treatment plant for solids and water. Separation and dewatering plant
Disposal off-site	Off-site transport vehicles Loading, lifting and dumping plant for on-site disposal, compactors, Intermediate cover materials
Requirement	Replacement materials Loading, lifting and dumping plant Compactors
Monitoring, health and safety and environmental protection	Portable air monitoring equipment; mobile laboratory: vehicle/equipment decontamination plant; wheel-wash; in-site observation wells for on-site disposal

- Plant involved only in the excavation of materials
- Plant that can only excavate and load material
- Plant that can only haul and deposit materials
- Plant that can excavate, load, haul and deposit

Excavation	Excavation and load	Haul and deposit	Excavation, load, haul and deposit
Rippers	Dragline	Dumpers	Dozers
Drill & Blast	Face Shovel	Dump trucks	Tractor-drawn scrapers
Impact Hammers	Forward loaders	Lorries	Motor scrapers
Hydraulic	Grabs	Conveyors	Dredgers
Breakers	Bucket wheel		
Skimmers	Excavator		

5.6 Laboratory Support

Laboratory analysis plays a major role in excavation and disposal operations in four main areas:

1. Additional site characterization, both before and during operation activities
2. Compliance monitoring (e.g. excavated materials for disposal, effluents to sewer)
3. In support to public health, occupational health and safety, and environmental protection monitoring
4. Post-treatment management (e.g. post-excavation validation, long-term monitoring of on-site disposal areas)

In some applications, sampling and analysis requirements may be significant in terms of the numbers of samples and tests to be processed often within a very short period of time e.g. on-site testing during excavation works to delineate the edges of contamination, or detailed monitoring prior to the off-site disposal of excavated material where the WRA has requested additional testing in support of site investigation data.

5.7 Planning

Excavation and disposal operations require detailed planning and management. The complexity of the planning and design stage clearly depends on the scale and nature of the operation: the small-scale removal of a few hundred cubic metres of superficial fill moderately contaminated with copper and zinc will not require the same detailed planning and design as an operation involving the removal of thousands of cubic metres of fill contaminated with beryllium, or deposits of radioactive or asbestos-bearing residues. However, good planning and management should address the basic issues listed in Table 5.6

Table 5.6. Planning for excavation and disposal

Unit operation	Operational requirement	Support
Pre-operational period	• Environmental impact assessment	• Base-line monitoring • Community consultation
Site preparation	• Site services (power/water/drainage) • Site access/internal access/working platforms • Temporary storage/recycling/materials treatment areas • Disposal area (use below) • Site security • Wheel and vehicle washing • Weigh bridge • Haul roads • Railway sidings	• Environmental protection measures (whole area, operational areas) • Monitoring (equipments/support facilities) • Health and safety requirement/emergency support area)
Excavation	• Depth and extent of excavation • Means of controlling depth and extent of excavation (physical stability nature of strata degree of contamination) • Size zoning/phasing (horizontally) vertically/ over time) • Volumes, types and variability of material to be excavation	• Environmental protection (air/water protection measures, vehicle decontamination, temporary cover over excavation) • Monitoring (QC an arising/recycled material/effluent, in support of health and environmental protection, in respect of residual contamination for partial excavation)
Excavation (Contd.)	• Rate of excavation (material flows) • Number, types and variability of material to be handled • Segregation, separation and dewatering needs • Material flows • Numbers and types of vehicles or other transport means • Plant and equipment needs	• Health and safety (equipment/procedures) • Record-keeping procedure

Table 5.6. Planning for excavation and disposal (Contd…)

Unit operation	Operational requirement	Support
Materials handling	• Volume, types and variability of material to be handled • Segregation, separation and dewatering needs • Material flows • Numbers and types of vehicles or other transport means • Plant and equipment needs	• Environmental protection for operational areas • Monitoring (QC on material flows, in support of health and environmental protection) • Health and safety (equipment/procedures) • Record-keeping procedures
Replacement	• Method of placement • Plant and equipment required • Protection against further migration	• Environmental protection for operational areas • Monitoring (QC on material flows, in support of health and environmental protection) • Health and safety (equipment/procedures) • Record-keeping procedures
Final disposal off-site	• Transport arrangements	• Environmental protection for transit vehicles/trains etc. • Monitoring (QC on materials, in support of health and environmental protection measures) • Health and safety (equipment/procedures) • Record-keeping procedures
Final disposal on-site	• Technical characterization of designated area • Volumes and types of materials to be placed • Engineering works to prepare area • Equipment and procedures for placement • Duration of operation, restoration requirement	• Environmental protection (containment for soils/liquids/gases) • Monitoring (QC on materials, in support of health & environmental protection measures) • Health and safety (equipment/procedures) • Record-keeping procedures
Post-treatment management	• Post-excavation validation for excavated area • Periodic review and maintenance of on-site disposal area	• Collection of long-term monitoring data from on-site deposits • Record-keeping procedures

5.8 Dumpsite Mining Projects in the Asian Region

Dumpsite mining has been used throughout the world during the last 50 years as a tool for sustainable dumpsiting. The first reported dumpsite mining project was an operation in Tel Aviv, Israel in 1953, which was then a method used to recover the soil fraction to improve the soil quality in orchards (Shual and Hillel, 1958; Savage et al., 1993). It was later employed in United States of America (USA) to obtain fuel for incineration and energy recovery (Hogland, 1996, Cossu et al., 1996, Hogland et al., 1996). Pilot studies carried out in England, Italy, Sweden, Germany (Cossu et al., 1995; Hogland et al., 1995), China and India are also reported.

The primary objective of the Tel Aviv Dumpsite Mining Project in Israel was to excavate the waste for recovery of soil amendment (Shual and Hillel, 1958). The excavation equipment consisted of a front-end loader and a clamshell and the processing equipment included several conveyors and a rotating trommel screen. In the process, waste material was excavated and transported to a conveyor belt. The conveyor belt transferred the waste to a trommel screen of about 7 m long, 2 m in diameter and rotated at about 13 rpm. The screen had openings of approximately 2.5 cm and the material that passed through the screen openings was used as soil amendment. The material retained in the screen was transported by conveyor belt to a resource recovery area where manual separation was used to recover ferrous metals and other recyclable materials. The soil amendment was used primarily in citrus groves.

Two developments took place in the USA between 1950 and 1980 that impacted on landfill mining. One was the emergence of a modular processing system designed to process mixed waste as it arrived at landfills or at transfer stations, primarily for the purpose of recovering steel containers. The second development took place in the late 1960s/early 1970s, and dealt with the assessment of the technical feasibility of composting landfilled MSW *in situ* (Strange, 1998). The project involved the construction of specially designed cells in a landfill. Some of the cells were filled with sorted MSW and others with mixed MSW and covered with a soil layer. A forced aeration system was set up to supply oxygen for the process. The project was not implemented at full-scale because of technical infeasibility.

Although the project was not executed, it provided information on the acceleration of the degradation of organic matter in a landfill and the importance of a multi-cell structure in a sanitary landfill (Strange, 1998). Subsequently, there have been six landfill mining projects in the USA (Lee and Jones, 1990). Murphy (1993) has reported a research project that investigated different aspects of MSW aerobic digestion and reclamation. Landfill mining has been reported as a method of waste management planned or implemented in many developed and developing countries (Murphy, 1993; Nelson, 1995; Foster, 2001; Hull et al, 2001).

5.8.1 Landfill mining in China

An opportunity to combine existing Chinese landfills and horticulture activities include landfill mining and greenhouse growing systems (Sino - Australian Mission on Integrated Solid Waste Management, 1997). Initial trials were carried out at San Lin, where the reclaimed wastes were screened to get soil fraction and a residual inorganic fraction. An inspection of the degraded wastes *in-situ* at San Lin, revealed that the soil fraction could provide a very fertile growing medium, while the inorganic fractions could be used as a source of energy. Old cells were excavated to recover more space. The excavated material was screened to produce three fractions; biodegraded organics, combustible inorganics, and non-combustible residuals. Excavated cells were prepared for refilling with new waste, allowing for the use of artificial lining of old cells, reduction in bund wall dimensions and upgrading of leachate and gas collection systems. The non-combustible residuals were returned to the prepared cell. Biodegraded organics from old cells were combined with freshly excavated silts and bund wall trimmings to make a rich and fertile growing medium as final cover and the basis for the horticulture program. The completed cells were managed as *in-situ* bioreactors with upgraded leachate drainage and collection plus leachate recycling to achieve faster and more complete biodegradation of cell organics and higher gas yields. Horticulture activities were conducted in greenhouses constructed on completed cells. A waste to energy plant on the site was used to combust the methane produced from the bioreactor cells plus the combustible inorganic fraction recovered from the excavation of old cells. The waste to energy plant produced electricity, for local use or sale into the grid with waste heat for use in greenhouses to maintain constant elevated temperatures for year round growth of high value added crops. Figure 5.3 illustrates the landfill mining operation in China.

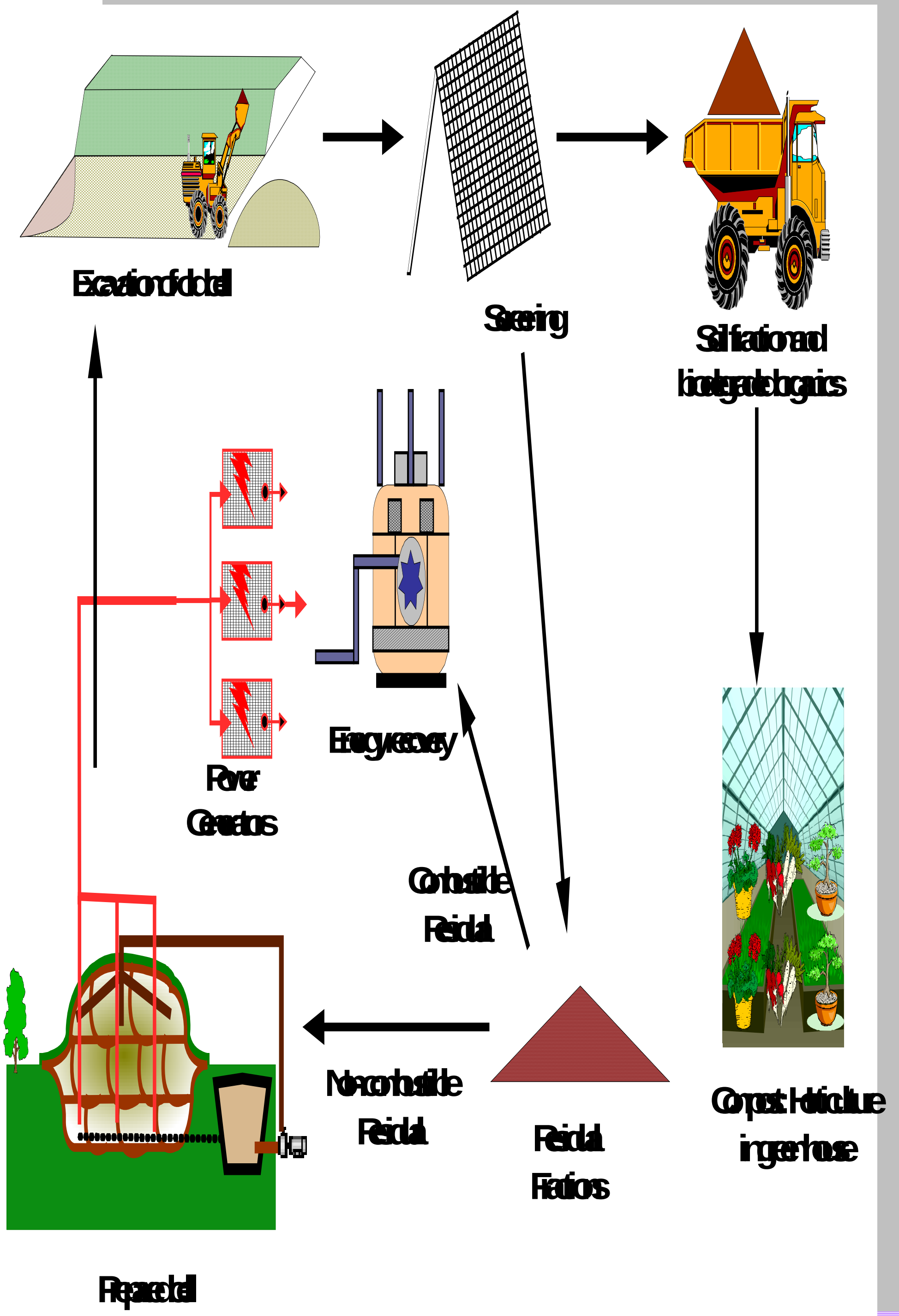


Figure 5.3 *Schematic of a landfill mining process in China*

5.8.2 Dumpsite mining in India

Manfred Scheu and Bhattacharya (1997) reported on the reuse of decomposed waste from the solid waste dumpsite in Deonar, near Mumbai, India. The site has been in use since the turn of the 20th century holding large amounts of waste, much of it at an advanced state of decomposition. Decomposed waste from a portion of this dumpsite between 4 and 12 years old was excavated manually, sun dried and screened with apertures of about 8 mm as shown in Figure 5.4. The fine material was bagged and removed from the site. The coarse material was left in the dumpsite itself. Two companies were involved in this work. The Municipal Corporation was paid Rs.106/- (US $ 2.2) per ton as a lifting and truck weighing charge. Estimates of the amount of screened material removed in this way varied from 80 to 150 tones per month to 30 tones per day.

