FIELD EXPERIENCE ON THE DAILY OPERATION OF A PILOT SCALE SANITARY LANDFILL IN BANGLADESH

by

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Declaration

This is to certify that the thesis work entitled as "Field Experience on the Daily Operation of a Pilot Scale Sanitary Landfill in Bangladesh" has been carried out by G. M. Abdur Rahman in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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June, 2012

DEDICATION

To

My beloved parents

who taught me morality, and

encouraged me for higher

education

ABSTRACT

The current disposal system of Bangladesh is not conducted in an environmentally sound manner and thus it leaves various environmental problems for the authorities to deal with. The authorities are eagerly looking for a solution to solve the piling up solid waste related problems such as negative environmental impacts, land scarcity and increasing solid waste. Even though various alternative methods have been identified but they are not economically and socially viable.

Sanitary landfill is still the most cost-effective and appropriate method for waste disposal. This thesis represents the findings of appropriation of sanitary landfill in Least Developed Countries (LDCs) like Bangladesh of its geo-environmental conditions the operational studies of Pilot Scale Sanitary Landfill (PSSL) at Rajbandh, Khulna, the ultimate disposal site (UDS) of Khulna City Corporation (KCC).

The construction process of PSSL that applied in this site is very simple but technically compatible design is considered to use local building materials and to avoid any imported or expensive materials such as any kind of geosynthetics. The available indigenous approach mostly manual labor where female participant was viewed a focus of 70% intensive was employed to complete the construction of landfill. During 14 months landfill operation 11790 tonnes of waste was deposited in the landfill cell and a huge amount of leachate about 7 million liters was generated due to heavy monsoon rain which hampered smoothly operation of landfill. It was planned that the period of landfilling was six months by 50 tonne/day but due to the climate condition only 28 tonne/day of waste was possible to fill in the PSSL. For more development of PSSL, it has required further study.

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Abbreviations

BOD	:	Biochemical Oxygen Demand
CBO	:	Community Based Organization
CEC	:	Cation Exchange Capacity
CDIA	:	City Development Initiatives for Asia
CDM	:	Clean Development Mechanism
COD	:	Chemical Oxygen Demand
DCC	:	Dhaka City Corporation
DGHS	:	Directorate General of Health Services
DoE	:	Department of Environment
DtD	:	Door to Door
GoB	:	Government of Bangladesh
JICA	:	Japan International Cooperative Agency
KCC	:	Khulna City Corporation
KCPA	:	Khulna City Project Area
KDA	:	Khulna Development Authority
KMP	:	Khulna Master Plan
KUET	:	Khulna University of Engineering and Technology

LCS	:	Leachate Collection System
LDACs	:	Least Developed Asian Countries
LDCs	:	Least Developed Countries
NEMAP	:	National Environmental Management Action Plan
MoEF	:	Ministry of Environment and Forest
MSW	:	Municipal Solid Waste
MSWM	:	Municipal Solid Waste Management
NGO	:	Non-Governmental Organization
PSSL	:	Pilot Scale Sanitary Landfill
RP	:	Roy Para
RPM	:	Respirable Particulate Matter
SDS	:	Secondary Disposal Site
UDS	:	Ultimate Disposal Site
UFC	:	Unified Facilities Criteria
US$	:	U.S. Dollar

CHAPTER ONE

INTRODUCTION

1.1 General

Solid waste is a useless, unwanted and discarded materials causing from production and consumption. It is produced at all levels of human activity. Its sources include residential areas, business and industrial facilities, construction and demolition, treatment plants and agricultural activities. An integrated management approach for municipal solid waste has to address the overall flow of material through the various waste management activities, such as collection, transport, separation, reuse, recycling, composting, treatment and final disposal. Disposal of solid waste is one of the most important functional elements of Integrated Solid Waste Management.

As the amount of waste produced in the country increases, new methods of disposal are needed to replace the old ones. Now a day, waste is often placed in open dumps, where waste is left open to the atmosphere and free to blow around. This results in bad smells and frequent fires that would burn uncontrollably, releasing pollutants into the atmosphere. In addition, verminous creatures such as roaches, flies, mosquitoes, rats, etc. would live in the dump increasing the chance for the spread of disease. A large quantity of organic waste is also fed to hogs. This led to the spread of trichinosis and more stringent regulations on the treatment of waste before it could be fed to the hogs. Other waste was dumped in the low laying areas like pond. These dumps are illegal, and hog-feeding is impractical. As a result, the most common disposal method for municipal solid waste is the sanitary landfill. Incinerators are also used in some localities, but are now being phased out due to air pollution problems and public pressure.

In adequate and inefficient solid waste management systems have become important environmental issues for the residents of the urban areas of most of these developing countries. The adverse environmental impact of solid waste is a major public concern in the cities. Uncontrolled and unplanned landfill of solid waste, a general practice in the cities of the developing countries, is a pervasive problem that causes significant external costs, such as health hazards etc.