The fine material was mixed with cow dung, dolomite, gypsum, and neem cake (the residue after the extraction of oil from neem seeds) and sold as a mixed fertilizer. The company which also sold agricultural chemicals, marketed the product in an attractive way, claiming that it would:

- increase root aeration and yield
- reduce pest and weed nuisance
- increase microbial activity
- correct micronutrient and secondary nutrient deficiency
- increase water retention
- increase fertilizer use efficiency

Figure 5.4
Dumpsite mining at Deonar, India

Results of the analysis of the blended product, carried out by the supplier, are presented in Table 5.7 while Table 5.8 shows the analyses of decomposed waste samples. It is interesting to note that the percentages of "other materials" such as plastic, glass and metal were very small.

Table 5.7. Analysis of decomposed waste soil conditioner

Parameter	Value
Moisture	10% to 12%
pH (dilution 1 : 10)	7 to 8
Organic carbon	15% to 17%
Organic matter	30% to 34%
Total Nitrogen as N	0.9% to 1.3%
Phosphorus as P_2O_5	1.5 % to 1.9%
Potassium as K_2O	0.5% to 0.8%
Sulphur as S	0.55% to 0.7%
Calcium as Ca	5% to 7.5%
Magnesium as Mg	0.5% to 0.8%
Copper as Cu	200 ppm
Zinc as Zn	900 ppm
Iron as Fe	900 ppm
Manganese as Mn	250 ppm
Boron as B	120 ppm

Source: Manfred Scheu and Bhattacharya (1997)

Table 5.8. Characteristics of decomposed waste from Deonar Dump, India

Description	Result
Density of wet sample	960 kg/m^3
Percentage passing 8 mm mesh	63.5%
Stones greater than 25 mm	31.5%
Evaporation and sieving losses	1.1%
Moisture content, fine material	14%
Organic matter, fine material	14.5%
Other materials	
Plastic (soft)	0.4%
Rags	1.1%
Glass and ceramic	0.9%
Metals	0.4%
Rubber and leather	0.6%
Coconut and wood	0.6%
Analysis of fine material	
pH	7.2
Organic carbon	5.8%
Nitrogen	0.5%
Sulphur	0.4%
Calcium carbonate	12.6%
Soluble aluminum	1000 ppm
Soluble manganese	270 ppm
Soluble iron	4800 ppm

Source: Manfred Scheu and Bhattacharya (1997)

5.9 Landfill Mining - Case Studies from Developed Countries

Savage et al. (1993) has mentioned how the concept of landfill mining was introduced already in 1953, when a landfill operated by the city of Tel Aviv, Israel, was mined. However, it remained the sole application reported until the late 1980s. From then on several mining projects have been mentioned. An important reason for this renewed attention is the shift towards resource recovery (Savage et al., 1993). Other motivations for mining are a lack of landfill space, pollution liability, costs of implementing government regulations, and benefits of mining in terms of e.g., landfill cover material and energy production, cf. Nelson (1994, 1995) and USEPA (1997). Cossu et al (1996) reported on the technical and practical experience gained on several commercial landfill mining projects in USA and pilot / research experience from Europe. Landfill mining studies from developing countries are not found in literature, possibly due to the fact that landfills are rare in these countries. However, there exist a large number of potential dumpsites for mining. Salient features of some of the landfill mining case studies in developed countries are presented in this section.

5.9.1 Collier County, Florida

The objectives of landfill mining of Naples Landfill in Collier County, Florida, were to reduce the potential for groundwater contamination; recover and reuse cover material, decrease site closure costs, recover recyclables and reclaim landfill capacity (Stein, 1993). With the County generating more than 400,000 tons of garbage each year, it was originally estimated that the landfill would be full in nine years (Tammemagi, 1996). It was reported that the smaller fraction, the "dirt-humus," was about 75 to 80% of the mined waste after removal of the oversized materials, or about 60 to 70% of the total mined waste (Lee and Jones, 1990). The intermediate-sized fraction was about 5% of the total processed waste. The remaining intermediate-sized waste, representing about 15% of the total waste mined, was primarily composed of plastic, rubber, wood, glass, brass, aluminum and cloth and had considerable calorific value. These fractions had the potential for further processing for recovery or recycling. By reclaiming waste from unlined sections of the 20-year-old landfill, Collier County reduced landfill-operating costs by recovering saleable materials, and extending the life of the site. The project's most significant benefit was the increased environmental protection through removal of dangerous and toxic wastes.

A comprehensive field test evaluation of the Collier County landfill mining system was conducted in 1992 under the US EPA's Municipal Innovation Technology Evaluation (MITE) Program (USEPA, 1997). The mined wastes were relatively well decomposed. The soil fraction recovered from the process (i.e. cover material plus fine decomposed wastes) accounted for about 60% of the in-feed material. With the exception of the soil fraction, the degree of purity of the recovered materials was in the order of 82% or lower. Thus, the ferrous and plastics fractions contained substantial levels of contamination that would probably impact their marketability. In the case of the soil fraction, the concentrations of metals were found to be below the limits imposed by the State of Florida for unrestricted use of waste-derived compost. The mining operations reclaimed 50,000 tons of soil suitable for use as a landfill cover material. Based on 1995 prices, the reclaimed cover soil had a cost saving of $1 per ton compared to conventional cover.

5.9.2 Lancaster, Pennsylvania, USA

The Lancaster County Solid Waste Management Authority (LCSWMA) operates the landfill and transfer stations in the county (Figure 5.5). The Frey Farm landfill, located in Manor Township, was opened for waste disposal in September 1988. Construction of a three-train, mass burn facility, with a design capacity of 1,100 tons/day, was completed in December 1990. Since the initial delivery of waste was less than anticipated, previously land filled wastes was excavated from the first 7 ha cell and added to fresh MSW as supplementary fuel for the mass burn facility (Nelson, 1995). Mined material was combusted with raw MSW in a ratio of about 1:3 (weight basis). Earlier tests using unscreened mined material required a ratio of 1:7 or 1:8 in order to maintain design conditions for combustion, due to the relatively low heating value of mined wastes. The facility yielded about 660 kWh/ton of raw MSW, based on a heating value of 12,200 kJ/kg. When mined material was combined with fresh MSW for combustion, the yield decreased to about 500 kWh/ton of fuel burned. Ash yield from mined material was about 35%. Combustion of mined MSW did not have a negative impact on the permits for either the source recovery facility or the landfill.

The Pennsylvania Department of Environmental Resources (PADER) monitored the mining. Concerns initially expressed by PADER included the potential for changes to storm water runoff, extra leachate generation, and gas releases from the mining operation. However, none of the concerns became a problem. The only negative impact has been the additional traffic generated by the delivery of mined material to the project. The LCSWMA's objective in landfill mining has been to minimize the area of landfill in use. The energy value of the mined material was estimated to be US $33/ton. Material recovery is economically less attractive and, therefore, it was not a component of the operation.

Source : www.lcswma.org

Figure 5.5
Landfill mining operation at Lancaster County

Between 1991 and 1993, approximately 219,500 m^3 of MSW were excavated from the landfill. As a result, Lancaster County converted 56 percent of the reclaimed waste into fuel. The county also recovered 41% of the reclaimed material as soil during trommel operations. The remaining 3% proved noncombustible and was reburied in the landfill (USEPA, 1997).

LCSWMA recommendations for the reclamation operations at the landfill and resource recovery facility are given in Box 5.4.

Box 5.4 LCSWMA recommendations for landfill mining

- Proper planning of the excavation site to control the flow storm water and methane.
- Reliable methods for measuring volumes and tons of reclaimed waste, cover soil, and non combustibles and to track volumes by field survey methods.
- Daily observations of the reclaimed waste and proper record for moisture content, waste composition, waste age, soil content of refuse, rainfall, weather, and odor.
- Minimize personnel exposure to the actual reclamation site during trommeling operations.
- Optimum mix of MSW and reclaimed waste to maximize the combustion efficiency.
- Supplement the reclaimed stream with materials having high HHVs.
- Ambient air-monitoring at the reclamation site.
- Daily monitoring for methane, oxygen, and VOCs, and establish action levels for each parameter.
- Quarterly physical and chemical characterization of screened wastes.

Source : Forster, 2001

5.9.3 Thompson, Connecticut, USA

In 1986, the municipal landfill in the town of Thompson, Connecticut initiated a landfill-mining project with the objective of recapturing landfill volume and extending the life of the landfill temporarily while a permanent disposal alternative could be selected (Strange, 1998).

A local excavation contractor conducted the project, using a bulldozer, a pay loader, a truck, and a screen. The contractor first excavated about 20 test pits in the landfill. The area mined was a combination of the residuals from an old dump (which was set on fire periodically) and bulky wastes. No odors were detected as a result of the mining program.

Waste decomposition was relatively incomplete and the materials were 15 years old or less. At the time of the mining project, the available disposal alternatives represented costs in the range of US$66 to US$88/ton, including transportation. The cost of the mining project was US$117,000, including grading the base of the mined area to receive new MSW. Representatives from the town estimated that the town saved US$ 1 million in tipping fees over an 18-month period.

5.9.4 Barre and Newbury, Massachusetts, USA

As part of a permit application to expand a private sanitary landfill in Barre, Massachusetts, a proposal was made to mine a section of the property that had been filled between mid-1950s and 1970. The sections to be mined were to be lined prior to any additional filling. Test pits were dug to evaluate the material that would be processed. Excavation showed that some of the cells had been constructed to be almost completely impervious to the external penetration of water. The contents of these cells showed little decomposition. The recovered soil fraction was retained for use as cover material (Strange, 1998).

At Newbury, Massachusetts, a 3.6 ha landfill serving a community of 6,400 people was reclaimed in 1993 to construct a new lined landfill of 1.6 ha. Two third of the mined material was soil which was stock piled for future use as cover material (Nelson, 1995).

5.9.5 Nashville, Tennessee, USA

The Nashville project, operated by American Ash Recycling of Tennessee removed 305,840 m^3 of soil and ash from a 2.8 ha ash monofil owned by the city for extending the life of the monofil and to use the recovered material as road base and asphalt aggregate (Nelson, 1995). The project, which commenced in 1993, was developed following the completion of a one-year pilot project in Sumner, Tennessee.

5.9.6 New Hampshire, USA

The New Hampshire landfill site in USA served small towns and rural tourist areas. Wastes were landfilled between 1979 and 1987. In 1989, the company that owned the landfill was sold and the new enterprise filed a permit to expand the landfill. The New Hampshire Department of Environmental Services (NHDES) required that approximately 160 tons of material be relocated from the old, unlined portion of the landfill to the newly lined section. As part of the relocation process, NHDES allowed the company to mine the unlined landfill. Once the plans were approved, the NHDES included various requirements in the permit to build the new landfill that pertained specifically to the mining operation. Due to concerns regarding odors, the permit prohibited any mining or waste removal operations during June, July, and August and required that odor-masking agents be applied to the wastes being processed (Strange, 1998).

Throughout the landfill mining process, the impacts on air quality and the quality of the storm water runoff were monitored. The monitoring process also included measuring the concentrations of oxygen, hydrogen sulphide, and volatile organics in the air. Water quality monitoring also focused on changes in conductivity and pH. Slight increases in conductivity were noted and no changes in pH were detected. Equipment used consisted of two excavators, one front-end loader, four dump trucks, two bulldozers, one trommel screen, and one odor control sprayer.

5.9.7 Edinburg and Hague, New York, USA

In 1988, the New York State Energy Research and Development Authority (NYSERDA) contacted more than 250 landfill owners and operators in the state to ascertain their interest in participating in a landfill mining demonstration project. The Town of Edinburg was subsequently selected by NYSERDA as the host site for a one-acre demonstration project. Edinburg is a small, rural community and has a relatively small landfill (Strange, 1998). NYSERDA's objectives in undertaking the Edinburg project are given in Box 5.5.

Box 5.5 Objectives of Edinburg project

- Determine equipment needs and develop optimal procedures for the excavation.
- Separation, handling, and storage of land filled materials.
- Determine appropriate uses for the reclaimed material.
- Identify available markets for the materials.
- Develop required processing needs for the reclaimed materials.
- Develop recommendations regarding health and safety requirements, and
- Conduct contingency planning for future landfill reclamation projects in New York.

Source : Strange, 1998

Screening of excavated wastes was the significant key unit operation employed during the Edinburg Landfill Mining project. Approximately 25% of the mined materials passed through a screen surface with 7.6 cm openings and was retained on a screen surface with 2.5 cm openings. This fraction consisted primarily of cans and bottles. Materials larger than 7.6 cm included plastics, textiles, paper, wood, and metal. A test burn of a sample of residue from the process was conducted at the Pittsfield, Massachusetts waste combustion facility. Results of the tests indicated that the higher heating values for the residue varied between 4,700 and 5,800 kJ/kg. Residue (i.e. material larger than 2.5 cm) from the screening of materials during a hand sorting phase of the project was evaluated. The evaluation indicated that more than 50% of the rejects could be taken to a Materials Recovery Facility (MRF) for recycling, although the excessive concentration of dirt in the residue could contaminate clean source-separated recyclables. White goods and scrap metal would require cleaning to remove soil, and then the material could be baled and sold. The assessment of manually-separated film and High Density Poly Ethylene (HDPE) plastic indicated that these materials could also be sold.

Materials were sampled and analysed. No significant contaminant concentrations were detected during tests for asbestos, compost parameters, Toxicity Characteristic Leaching Procedure (TCLP) parameters, Target Compound List (TCL) parameters, and pathogens. The soil fraction met the State of New York standards for Class I compost and qualified for off-site use in a variety of applications, including as clean fill in public construction projects and daily landfill cover. The Edinburg Landfill Reclamation Project was successful both in securing offsite uses for the reclaimed soil and in reducing the landfill footprint to decrease closure costs (USEPA, 1997).

The first effort in USA to dig up and entirely remove an old landfill to return the site to its natural state was the Hague Landfill Reclamation Project which began in 1994 following a feasibility study (Nelson, 1995). The project aimed at removing a 2.7 ha landfill from the middle of a 52 ha site owned by the rural township for the purpose of using the land for recreational purposes. About 76,500 m^3 of was removed and separated for recovery of ferrous metal and for the beneficial use of soil fraction. The project budget was $ 1.3 million. Implementation of a full scale composting operation was shown to be feasible at the Hague reclamation project. Composting and re-screening resulted in a 31% weight reduction in material requiring off- site transportation (Steuteville, 1996).

5.9.8 Live Oak Landfill, Atlanta, Georgia, USA

In January 1997, a pilot-scale project to assess the feasibility of *in situ* aerobic bioreduction of municipal solid waste was initiated at the Live Oak landfill, located near Atlanta, Georgia (Smith et al, 2000). This project was carried out in a 10 m lined cell containing approximately 53,522 m^3 of MSW. The materials in the cell had been placed no more than three years before beginning this project. The materials contained a significant portion of biosolids from wastewater treatment plants. To simulate aerobic decomposition of the MSW, air and water (recycled leachate and additional fresh water) were injected into the fill material through wells. Routine monitoring of the process included temperature measurement; landfill gas composition; water volumes pumped and leachate generation; and physical, chemical, and biological characterization of leachate.

From October 1997 to 1998, small sections of the test cells were mined and separated to assess procedures, equipment needs and to characterize the materials recovered. The results showed that none of the wastes were stabilized at this time of sampling. Laboratory analysis of the trace metals of the humus fraction showed that As, Cd, Cr, Cu, Pb, Mo, Ni, Se and Zn were well within limits set by USEPA for high quality compost.

5.9.9 McDougal, Ontario, Canada

The Mc Dougal project started in 1994 and its goal was to remove the entire 3 ha landfill cell, line the site and put the waste back in after screening with a power screen trommel to remove soil fraction (Nelson, 1995). The project was undertaken to remediate leachate problems at the landfill when contaminants were found in monitoring wells. In addition, the project was expected to have enhanced the landfill capacity by 5-10 years. About 50% of the reclaimed waste was soil, most of which was used as daily cover and landscaping. The total budget including relining was $ 7 million.

5.9.10 Landfill Mining in Europe

The first landfill mining in Europe was in Germany, at the Burghof landfill site in 1993 (Rettenberger et al, 1995; Hogland et al, 1997). The main purpose of the excavation was environmental remediation and the construction of new landfills according to modern technology. A total of 53,700 tons of material was excavated and sorted from the landfill in 14 months. The mean bulk density of the material was 1,160 kg/m^3. About 70.5% of the reclaimed waste by weight was fine fraction and was reused at the landfill. 17.5% of the reclaimed waste was light fraction and was used at a waste-to-energy facility. The project helped achieve additional volume for waste deposition, improve the long term behaviour of the displaced waste, assess the technical and economical feasibility of landfill mining and to define more suitable measures for assuring optimal environmental conditions for workers and neighborhood (Cossu et al, 1996). Further research activities are in progress at the Schoneiche Landfill, one of the largest European sites, where domestic waste from the western side of Berlin was dumped for over 15 years.

The first study of landfill mining in Italy was conducted at an old landfill site in Sardinia, in 1994 (Cossu *et al.*, 1995). The study was aimed at obtaining all the design parameters such as landfill characteristics and quality of old waste.

During the summer of 1994, a 10-year-old part of the Filborna landfill in Sweden was excavated as a pilot test in a research project (Hogland et al, 1995). The landfilled waste consisted of a mixture of household, industrial, construction and demolition waste. About 1,300 m^3 of waste was excavated to a depth of 8.5 m from a 10-year-old part of the landfill. The excavation was made in two stages: down to 5 m level, and then to 8.5 m over a plot size of 30 m^2. There was no presence of dust or flies, however, a slight smell was observed. Hazardous wastes such as asbestos, batteries and cans containing unknown liquids and hospital wastes were found at different levels. Large amounts of biodegradable waste were found without any significant changes. Large areas in the fill were found to be very dry indicating that the lack of moisture in the landfill could have contributed towards the poor biodegradation. The characteristics of the material obtained from the landfill mining studies are provided in Tables 5.9 and 5.10. The major constituents of the leachate and its heavy metal contents are presented in Tables 5.11 and 5.12. Carius et al (1999) have reported development of thermoplastics from wastes recovered from landfills.

Table 5.9. Characteristics of the mined waste

Characteristics					Coarse fraction: amount by volume, amount by weight, density and moisture				Fine fraction: amount by volume, amount by weight, density and moisture			
Level below surface	pH	Temp °C	CH_4 %	CO_2 %	by vol. %	by wt. %	Density t/m^3	Moist. by wt %	by vol. %	by wt. %	Density t/m^3	Moist. by wt.
0 - 5 m	4-5	17	--	--	35	45	0.5	38	65	55	0.4	30
5 - 8 m	6.5	18-20	59	40	70	25	0.4	43	30	70	2.5	39

Source : Hogland et al, 1995

Table 5.10. Total solids, ash content, low calorific value and concentration of different constituents in the waste at 0-5 and 5-8 m below the surface

Parameter	Unit	Coarse fraction 0-5m	Fine Fraction 0-5m	Coarse fraction 5-8m	Fine Fraction 5-8m
Total solids	TS (%)	62.0	70.0	56.6	61.0
Ash content	% of TS	39.3	78.9	36.6	84.0
Calorific Value	MJ/kg sample	6.9	<2	7.9	<2
Carbon (C)	% by weight TS*	32	13	44	11
Nitrogen (N)	% by weight TS*	0.74	0.45	0.49	0.57
Sulphur (S)	% by weight TS*	0.39	0.71	0.27	0.56
Phosphorus P(tot)	g/kg TS*	0.77	0.72	0.66	1.5
COD_{Cr}	g/kg TS*	720	250	620	270
Magnesium (Mg)	g/kg TS*	0.84	1.6	0.99	1.6
Calcium (Ca)	g/kg TS*	12	17	7.6	15
Potassium (K)	g/kg TS*	1.4	0.99	0.85	1.3
Zinc (Zn)	g/kg TS*	1.9	0.50	0.33	0.58
Nickel (Ni)	mg/kg TS**	6.7	12	8.7	30
Copper (Cu)	mg/kg TS**	90	53	41	140
Chromium (Cr)	mg/kg TS**	0.39	36	8.1	39
Lead (Pb)	mg/kg TS**	88	160	18	100
Cadmium (Cd)	mg/kg TS**	7.1	1.6	0.57	3.4

TS – Total Solids; * Calculated based on the whole sample

Source: Hogland et al, 1995

** Calculated based on the whole sample, but for the fractions metals, glass, stone etc.

Table 5.11. Main constituents in the leachate from landfill mining (mg/L)

Sample	1	2	4	8	9	10
pH	8.2	7.9	7.7	8.5	8.6	7.9
Cond. (mS/m)	348	205	788	1048	972	1080
Cl^-	270	135	585	800	730	780
SO_4^{2-}	--	196	139	88	88	93
Ptot	1.4	0.7	4.5	8.1	7.4	8.1
PO_4-P	0.7	0.6	4.5	7.0	5.9	6.7
Kj-N	252	122	616	798	728	798
NH_4-N	252	112	602	785	700	798
NO_x-N	4.0	4.2	3.4	5.9	5.4	5.4
BOD_7	60	173	80	85	55	70
COD	635	510	675	1055	1025	1065
Susp. Solids	2195	1132	582	652	634	382
Total Solids	3552	2180	3472	5384	5072	5294
Fixed Solids	2782	1620	2616	4304	4154	4194
FFA %	0.60	0.35	1.54	1.89	1.68	2.13
Fat	--	--	4.5	81.5	<1	<1

Source : Hogland et al, 1995

Table 5.12. Concentration of metals in the leachate during landfill mining

Sample	1	2	4	8	9	10
Al	0.254	2.305	0.438	0.176	0.153	0.158
Ca	238.584	325.137	222.822	202.471	202.449	175.26
Cd	0.003	0.002	<0.001	<0.001	<0.001	<0.001
Co	<0.020	<0.020	<0.020	0.022	<0.020	<0.020
Cr	<0.007	0.029	0.068	0.132	0.134	0.117
Cu	0.034	0.052	0.021	0.043	0.029	0.022
Fe	70.23	62.44	5.93	9.3	11.89	7.57
K	181.383	82.133	297.289	418.872	386.641	414.91
Mg	55.688	40.324	84.882	103.995	99.361	104.382
Mn	0.557	2.096	0.574	1.079	1.163	1.113
Ni	0.029	0.024	0.037	0.089	0.053	0.074
Pb	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Zn	0.277	0.350	0.455	0.170	0.144	0.103
Ba	0.040	0.236	0.516	0.672	0.577	0.750
As*	0.63	2.43	1.91	3.24	3.00	2.13
Hg *	1.07	1.41	0.52	0.64	0.79	1.04
Na	235.07	146.34	555.33	1223.82	1077.51	1034.6

* *ppb*; others in *ppm*

Source : Hogland et al, 1995

The test screening and the recovery of material from the Måsalycke landfill (Figure 5.6) as well as a variety of projects showed that excavation is a realistic alternative for lifetime expansion and remediation of small and medium size landfills and can therefore be used in the Baltic Sea Region (Hogland, 2002). The Baltic Sea Catchment, with an area of 1,745,000 km^2, encompasses 14 countries (nine of them having a common borderline with the Baltic Sea) and has a population of 85 million people. The catchment is estimated to have 70,000-100,000 old landfill sites. The material excavated in the test was screened into the fractions: < 18 mm, 18-50 mm and > 50 mm. The coarsest fraction (> 50 mm) contained 50 % wood and paper. The medium-sized fraction (18-50 mm) contained stones and indefinable soil-like material, while the fine fraction contained peat-like material with some other small waste components. The spectral analysis of heavy metals indicated only high concentrations of zinc and there was no significant difference between the fine and the medium-sized fractions. The medium sized and the unsorted fraction was moisturized and refilled into the pit. The methane content in the landfill gas from the pit was 50-57 % in the sorted material with a flow 8-17 L/min and 38-57% in the unsorted fraction with a flow of 2-13 L/min during the first 1.5 year.