As one of the densely populated countries and the increase of population in the urban areas, the city authorities have been facing severe problems to get new sites for ultimate disposal of municipal solid waste (MSW). There is no sanitary landfill in Bangladesh except conversion of open dumping to landfill in Matuail, Dhaka (Ahmed et al., 2008). Due to non-engineered nature, the existing sites are also going to early closure. Peoples are also protested to close some existing sites because of their inherent hazards nature. The city authority might think about the upgrading of existing sites to improve the present situation and future disposal sites in accordance with local conditions and technological capabilities (Alamgir et al. 2005).

Environmental pollution at open dumping site includes air pollution, water and soil contamination due to propagation of generated leachate, emission of landfill gasses, odor, dust and potential fire hazards etc (Diaz et al. 1996). In ultimate disposal site (UDS), leachate percolates and contaminates surface and ground water. In some sites, the sources of ground water are very close to UDS. Peoples are uses this water in various purposes such as bathing, washing and farming. Surface water is also contaminated because solid wastes are being dumped near/at the marshy land, ponds, rivers and canals. Contaminated water is harmful for fish and aquatic lives by reducing the amount of oxygen in the water. Chemical and oil spills, which are mixed with MSW, also cause water contamination.

In developing countries like Bangladesh more than 90 % of solid waste is disposed of in open dumps. Considering this region's specific climatic conditions, it is necessary to develop strategies to design and operate simple landfills, which are in-transition between dumpsite and engineered sanitary landfill. This approach demands comprehensive research on an environment safe waste deposition. To this endeavor, field research has been conducted through the construction of a Pilot Scale Sanitary Landfill (PSSL) at Khulna.

1.2 Background of This Study

Khulna, the 3rd largest city of Bangladesh is located at the south-west side of the country beside the river Rupsha, near the world largest mangrove forest "Sundarban". With a population of about 1.5 million the city is estimated to generate about 550 tons of municipal solid waste (MSW) every day of which 320 ton of MSW has been estimated to open dump in nature.

To address one of these most striking environmental and social issues in the urban areas of LDACs i.e. MSW management, a 12 months feasibility study project entitled *as "Integrated management and safe disposal of municipal solid waste in LDACs - WasteSafe*", was conducted by the Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh during the period of 2004 to 2005, co-financed by Asia Pro Eco Programme of the European Commission. The project proposed a system named as *'WasteSafe Approach'* with some specific guidelines to address the MSW issues in an integrated and sustainable way. An appropriate method of MSW management can be established for any specific location/region of LDACs considering local conditions with the analysis and evaluation of practical application of this approach. To develop a safe and sustainable management of MSW in Bangladesh through the practical application of *WasteSafe Approach* with required reality check and evaluation of the implemented parts, a three years (2007 to 2009) partnership project entitled as "*Safe and Sustainable Management of MSW in Bangladesh through the Practical Application of WasteSafe Proposal – WasteSafe II*" had conducted since January 01, 2007 co-financed through a grant received from EU-Asia Pro Eco II Programme of the European Commission. One of the key activities of this research project is to establish the landfill construction technologies suitable for Bangladesh conditions as realized from field level experience through a pilot scale sanitary landfill (WasteSafe II 2007). To this endeavour, the landfill cell of the dimension of 50x50x6m, which is 3m below and 3m above the existing ground surface, has been constructed with the necessary components, at Rajbandh, Khulna, at the ultimate disposal site of MSW of Khulna City Corporation (KCC) (Alamgir et al. 2009).

1.3 Purpose of This Study

This research establishes an appropriate method of MSW management for any specific location/region of LDACs considering local conditions of practical application of Pilot Scale Sanitary Landfill operation in the LDACs like Bangladesh.

1.4 Objectives of This Study

- To study the daily field operation of a Pilot Scale Sanitary Landfill.
- To build up specification and construction of proper sanitary landfill practice in the existing conditions of Bangladesh.

1.5 Methodology of This Study

It is a logical explanation of steps that can be followed to replicate the same kind of research in the future at elsewhere. It explains daily operation of pilot scale sanitary landfill towards and willingness to build a operation guideline of sanitary landfill for waste management programme. The major steps are to

(i) define the aim of the study;
(ii) define ways how to achieve the objectives;
(iii) describe the data required to achieve the aim of the study;
(iv) describe operation action plan of pilot scale sanitary landfill;
(v) performance analysis to results that approach for appropriate operation for sanitary landfill in Bangladesh; and
(vi) conclusions and assess the successfulness of the research.

Aim:
To build up specification and construction of proper sanitary landfill practice in the existing conditions of LDACs like Bangladesh.

Objectives:
Facilitate environmental improvement through safe initiatives and technology propagation with a focus on significant appraisal of existing system of MSW management in KCC.

(Chapter 1)

Literature review:
Details about SWM system in Bangladesh and Khulna, characteristics of MSW, sanitary landfill, evaluation of sanitary landfill, different component of landfill and purpose of landfill disposal are described in this chapter. Brief reviews of relevant literatures are also discussed here.