The town of Veenendaal, in the Netherlands has removed two landfills through landfill mining with separation of partly reusable fractions (Geusebroek, 2001). Eighty percent of the excavated wastes were screened for reuse. The presence of asbestos in the waste material posed a problem for both working conditions and limited reuse possibilities.

5.10 Cost of Landfill Mining

The costs and benefits of landfill mining vary considerably depending on the objectives (closure, remediation, new landfill etc.) of the project, site-specific landfill characteristics (material disposed, waste decomposition, burial practices, age and depth of fill) and local economics (value of land, cost of closure materials and monitoring) (Cossu et al, 1996; Van der Zee et. al, 2003). Cost heads related to project planning including capital and operational costs of the landfill mining project are as summarized in Box 5.6.

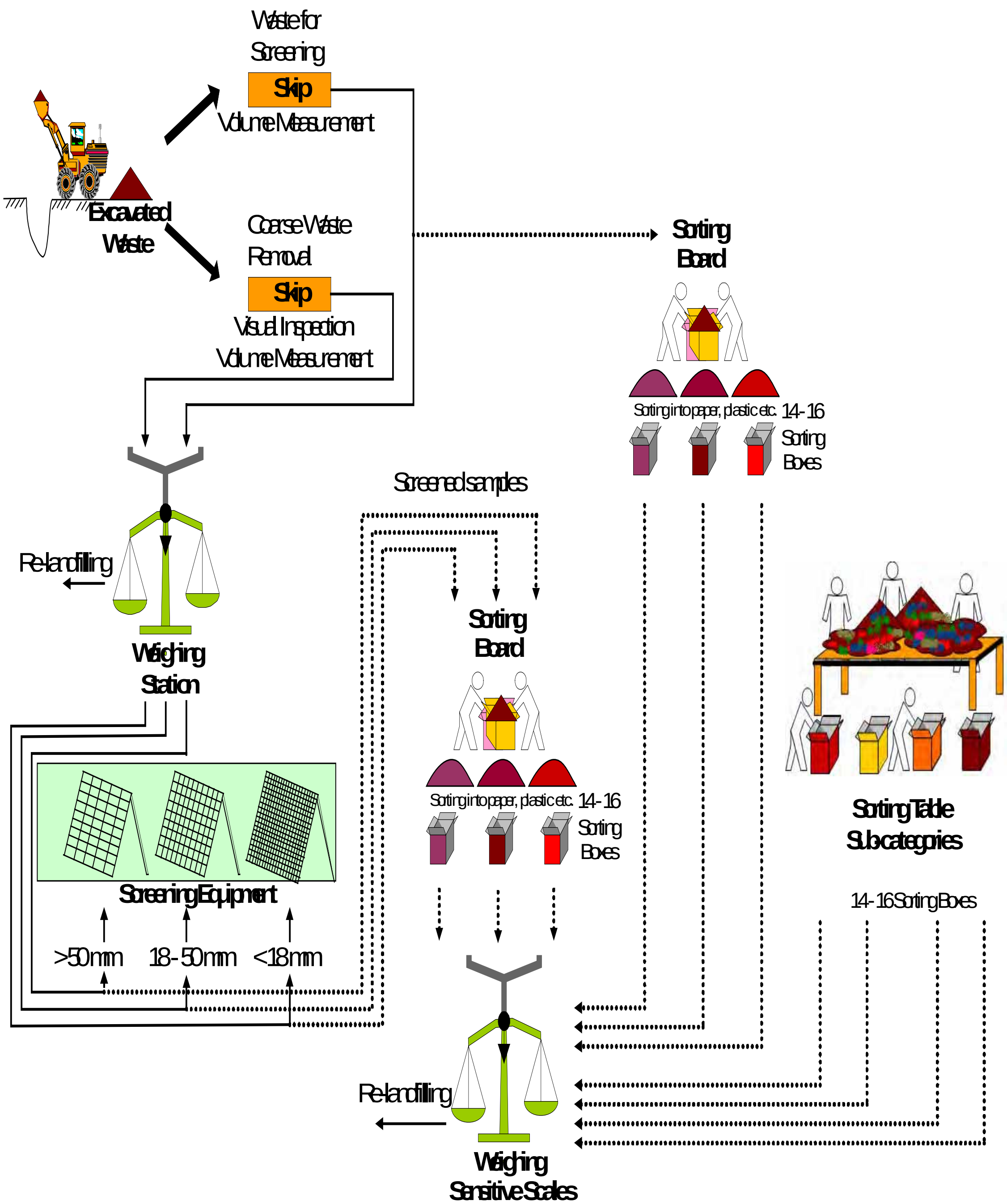


Figure 5.6 *Scheme of work for landfill mining studies in Masalycke Landfill*

Source : Hogland, 2002

Box 5.6 Cost of landfill mining

Capital costs:

- Site preparation
- Rental or purchase of reclamation equipment
- Rental or purchase of personnel safety equipment
- Construction or expansion of materials handling facilities
- Rental or purchase of hauling equipment

Operational costs:

- Labor (e.g., equipment operation and materials handling)
- Equipment fuel and maintenance
- Administrative and regulatory compliance expenses (e.g., record keeping)
- Worker training in safety procedures
- Hauling costs

The most potential economic benefits associated with landfill reclamation are indirect. However, a project can generate revenues if markets exist for recovered materials. Although the economic benefits from reclamation projects are facility-specific, they may include any or all of the following:

- Increased disposal capacity
- Avoided or reduced costs of:
  - landfill closure
  - post closure care and monitoring
  - purchase of additional capacity or sophisticated systems and
  - liability for remediation of surrounding areas
- Revenue from:
  - recyclable and reusable materials (e.g., ferrous metals, aluminum, plastic, and glass)
  - combustible waste sold as fuel
  - reclaimed soil used as cover
  - materials sold as construction fill or sold for other uses and
  - land value of sites reclaimed for other uses

While the rate of mining with a single piece of processing equipment may be as high as 180 tons/h, typical operation is at a rate of 50 to 150 tons/h. Based on the information developed by Landfill Mining, Inc. from its operation in the Collier County at 1995 prices, the cost of landfill mining is expected to be less than about US $10/ton of waste mined. A large amount of that cost is associated with rental of the processing equipment. The rental fee is typically between US$16,000 to 19,000/month. For a large scale operating plant in Europe, a cost of $ 75-100 per cubic meter was reported (Cossu et al, 1996). The cost of landfill mining at the Filborna landfill in Sweden in 1994 was US $6.7/ton.

The results of an analysis of the weekly production data, project costs and assets realized during 1992 and 1993 at the Frey Farm Landfill of Lancaster County presented in Table 5.8 show that 33% of the project costs was associated with excavation and trommeling operations at the landfill.

Transportation of reclaimed waste to the resource recovery facility (RRF) and hauling ash residue back to the landfill incurred 30% of the cost. The balance of the project costs was associated with processing fees paid to the landfill mining operator, RRF and landfill host communities. Revenues obtained from the sale of electricity from the RRF and recovered ferrous metal offset these operating costs and resulted in net revenues of US$ 3.94 for every ton of reclaimed material delivered to RRF. Additional assets recovered included cover soil and landfill volume making the overall profit to US$ 13.30 for every ton of material excavated.

In general, the economics of landfill mining depend on the depth of the waste material and the ratio of wastes to soil. The deeper the waste is buried, the more expensive it is to reclaim a landfill, per unit area (Salerni, 1995). In most cases, the presence of hazardous materials will also affect the economic feasibility. Thus, this step in project planning of analyzing the economics of landfill mining calls for investigating the following areas:

- Current landfill capacity and projected demand
- Projected costs for landfill closure or expansion of the site
- Current and projected costs of future liabilities
- Projected markets for recycled and recovered materials
- Projected value of land reclaimed for other uses

Table 5.13. LCSWMA reclamation weekly cost / revenue summary

Item Description	Total (Averages)		Total (Averages)
Project weeks	95	REVENUES	
Total volume excavated (yd.^{3})	286,501	Ferrous sales	$370
Average excavated weekly (yd.^{3}/wk.)	3,016	Electricity sales	$27,304
Total tons excavated per week	2,645	TOTAL REVENUES	$27,674
Total tons reclaimed	140,207	$/ton reclaimed	&18.75
Average tons reclaimed weekly	1,476	NET REVENUES	$5,812
Tons of cover soil recovered per week	1,076	$/ton reclaimed	$3.94
Tons of noncombustibles landfilled per week	93	ASSET ADDITIONS	
Net volume recovered (yd.^{3}/wk.)	2,459	Reclaimed soil (1,076 tons @ $2/ton)	$2,152
COSTS: LANDFILL OPERATIONS		Reclaimed landfill volume (yd.^{3})	2,478
Excavation/sorting	$4,362	Current value @ $11/yd.^{3})	$27,258
Trommeling	$1,305	TOTAL ASSET ADDITIONS	$29,410
Fuel	$579	PROJECT PROFIT	
Refuse transport to RRF	$4,943 ($3.35/ton)	Asset additions + net revenues ($/wk)	$35,222
COSTS: REFUSE PROCESSING AT RRF		MISCELLANEOUS DATA	
Lime	$970 ($0.66/ton)	Average LF HHV (Btu/lb)	3,149
OMSL fee ($/ton waste processed)	$4,471 ($3.03/ton)	Ash tons per week	586 (352 yd.^{3})
Host fee ($/ton processed + ash tons landfilled)	$2,441 ($1.65/ton)	Ferrous tons per week	28
Ash transport to landfill ($/ton)	$1,846 ($3.15/ton)	Electricity (kWh, 2-year average)	528,845
Administration/compliance	$671	Reclaimed material	3568 kWh/ton
TOTAL COSTS	$21,862 ($14.81/ton)		

5.11 Cost Benefit analysis

Analyzing the economics of dumpsite mining calls for investigating the current capacity and projected demand of the landfill, projected costs for landfill closure or expansion of the site, current and projected costs of future liabilities, projected markets for recycled and recovered materials and projected value of land reclaimed for other uses. Major factors influencing the cost of such projects will include the volume and topography of the dumpsite; equipment parameters; soil conditions; climate; labor rates; the regulatory approval process; excavation and screening costs; sampling and characterization; development costs; the contractor's fees; hazardous wastes disposal; and revenue from the sale of commodities such as compost and recyclables.

The quantification and monetization costs and benefits associated with the rehabilitation of a dumpsite in Chennai, India are summarized in Tables 5.14 and 5.15. The volume of the dumpsite requiring excavation and screening is estimated to be 5,00,0000 m^3 based on the dumpsite area of 100 ha and average depth to be excavated as 5 m. This is estimated to have a mass of 3.5 million tonnes with a density of 700 kg/m^3. About 50% of the waste mass is considered to be soil fraction and 10% will be recyclables. The remaining 40% requires landfilling. Disposal of residuals in a landfill with a height of 15 m will require about 17.3 ha of land and the remaining land of 82.7 ha can be reclaimed and at least 90% of it will be available for future landfilling applications.

The project will cost Rs. 147 million as against a benefit of Rs.162 million resulting in a positive benefit to cost ratio of 1.1 and it is economical to take up the project for implementation. In practice, the environmental costs and benefits should be added to the project costs and benefits before using decision criteria like Net-Present Value, Benefit-Cost Ratio, or the Internal Rate of Return of the project. The main challenge is to estimate the environmental costs and benefits properly. Unlike project costs and benefits which are more tangible, estimating environmental costs and benefits is not so easy. As such no data are currently available to monetise the local environmental benefits that will arise out of the project from the control of smoke and air pollution due to open burning of garbage and control of odor and fly nuisance as well as ground water pollution due to leachates.

The project will also have global environmental benefits from the point of view of controlling the methane emissions that contribute to global warming. It is estimated that about 40 % cost of the closure can be off-set by CDM revenues for a typical dumpsite. These estimates do not include the revenues from the sale of landfill gas or the CDM benefit that may accrue due to fuel substitution.

Table 5.14. Quantification and monetization of costs associated with Rehabilitation of a Dumpsite in Chennai, India

Sl. No	Item	Quantity, (wherever applicable)	Unit Rate (Rs.)	Cost (Rs. in million)	Cost (USD in million)
1.	Specialist advice (engineering, environmental, laboratory) involved in the design and implementation of the operation including site assessment, base-line monitoring and community consultation	in the beginning	lumpsum	3.0	0.067
2.	Planning and permit charges		lumpsum	1.0	0.022
3.	Site preparation, site services (power/ water/drainage/site access/ internal access/working platforms/ temporary storage/ recycling/ materials treatment areas / disposal area / site security / wheel and vehicle washing/ weigh bridge/haul roads	Once	lumpsum	2.0	0.045
4.	Rental/Purchase of Plant and equipment needs (excavation and loading plant, dumper and tipper trucks, screening plant and Treatment plant for leachates, loading, lifting and dumping plant for on-site disposal, compactors)			10.0	0.22
5.	Excavation operation (m^3) including labour, equipment fuel and maintenance Area of the dumpsite covered by the waste = 100 ha Average depth to be excavated = 5 m Total volume to be excavated = 5000000 m^3	5000000 m^3	100/m^3	50.0	1.11
6.	Material handling and Screening Operation including labour, equipment fuel and maintenance (5000000 m^3 @ 700 kg/m^3 = 3500000 t)	3500000 t	100/t	35.0	0.78

20

Table 5.14. Quantification and monetization of costs associated with Rehabilitation of a Dumpsite in Chennai, India (Contd…)

Sl. No	Item	Quantity, (wherever applicable)	Unit Rate (Rs.)	Cost (Rs. in million)	Cost (USD in million)
7.	Disposal of Residuals in a landfill cell including its closure (@40% of 3500000 t = 1400000 t in a landfill of 15 m height with a density of 900 kg/m^3)	172846m^2 (17.3 ha)	Rs. 2000/m^2	21.0	0.47
8.	Project management including record keeping and Environmental protection measures and Monitoring of arisings/recycled material/effluent and in support of health and environmental protection)		lumpsum	10.0	0.22
9.	Contingency planning (@ 10%)			15.0	0.33
			Total cost	147.0	3.26

Table 5.15. Quantification and monetization of revenue associated with Rehabilitation of a Dumpsite in Chennai, India

Sl. No	Item	Quantity	Unit Rate (Rs.)	Revenue (Rs. in million)	Cost (USD in million)
1	Sale of reclaimed soil as cover soil/compost in place of clay (@50% of 3500000 t)	1750000 t	400/t	70.0	1.56
2	Reclaimed land for landfilling @ 90% of (100 – 17.3 = 90 ha)	7443000 m^2	1000/m^2	74.4	1.65
3	Sale of recyclables/combustibles (@10% of 3500000 t)	350000 t	500/t	17.5	0.39
			Total Revenue	161.9	3.60

CHAPTER 6

DUMPSITE CLOSURE AND REHABILITATION PROJECTS

6.1 Dumpsite Reclamation Research in Chennai

The research on "Sustainable Landfill Management" funded by Sida focused on the reclamation and upgradation of the dumpsites at Kodungaiyur (KDG) and Perungudi (PDG), in Chennai, India through Landfill Mining. This project started in 2001 under the Asian Regional Research Programme on Environmental Technology (ARRPET). The objective of this study is to evaluate the degradation status of solid wastes of different age in the MSW dumpsites. The data generated could be used for comparing the waste degradation status in open dumps and sanitary landfills and for assessing the potential of recovering useful materials such as compost and inorganic recyclables from the dumpsites. These two dumpsites have been in operation for the past 15 years and currently receive about 3500 tonnes of MSW daily. The wastes are disposed through open dumping without use of any cover or compaction.

The elements of the study are depicted in Figure 6.1. The methodology involved collection of samples from two dump-sites at intervals of 1 m depth from the top of the waste dumps and analyzing them to determine density, temperature, moisture content, particle size, organic and inorganic fractions, macro nutrients (N, P, K) and heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc). The heavy metal content of the soil fraction is compared with the Indian and international standards to check its use as compost.

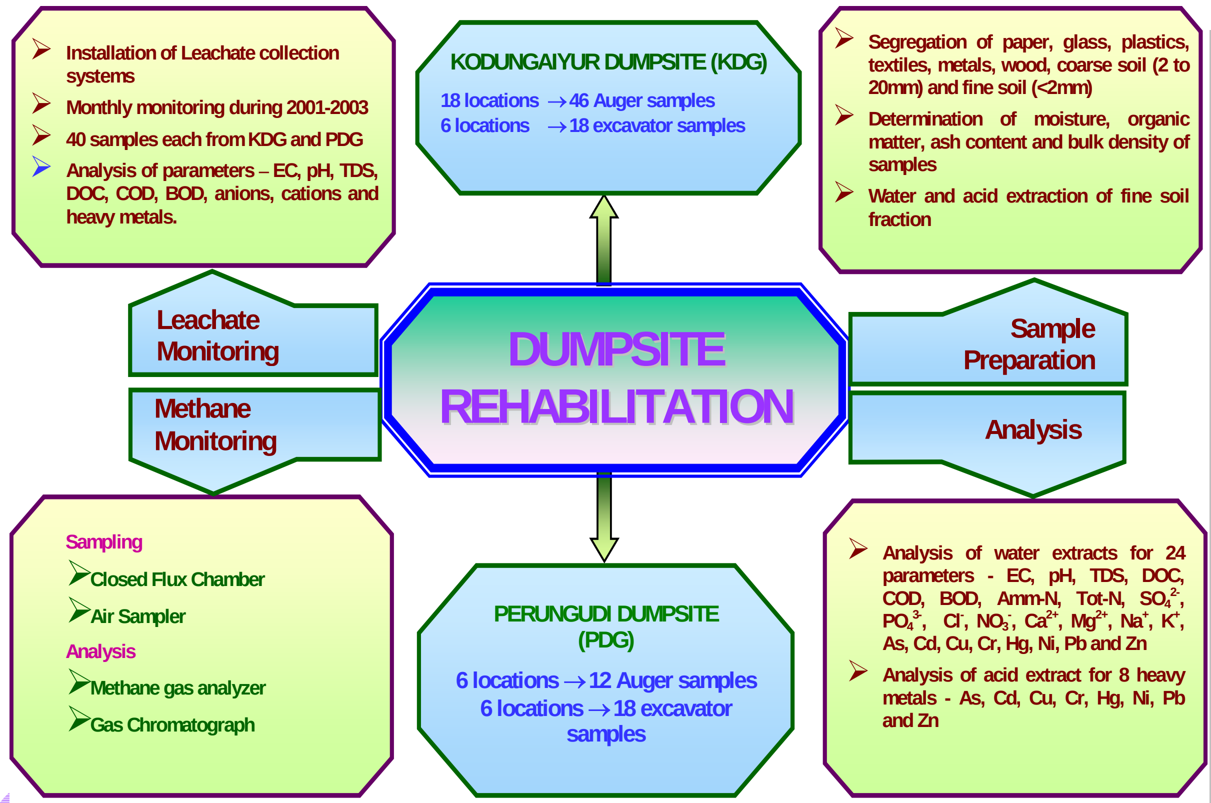


Figure 6.1
Elements of dumpsite rehabilitation

The major conclusions drawn from the study are summarized in Box 6.1.

Box 6.1 Results of landfill rehabilitation research in India

- Excavation and Auger boring techniques (Figure 6.2) can be used for collection of samples of degraded waste. The techniques gave good results where the waste is homogeneous (Tables 6.1 to 6.3).
- Arsenic, Hg and Cd are found to be less than 3 mg/kg. For other metals, the descending order of metal content is Zn, Cr, Cu, Pb and Ni. (Table 6.4). Comparison of heavy metal contents with Indian Standards for compost shows that Cr, Cu, Hg, Ni and Pb are exceeding the limits. When compared with USEPA standards, all are within the standard limits for the compost. Hence, this fine fraction can be applied as compost to non-edible crops or as cover material after determining the geotechnical suitability.
- Water extractable pollutants are within the disposable limits in the fine fraction of the solid waste collected from both PDG and KDG. Low BOD, COD and DOC indicate the poor leachability of organic pollutants in water (Table 6.5).
- For landfill leachates collected from PDG and KDG, pH varied from 7 - 8.5; in some cases the TDS was as high as 15000 mg/L; for most cases the BOD values were less than 100 mg/L while the COD varied from 100 – 8000 mg/L (Figures 6.3 and 6.4). Monsoon modifies the leachate quality. The heavy metal contents in leachates are in microgram levels.
- The CH_4 level in landfill gas is less than 1%, methane emission potential of dumpsites is insignificant.

Source : Esakku et al., 2003;
Kurian Joseph et al., 2003

Figure 6.2
Sampling by Excavation (A) and Auger (B)

Table 6.1. Physical composition of Auger and excavator samples from PDG and KDG dumping grounds

Site	Sampling method	No. of samples	Combustibles % ± SD	Non-combustibles % ± SD	Soil fraction % ± SD
PDG	Auger	12	39.4 ± 13.3	19.5 ± 6.2	41.0 ± 10.4
	Excavation	18	22.0 ± 14.1	44.7 ±13.3	33.29 ±6.8
KDG	Auger	46	3.5 ± 2.9	28.7 ± 11.9	67.7 ± 13.1
	Excavation	18	4.3 ± 1.9	39.3 ± 3.6	56.5 ± 4.3

Soil fraction varied from 33 to 68% which is in the range of 11 to 77% reported in literature (Table 4.1).

Table 6.2. Physico-chemical characteristics of the soil fractions of MSW from PDG

Particulars	Auger *			Excavation **		
	Min	Max	Ave ± SD	Min	Max	Ave ± SD
Temperature (°C)	32	39	35 ± 5	34	36	35 ± 1.4
Moisture content (%)	21.4	52	39.5 ± 9.5	19	40	30 ± 6.1
pH	7.6	8.6	8.06 ± 0.29	7.2	8.2	7.8 ± 0.28
VOM (g/kg)	89	158	117 ± 21	63	144	111 ± 21
Ash content (g/kg)	842	911	883 ± 21	856	937	889 ± 21
TOC (g/kg)	52.3	78.8	55.6 ± 9.4	30.2	69.1	53.2 ± 10.2
Dry density (kg/m^3)	745	1147	965 ± 132	809	1185	995 ± 85

* Average of 12 sample values ** Average of 18 sample values

Table 6.3. Physico-chemical characteristics of the soil fractions of MSW from KDG

Particulars	Auger *			Excavation **		
	Min	Max	Ave ± SD	Min	Max	Ave ± SD
Temperature (C°)	30	34	32 ± 2.8	32	34	33 ± 1.4
Moisture content (%)	15.5	46	24.4 ± 6.1	15	33	23.1 ± 5.9
pH	6.9	8.1	7.6 ± 0.39	7.9	8.7	8.2 ± 0.2
VOM (g/kg)	89	207	138 ± 32.6	124	230	170 ± 29.1
Ash content (g/kg)	793	911	862 ± 32.6	770	876	830 ± 29.1
Dry density (kg/m^3)	853	1254	1106 ± 108	888	1136	987 ± 70

* Average of 46 sample values ** Average of 18 sample values

Table 6.4. Heavy metal content in fine fraction of dumpsite soil

Particulars	Hg	As	Cd	Ni	Pb	Cu	Cr	Zn
Minimum	0.039	0.077	0.820	21.0	53.0	75.0	110.0	167.0
Maximum	0.78	1.561	1.77	50.0	112.0	217.0	261.0	503.0
Median	0.21	0.451	1.28	33	85	105	129.5	230.5
Mean ± SD	0.29 ±0.22	0.57 ±0.38	1.29 ±0.31	32 ±8	86 ±16	113 ±42	140 ±40	284 ±111
Indian CS*	0.15	10.0	5.0	50	100	300	50	1000
USEPA CS**	17.0	41.0	39.0	420	300	1500	1200	2800

All the values are in mg/kg. No. of samples: 12 CS - Compost Standards

* MSW (Management and Handling) Rules, 2000, India ** US Composting Council, 1997

Table 6.5. Comparison of water extracts of dumpsite soil and leachates of KDG

Sample	No. of samples*	pH	EC (mS/cm)	TDS (mg/L)	COD (mg/L)	BOD (mg/L)	Cl- (mg/L)	Cr (µg/L)
Water extract	46	7 - 8 **7.5**	0.9 – 2.3 **1.04**	230 – 1904 **822**	32 – 264 **115**	1-16 **4**	40 – 1116 **147**	1.6 – 23 **10**
Leachate	21	7 – 8.5 **7.7**	1.8 – 24.2 **7.8**	1755 – 13312 **5222**	131 – 1925 **788**	6 – 207 **43**	350 – 5856 **1590**	1.1 – 136 **64**

* Values are average of number of samples presented; Mean values are in b**old face**

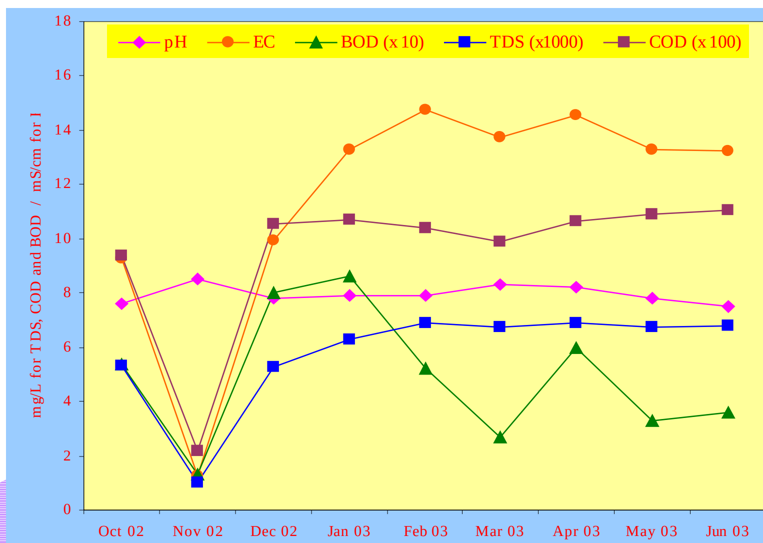


Figure 6.3
pH, EC, BOD, TDS and COD of leachate collected from PDG

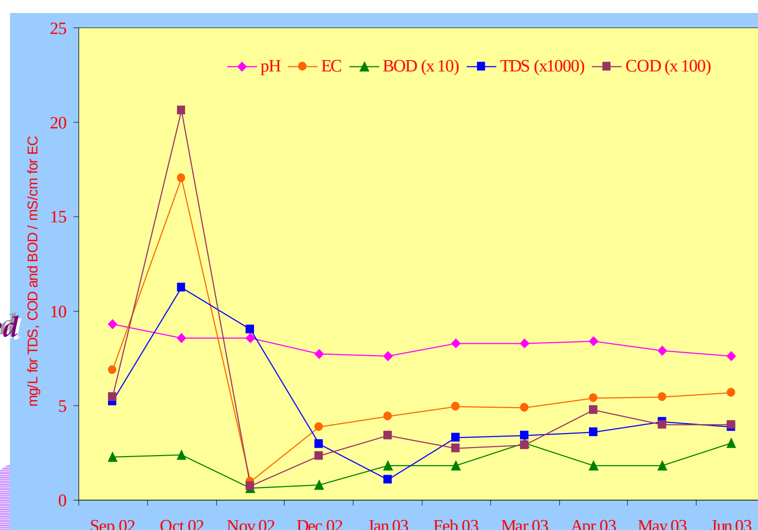


Figure 6.4
pH, EC, BOD, TDS amd COD of leachate collected from KDG

6.1.1 Constraints and Challenges in Dumpsite Characterization

Several constraints (Table 6.6) were encountered during the dumpsite reclamation study (Esakku *et.al.*, 2005). Many of the field sampling stations was disturbed by local intruders and rag pickers, calling for special security protection. Open burning of MSW in dumpsites is an example of uncontrolled activity that interferes with sampling and causes harmful effects on the health of workers at dumpsite.

Table 6.6. Approach to minimize constraints and difficulties during dumpsite characterization

Sl. No.	Activity	Problems encountered	Suggestions to overcome the problems
1.	MSW sampling	- Limitations of auger sampling in sections of sites where the waste is not homogenous and where underlining blocking materials are encountered	- Cost effective sampling techniques need to be developed to get real picture of the waste composition
2.	Leachate sampling	- Scavenger disturbances to leachate collection systems	- Control of scavengers activities at dumpsite. - Rehabilitation of scavengers - Additional security at site. - Involvement of nearby residents for protection of leachate monitoring systems
3.	Leachate analysis	- Color interference in volumetric and spectroscopic determinations - Sub-micron filtration for instrumental analyses - Restriction to IC analyses and the difficulties in TKN determination	- Alternate methods - Adoption of available corrective measures on case to case basis - Grouping of parameters and selection among them for analyses on correlation basis
4.	Methane measurement	- Inability to determine low levels of CH_4 in LFG using portable monitors	- Proper air sampling and GC method have to be used.
5.	Remediation studies	- Scavengers disturbance to experimental setup	- Restriction of un authorized entry in to the dumpsites
6.	Open burning	- Health risks due to the emissions on open burning of MSW	- Control of open burning and organizing awareness programs on the environmental risks
7.	Cost aspects	- Lack of fund for MSWM	- Government and other concerned agencies have to provide sufficient funds

Auger sampling operations were to be terminated many times before the desirable depth of sampling owing to the presence of blocking materials such as bolders, plastics and rags, limiting the use of auger samplers to dumpsites with homogeneous materials. Mechanical excavators are recommended in other cases.

The problems encountered during leachate analysis were: odor, color and high solid content in the leachate. Many of the samples needed pretreatments such as odor and color removal by charcoal treatment and sub-micron filtration before further characterization. While sub-micron filtration consumed more time, the presence of intensive colors in certain samples interfered with volumetric (chloride, calcium, and magnesium etc.) and spectrophotometric determinations (nitrate, nitrite, and phosphate etc.). High organic constituents in leachates restricted the use of ion-chromatography to determine multiple ions in a single run. Estimation of Kjeldhal nitrogen was also rendered difficult by interfering constituents of the leachate. Considerable research opportunities exist to develop newer pretreatment methods in areas such as filtration, odor control and color removal.

6.2 Rehabilitation and Material Recovery Assessment in Thailand

The condition of Maung Pathum dumpsite in Pathumthani province, Thailand was investigated for potential rehabilitation and material recovery (Romchat, 2005). This dumpsite was operated for approximately 20 years. However, it is used recently as a temporal dumping station by stacking new waste at the top of the pile. The height of dumpsite pile is 2.2 m above ground level and the volume of pile including a part below the ground level is 15,000 m^3. The depth of dumped waste from ground level is 1.5-2 m.

Various solid wastes and leachate samples were collected and analyzed. This study showed that the waste is stabilized, mainly consists of soil fractions (69-75%) with small amount of organic materials (0.3-2.7%). The composition of two samples is presented in Figure 6.5. The result of toxicity characteristics leaching procedure (TCLP) revealed that the solid waste was not hazardous. Thus, the soil fraction has potential to be reused as landfill cover material. Moreover, soil fractions of particle size <10 mm and <2 mm are potential to be used as compost material after supplementing P and K content.

However, the leachate quality does not comply with the criteria of a typical stabilized landfill and the heavy metals concentration is higher than the Thai Effluent Standard. This is due to the young leachate infiltration from the newly dumped waste at the top of the pile. The calorific values of combustible waste (Table 6.7) except for organic materials can be reused as refuse derived fuel.

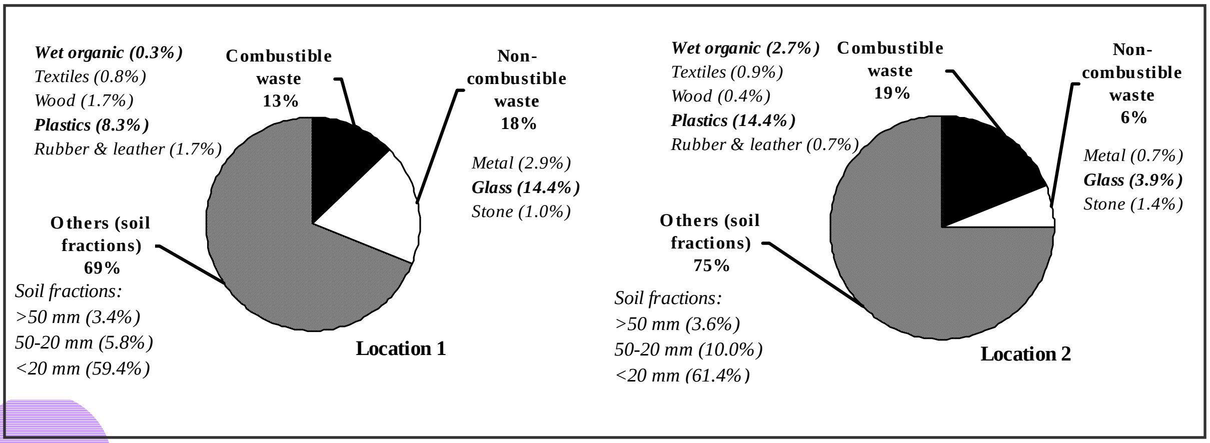


Figure 6.5
Composition of two samples from Maung Pathum dumpsite

Table 6.7. Calorific value of mined waste

Sample	Calorific value (MJ/kg)
Plastic	29.7
Wood	18.2
Textile	20.7
Rubber and leather	22.2
Wet organic	13.5
Combustible wastes	25.0
Segregated wastes	32.3

6.3 Dumpsite Rehabilitation in Pune, India

The city of Pune generates approximately 1000 tons MSW per day. Like most of the other municipalities in India, the Pune Municipal Corporation (PMC) has been resorting to dumping of the MSW in open land and abandoned quarries. One such site is in the village of Uruli Dewachi, about 5-6 km beyond PMC limits off Saswad road. The site was originally a stone quarry and had deep excavated areas. The daily waste coming to the site is about 750 tons/day (TPD). Dumping at this site was in progress to full capacity since 2002. When serious ground water contamination was observed in wells on the down stream slopes up to 2 km away from site, the PMC adopted a strategy of rehabilitating the dumpsite by capping and construction of a sanitary landfill over the capped site (Purandare, 2003)

The task of rehabilitating the dumpsite was undertaken by M/s. Eco Designs India Pvt. Ltd., Pune in February 2002. After all the preliminary data were collected, the landfill was designed as per the MSW 2000 rules. The design included the following tasks:

- Closure/capping of the existing dumpsite;
- Design of a landfill above the capped waste, with a volume to handle waste for a period of one year; and
- Design of a landfill adjacent to the capped waste, with a volume to handle waste for a period of 5 years.

The waste had been randomly deposited without any spreading or compaction. A preliminary inspection found that the waste heap was very unstable primarily because of the face angle of the waste, which was in excess of the stable angle of repose. It was therefore necessary to change the slopes as well as compact the waste, so that it would be permanently stable. The waste was evenly spread out and compaction was carried out on the slopes and the top by using heavy duty bulldozers. The closure covered an area of about 34,600 m^2. The height of waste was as much as 18 m at the edge after proper leveling.

Once the waste was graded and compacted, a 0.75 mm thick Very Flexible Polyethylene (VFPE) liner was installed above it to avoid ingress of rain water. This was protected with a geotextile overlaid by 300 mm thick soil layer. The soil layer was finally covered with sweet earth for planting of grass, which would prevent erosion of the cover soil. Drains were provided on the slopes so that the storm water could be drained and collected at the bottom, where a gutter along with a toe wall was provided. Gas vents were provided to allow for the release of gases that could be potentially formed within the covered landfill.

The capped landfill had a top plain surface area of about 18,500 m^2. The cost of dumpsite closure was Rs.10, 080,000 (about US $ 0.2 million). PMC had no other acquired land on which to develop a new landfill facility. It had started composting the organic waste and was still generating large amounts of waste to be landfilled. Hence it was decided that until a larger landfill was constructed in the adjoining property, a smaller landfill would be constructed over the capped waste. This served the purpose of not only buying some time until the new facility was built, but also in developing some confidence about being able to build and operate a sanitary landfill. The construction of the landfill has now been completed and is in operation. Figure 6.6 shows different photographs taken before, during and after this dumpsite rehabilitation process.

Figure 6.6
Photographs of dumpsite rehabilitation in Pune, India

6.4 Dumpsite Upgradation in Kanpur, India

Kanpur, an important industrial city of Uttar Pradesh, India located at the bank of the river Ganga, is spread over an area of 299 km^2 with an estimated population of 3 million. An estimated quantity of 1000 t/day of MSW is generated from the city out of which about 700 t/day reaches the dumpsites. Panki site, presently the only active site in Kanpur, is spread over an area of 8 hectares and has been existing for the past 10-15 years. The average depth of the waste is around 4-5 m above ground level. The New Delhi National Productivity Council was engaged by the local authorities for assistance in upgradation of this dumpsite site in line with the requirements of MSW Rules (2000). Based on a detailed environmental impact assessment of the site the upgradation plan suggested by NPC (Saxena and Bharadwaj, 2003) is presented in Table 6.8.

Table 6.8. Upgradation plan for Panki Dumpsite, Kanpur

Proposed Activities
Shifting of waste Waste lying on the northern side of the road has to be shifted to the southern side.
Closure of waste body created in one half area of site The waste body has to be closed scientifically which includes the following activities: • Bund formation , Grading of waste • Compaction and slopping of waste • Drainage channel construction • Capping consisting of clay liner, HDPE liner, drainage layer, gas vent system, top soil etc. • Growing of vegetation cover over the top soil • Laying of green belt at the periphery of site
Development of excavated area as Scientific Landfill The excavated area has to be developed into a scientifically designed landfill facility where the municipal waste can be disposed and managed in proper way. This may include the following activities: 1. Leveling of base and side slopes of the landfill and achieving the desirable grades at the base of landfill. 2. Construction of temporary embankments and surface water drains along the perimeter of the landfill. 3. Laying of single composite bottom and side liner consisting of the following: • A compacted clay/amended soil barrier of 1 m thickness ($K<10^{-7}$ cm/sec); • HDPE/geomembrane layer $\geq$ 1.5 mm thick along with the 20 cm compacted clay (protection layer) over it; • Leachate drainage layer 30 cm thick made of granular soil ($K>10^{-2}$ cm/sec); and • A leachate collection system comprising of a perforated pipe collector system (with 2% slope) inside the drainage layer, sump collection area and a removal system. Installation of leachate treatment facility. Providing infrastructure facilities at the site such as: • Power supply, Dozers • Compactors, Backhoes and front end loaders • Tractor trailors, Weighing scale • Office, Environmental Monitoring facilities • Security, Fencing etc. Installation of two monitoring wells at the up gradient and three at down gradient

6.5 Biomining of Dumpsites in Indian cities

Patel (2007) has reported bio – mining of several dumpsites (Table 6.9) in Indian cities applying the bioremediation principle described in section 4.7.3.1.

Table 6.9. Dumpsite Bio-Remediation Projects in Indian cities

Year	Location	Area cleared, hectares	Waste height, meters	Time taken, months	Total cost, Rs. millions	Cost / cubic meter	Remarks
2002-03	Nasik	11.6	5	3	6.4	Rs 110	Stadium construction
2003-04	Madurai	12.0	2	1	0.75	Rs 3	Vegetable growing
2003-04	Mumbai, Gorai	1.0	10	3	1.0	Rs 10	Creation of extra landfill space
2003-04	Hyderabad, Autonagar	3.0	20	24	NA	NA	Garbage overflow on forest land removed
2007	Hyderabad	19.0	20	< 60	NA	NA	Agreement signed
2006	Pune demo,	1.0	10	NA	NA	NA	Dumpsite Rehabilitation

Source: Almitra Patel, 2007

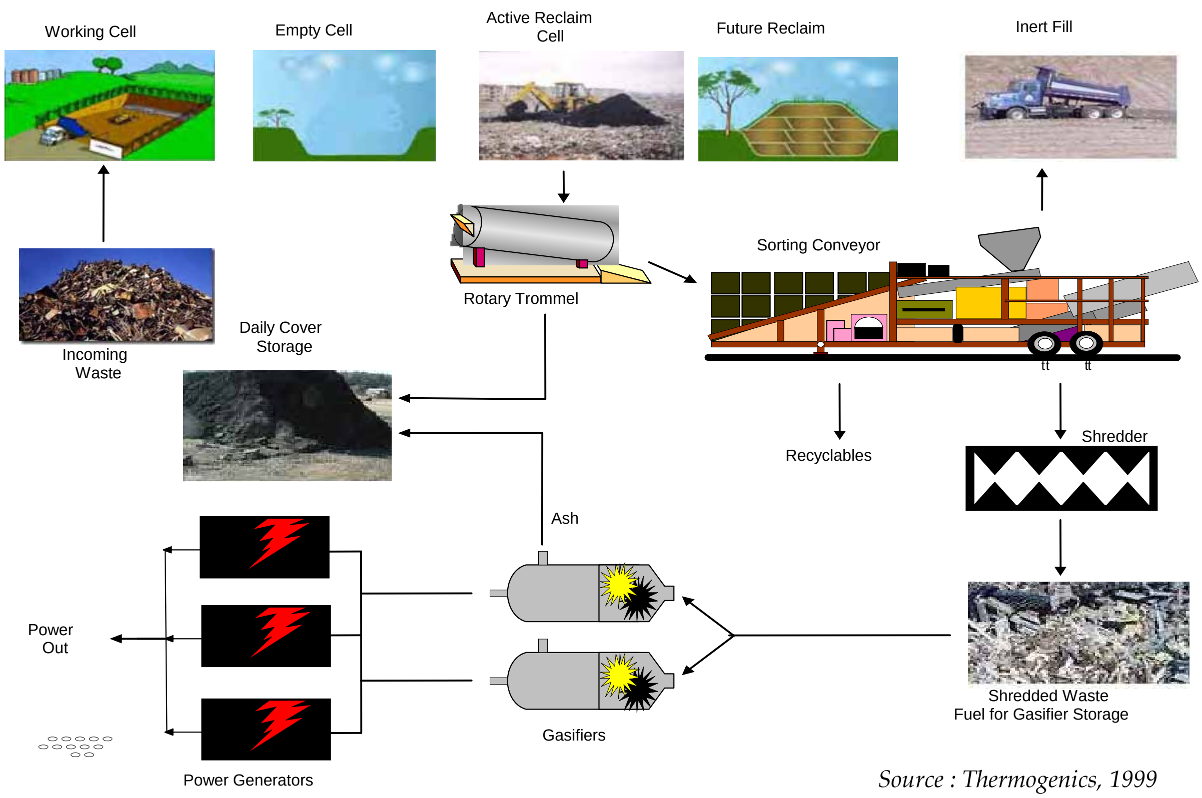
The first bio-mining experiment was done in 2002-03 at Panchvati in Nasik city, where a 28 acre site with an average 4-7 m depth of garbage was engulfed by the expanding city and the dumping of 260 tons per day over a twelve-year period needed to stop. The site was cleared of all old waste in just 120 days by a Bombay firm at a cost of Rs 6.4 million. Composting bioculture at the rate of 250 g/m^3 of old waste was used to enhance the windrow composting process. In 2003-04, the Bombay Municipal Corporation paid Rs 1 million for a pilot project to clear down to ground level, one hectare of land under about 10 meters of old waste at the Gorai dumpsite. Convinced by the proven benefits of bio-mining old waste dumps, the Government of India through its JNN Urban Renewal Mission is now considering funding for similar dumpsite bio-remediation projects (Patel, 2007).

6.6 Thermogenics Landfill Reclamation System

In the Thermogenics Landfill Reclamation System (Thermogenics, 1999), depicted in Figure 6.7, the landfilled material is recovered by front-end loaders in an operating sustainable landfill. The mined material includes all materials in a given cell plus the daily cover that is placed during the active life of the cell. By using a rotary trommel screen it is possible to separate the daily cover materials, plus broken glass, etc. from the balance of the waste. This recovered material is stored on-site and reused as daily cover for the active cell then receiving incoming waste. The remaining materials coming from the trommel screen are then sorted to remove metals, glass, and other inert material, which is either sent to recycling or returned to the active cell of the landfill. The final product from the sorting conveyor is organic material, which is then shredded and stored for use in the Gasifiers located on-site. This organic material is properly classified as Refuse-Derived-Fuel (RDF) and when used in the Thermogenics Gasifiers produce about 870 kWh per ton of fuel (Thermogenics, 1999). It is also feasible to construct a liquid fuels production module in addition to producing sufficient electrical power to operate the entire facility. The gas produced is fed directly to multiple engine-generator sets to produce excess power that can be placed back on the utility grid or sent to a local user. Waste products from the gasifier, such as ash can be used in the daily cover material and excess wastewater, if any, can be treated for discharge. All of the equipment used for this type of project can be moved to a new site once the entire landfill has been reclaimed and the empty cells upgraded for future use.

6.7 Recovery of plastic waste from dumpsite as Refuse Derived Fuel (RDF) (AIT/Thailand to Add and improve)

In order to evaluate the potential of utilizing dumped wastes, the excavated wastes were characterized for their physical composition and chemical characteristics according to their disposal age. Mined solid wastes (2 to 10 years old) contained plastic and soil like fine materials as their major components. The plastic content in waste bulk was between 25 and 45%. After the purification of wastes, plastic contents in purified wastes increased to 83-90%. They were formed into briquette in which maximum plastic content of 55% could be contained. The quality of RDF produced was found acceptable for industrial combustion processes.



Source : Thermogenics, 1999

Figure 6.7

Thermogenics landfill reclamation process

6.8 Dumpsite Rehabilitation in Ampang Jajar, Malaysia

In the early eighties, the open dumpsite at Ampang Jajar in Malaysia witnessed constant fire, smoke and malodor from the disposed waste; neither had any leachate collection system nor defined space available for dumping. The site covers a total area of about 1.5 ha and has been incessantly dumped with about 50 tons of solid waste (both municipal and industrial waste) per day. This indiscriminate dumping of solid waste has been a potential source of pollution, especially affecting the groundwater and air quality. Figure 6.8 shows the condition of the Ampang Jajar dumpsite in 1988. In 1996, a particular type of semi-aerobic landfilling method, known as the "Fukuoka Method" was initiated and has been successful in rehabilitating the dumpsite. In this method, leachate is collected in leachate collection ponds through properly sized perforated pipes embedded in graded boulders (Figure 6.9).

Figure 6.8 Dumpsite in Ampang Jajar

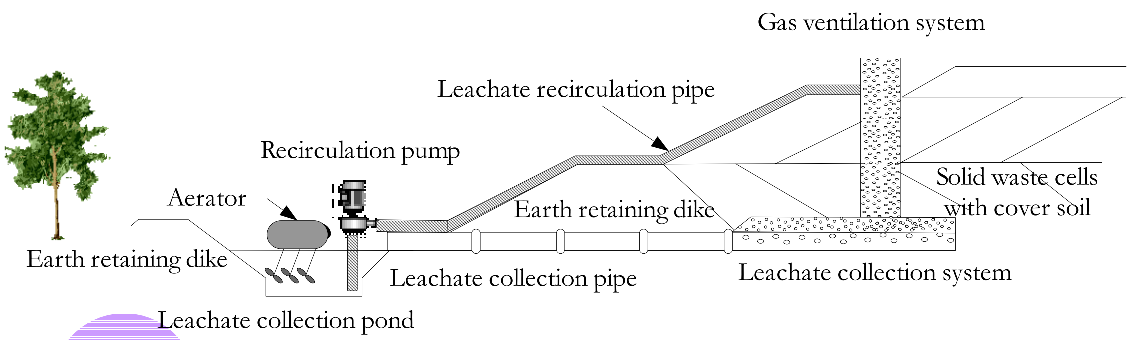


Figure 6.9 Recirculatory semi aerobic landfill (Fukuoka method)

Although the landfill was based on the semi-aerobic concept, leachate stabilization was principally through anaerobic biological degradation of methanogenic phase in the pebble layer surrounding the leachate collection pipes and gas vents. After one year placement of the solid waste inside the landfill, leachate sampling indicated that the landfill was generating low strength leachate containing BOD and COD of around 400 mg/L and 2,000 mg/L, respectively. Gas samples indicated 60% of methane content. The pebble layer acted as an anaerobic bio-filter at the bottom of the landfill. Pollution control at the landfill was provided by the design of the landfill on clay soil, and the leachate collection and gas venting facilities. Leachate stabilization was achieved through the semi-aerobic biological process over a few years after landfill operation. From the low strength of leachate generated it can be concluded that *in-situ* treatment of leachate can be achieved even for young landfills. The treatment is mainly by anaerobic process of methanogenic stage in the pebble layer which acts as a fixed-bed bio-filter (http://fsas.upm.edu.my/~sas/ envpage/Research.html).

The Ampang Jajar dumpsite is now a model landfill using semi-aerobic process with leachate treatment through aeration and recirculation. It is operated based on the area method of filling with a main leachate collection pipe connected to leachate feeding lines of bundled bamboo pipes arranged perpendicular to the main pipe at 50 m intervals. Both the main pipe and the bamboo pipes are covered with a layer of pebbles for leachate screening and securing the pipes. Figure 6.10 reflects the rehabilitated dumpsite area in the year 2000 with improved management system.

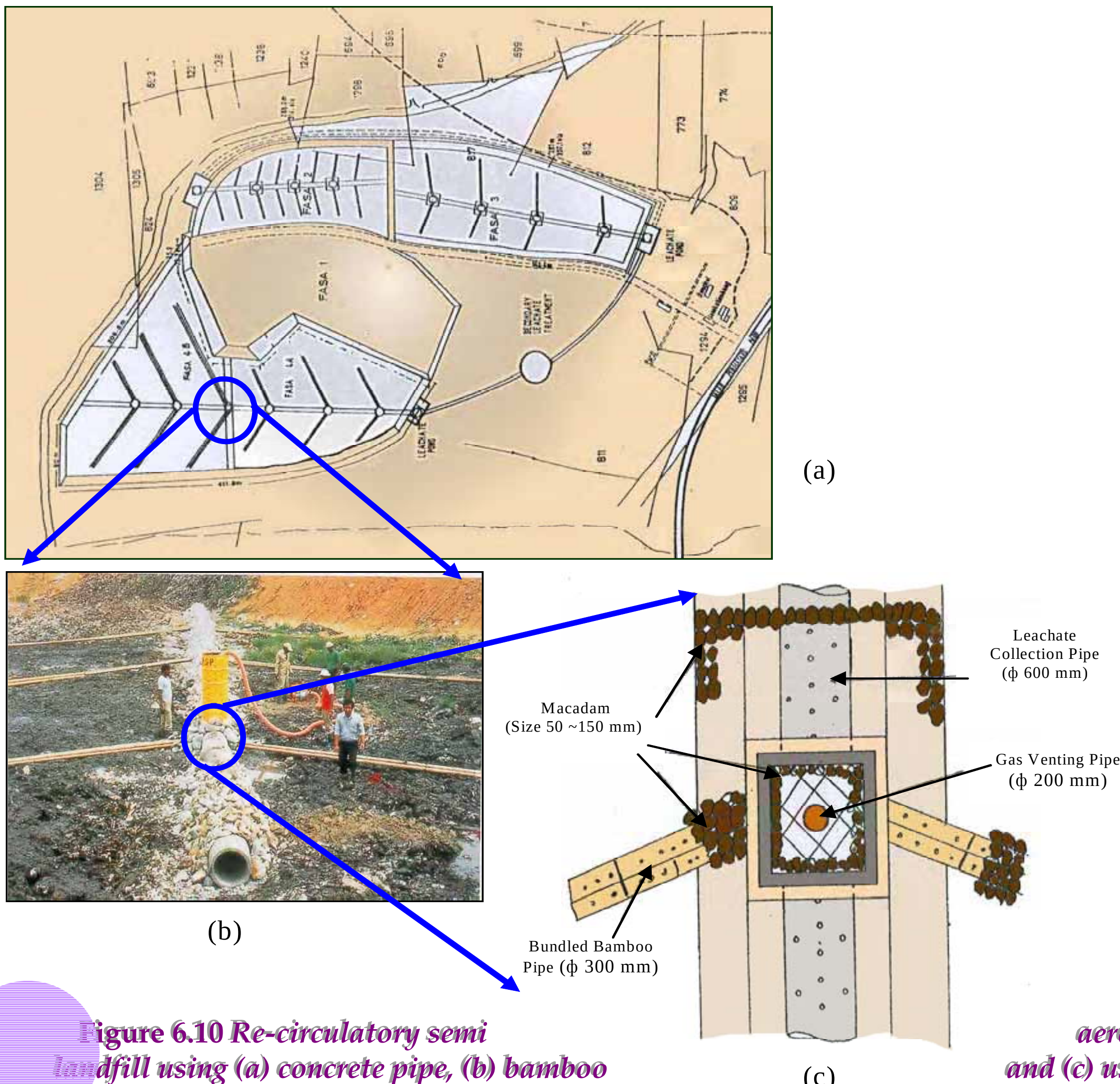


Figure 6.10 Re-circulatory semi aerobic landfill using (a) concrete pipe, (b) bamboo and (c) used steel drums

CHAPTER 7

CONCLUSION

The open dump approach, a primitive version of municipal solid waste disposal remains the predominant option in most of the Asian countries. Problems of shortage of cover, lack of leachate collection and treatment, inadequate compaction of wastes, poor site design and ragpickers working and setting the refuse on fire to recover valuable inorganic items are common at such dumps. It is essential that an appropriate *status quo* analysis is carried out and an achievable, acceptable and affordable strategy and action plan developed for implementation in a phased manner. The reality of financial resources earmarked for solid waste management in many developing countries would mean that solid waste managers must attempt to ameliorate open dumping practices and gradually upgrade the sites. The waste managers should aim at modest improvements to their landfill operations and gradually move from open dumps to sustainable landfills in a phased manner. In this context, this document provides guidance on characterizing, investigating and rehabilitating open dumps to provide adequate protection to public health and safety.

In order to achieve the benefits, however, it is advisable to take immediate measures to move from open dumps to controlled dumps and finally to sustainable landfills in a phased manner. The rehabilitation of a dumpsite should be preceded by a cost–benefit analysis in case of re-use of the area for other purposes or for landfilling of new waste and also for the value of potentially recoverable materials. A rapid risk assessment must be carried out before decision-making. The danger that contamination may occur during excavations, storage, transportation, recycling of material and handling of hazardous waste, mostly during intense rainfalls, must also be considered.

The first step in upgrading open dumps to sanitary landfills involves reducing nuisances such as odors, dust, vermin, and birds. The principle of landfill mining may be used as the driver to convert this challenging task into an opportunity. The possible outcome would include recovery of space for future landfills, soil fraction for growing non edible crops as well as landfill cover material and the plastics for making refuse derived fuel. A natural remediation technique such as phytoremediation using higher vascular plants, though slow, is also worth considering.

Case descriptions reviewed in this report indicate that many projects have met successful in terms of costs and benefits. What is striking about all of these cases is the fact that almost all of them belong to stand-alone category. In many cases, the initiative comes from a regional authority and addresses a specific landfill. Another point of interest concerns the decision process – whether to mine or not. In some cases this was no issue because of the real danger of pollution or government regulations. Given its developmental status, only tentative conclusions can be drawn regarding dumpsite rehabilitation options and potential, especially in Asia. More demonstration projects are required for further evaluation and conclusion.

When used appropriately, the options described in this document will help to ensure that a good strategy is developed and implemented effectively. Once the site has been assessed and stakeholders agree that cleanup is needed, planners will need to consider the cleanup options. The guidance provided in this document on selecting appropriate methods directs planners to base cleanup initiatives on site-and project-specific conditions. The type and extent of cleanup will depend in large part on the type and level of contamination present, reuse goals, and the available budget. In certain circumstances, containment of contamination onsite and the use of institutional controls may be important. Finally, planners will need to include budgetary provisions and plans for post-cleanup and post-construction care. By developing a technically sound site assessment and cleanup approach based on site-specific conditions and the concerns of all stakeholders, planners can achieve dumpsite development and reuse goals effectively and safely.

Options for dumpsite rehabilitation include everything from its closure, remediation, mining and using it again for waste disposal or planting trees on it. The observations discussed in the manual indicate that partial closure of dumpsites by scientific rehabilitation and effective use of the site for continued MSW treatment and disposal operations is the preferred way to improve the downstream components of solid waste management in India. Further, as partial closure of the sites involves shifting of waste lying at the site to an area of smaller footprint, the cost of closure will reduce, if the municipalities take measures to dispose the Construction & Demolition (C&D) and inert waste (road sweeping and de-silting operations of drains) separately. This appears to be the only feasible approach until "good practice examples" help overcome the resistance by the communities to site the waste processing and landfill facilities in their neighbourhood. At that point of time, it may be feasible to plan green field waste processing sites with full environmental controls and safeguards.

Landfill mining as a method of waste management is yet to be widely practiced. It is the excavation of buried MSW for its processing to recover material for beneficial use. The quantity and characteristics of materials recovered from a landfill are functions of the landfilled wastes. Communities which mine their landfills may burn, compost, or recycle the waste, although recycling of cans and bottles tends to be impractical because they are heavily soiled. They may choose to start over, lining unlined cells and reusing liners where possible, or, like in Hague, New York, they may prefer to close the landfill forever.

Excavation coupled with on-site disposal is likely to remain an economic method of treating large areas of contamination in the context of redevelopment. In a wider environmental context, this option has a number of advantages. It allows the problem to be dealt with at the site in question, thereby minimizing environmental impact elsewhere, and allows landfill capacity to be conserved for wastes for which there are no alternative disposal routes. It also provides for a high degree of technical control over the disposal operation.

The recovery of a landfilled resource depends upon the physical and chemical properties of the resource, the effectiveness of the type of mining technology and the efficiency with which the technology is applied. Judging from available information and mechanical processing efficiencies, recovery of soil could be expected to fluctuate between 20 and 80% of wet waste by weight. The major difficulty could be in marketing mined material due to its poor quality. Purity of the recovered materials could be expected to be 90 to 95% for soil, 80 to 95% for ferrous metals, and 70 to 90% for plastic. The higher percentage of purity for each material category would generally be attributed to relatively complex processing design.

Based on a few studies on heavy metal content in recovered soil fraction reviewed here, it may be said that it is suitable for landfill covering. The compost standards are met for most parameters in the soil fraction of most studies. However, it is possible that high concentrations of hazardous substances and heavy metals could be found in local pockets. Several safety equipment and precautionary measures may be needed during a landfill mining project. This may include safety goggles, hard hats, respirators, first-aid kits, leather work gloves, hearing protection, back support, steel toed work boots, combustible gas meter, oxygen analyzer, hydrogen sulfide chemical reagent diffusion tube indicator, and water spray system to suppress dust.

Costs associated with the dumpsite rehabilitation operations are highly variable because of local conditions and site-specific factors. These include wide variations in the definition, and hence disposal cost, of contaminated solid material which is not designated as special waste, impact on disposal and transport costs according to distances traveled and mode of transport (e.g. road, rail) as well as volatility of contracting rates according to both national and local commercial conditions. Site-specific factors such as the size, scope and duration of the proposed civil engineering works, variation in the cost of construction, replacement and intermediate cover material, liners and final covers also influences the cost.

Clean Development Mechanism (CDM) benefits available in waste management sector are another important aspect that needs attention by the municipal bodies. CDM application has potential to reduce the cost of closure significantly. In order to achieve these benefits, however, it will be advisable for the municipal bodies to take immediate measures to control the fires currently prevalent at the disposal site.

The traditional model of a landfill as a permanent waste deposit in which decomposition processes are minimized is expected to give way to the concept of a controlled decomposition process managed as a large-scale bioreactor. This controlled bioreactor landfill is seen as being a flexible, cost effective, and sustainable approach to current waste disposal problems, particularly when combined with material recovery either before or after the biological treatment step. Indeed, it may no longer be necessary to view landfilling as a disposal system at all but rather to see it as a method for large-scale processing of waste to be combined with recovery and recycling processes. The concept of landfill mining and reclamation and related technology merits serious consideration. It may be relevant to consider the incorporation of the concept into landfill design so that the landfill waste can be readily accessible for mining a multi-disciplinary approach to landfill management. Involving such professional groups as geochemists, geotechnical engineers, civil engineers, environmental engineers and microbiologists will lead to a rapid development of the concept of landfill mining as a sustainable technology. Besides dumpsites there are many polluted sites all over the world that needs remediation and this rehabilitation needs to be done quickly in order not to destroy more of the scarce groundwater and surface water resources available. It is likely that land rehabilitation will be more common in the future all over the world and in particular necessary in countries that also in future will use waste dumping as a waste handling method.

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Research Programme on Sustainable Solid Waste Landfill Management in Asia

The Asian Regional Research Programme on Environmental Technologies (ARRPET) is conducting research on environmental issues in the Asian context including wastewater, solid waste, air pollution and hazardous waste.

ARRPET is coordinated by the Asian Institute of Technology (AIT) and funded by Swedish International Development cooperation Agency (Sida). It involves 20 National Research Institutes (NRIs) from 8 Asian countries.

The Phase I of the Research programme on sustainable solid waste landfill management in Asia under ARRPET commenced on January 1, 2001 was completed on June 30, 2004 and the Phase II activities were completed on June 2008. The major issues addressed by the project include:

- Dumpsite rehabilitation
- Sustainable landfill management
- Anaerobic dry fermentation
- Aerobic composting
- Plastic recycling and Refuse Derived Fuel
- Greenhouse gas emission from solid waste dumpsite
- Implementation of bioreactor landfill concept
- Lysimeter studies on dumpsites, landfills and pre-treated landfills
- Constructed wetlands for leachate treatment
- Enhanced degradation of MSW for agricultural use

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