(Chapter 2)

Pilot Scale Sanitary Landfill operation studies at Khulna:
Feasibility study, site characteristics, topography, sub soil investigation, mineralogy and Meteorological Conditions are analyzed in this chapter for Pilot Scale Sanitary Landfill operation studies at Khulna.

(Chapter 3)

PSSL operation:
Details of PSSL operation like, vehicle recording, waste weighting, compaction and waste plantation, waste cover, waste deposition, control excavenging, physical characteristics of waste, leachate management, maintenance and monitoring are discussed here.

(Chapter 4)

Results and Discussion:
The field performance of PSSL operation is discussed here to establish appropriate landfill technology for LDACs country like Bangladesh.

(Chapters 5)

Summary and conclusions:
Assess the achievement of objectives; draw conclusions of the findings and provide summary to improve the design of sanitary landfill and operation guideline in this region.

(Chapter 6)

Figure 1.1 Research design of this Study.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The problems associated with MSW management have acquired an alarming dimension in the developing countries during the last few decades. High population growth rate and increase of economic activities in the urban areas of developing countries combined with a lack of infrastructures, appropriate system and associated training, awareness and commitment in modern solid waste management practices complicate the efforts to improve the solid waste service. Compared to developed countries, the urban residents of developing countries produce less per-capita solid waste, but the capacity of the developing countries to collect, process, dispose or reuse it in a cost effective way is limited.

2.2 History of Solid Waste Disposal

Before World War II, the Army disposed of refuse on land (open dumps) in remote areas of the installation and burned the combustible materials periodically. The Army did not adopt sanitary landfilling as a solid waste disposal practice until 1942, when published instructions recommended that refuse be compacted into trenches and covered daily with soil. In 1946, the Army published TM 5634, which provided specific guidance. At that time, the primary emphasis of waste disposal was to reduce garbage odors and blowing litter and to control insects and rodents.

The 1958 version of TM 5-634 was the first Army guidance to address landfill site selection. Although site selection criteria dealt mainly with distance to refuse sources and access to the site, the manual did indicate that landfill sites should not have surface or subsurface drainage that might pollute a water supply.

These practices were undoubtedly considered "state of the art" and environmentally safe at the time. This view prevailed, even though it was common practice to codispose waste engine oil, spent solvents, industrial sludges, and municipal type wastes together in the landfill. Furthermore, no one considered that these liquids might escape from a landfill and seriously contaminate surface waters or subsurface aquifers or otherwise harm the natural environment. In the 1960*s and 1970*s engineers started designing sanitary landfills that relied on the depth to ground-water, and biological, chemical, and physical mechanisms of the soil to protect the ground-water. However, more recent findings have proven that these natural mechanisms do not fully protect the environment from methane gas, a by-product of decaying organic matter, or from leachate. Because of these past practices, many of these old "sanitary landfills" are now found to be "hazardous waste sites" (UFC, 2004).

2.3 Solid Waste Management in Bangladesh

Solid waste management has so far been ignored and least studied environmental issues in Bangladesh, like in most developing countries, but recently the concerned stakeholders have begun to consider this area to be an inseparable component to protect human and nature. In Bangladesh, urban population have been increasing at a very steep rate, about 6% and concentrated mostly in six major cities, where nearly 13% of total population and 55 to 60% of total urban population are living. In the cities, the city authority generally manages MSW; however, recently, some NGOs, CBOs and Private organization are working with city authority's initiatives.

2.3.1 Source storage to disposal

Residential wastes are the main sources of MSW in Bangladesh. Householders those cooperating existing management system, store wastes in a plastic or metal container of different size and shape and keep it inside the house or premises, mostly in kitchen and/or corridor. Solid wastes are collected from generation sources by NGOs, CBOs and city authority by door to-door collection systems, and most of the cases owner by himself disposes it to the nearest community bins or secondary disposal sites.

There is no transfer station and handover point in Bangladesh in true sense. Secondary disposal sites are considered as the facilities where large amount of wastes are accumulated and finally transferred to the desired sites by large vehicles such as open or closed Trucks, Demountable haul container truck, etc. City authority collects wastes from SDS and transfers them to ultimate disposal sites. Only motorized vehicles are used for collection of MSW from Secondary disposal sites. The safe and reliable long-term disposal of solid wastes is an important component of integrated waste management. There is a sanitary landfill at Matuail, Dahka, in which waste is disposed by semi anaerobic process. Figure 2.1 shows the flow path of MSW from source to ultimate disposal site, a typical way to handle MSW in Bangladesh.

2.3.2 Sources of Solid Wastes in Bangladesh

The sources and types of MSW with the data of composition and generation are the basic parameters in the design and operation of the functional elements associated with the management of solid waste (Tchobanoglous and Kreith, 2002). Sources of waste in a community are usually related to land use and zoning. In general, sources of MSW are categorized as: (1) Residential, (2) Commercial, (3) Institutional, and (4) street sweepings (Chan, 1993).

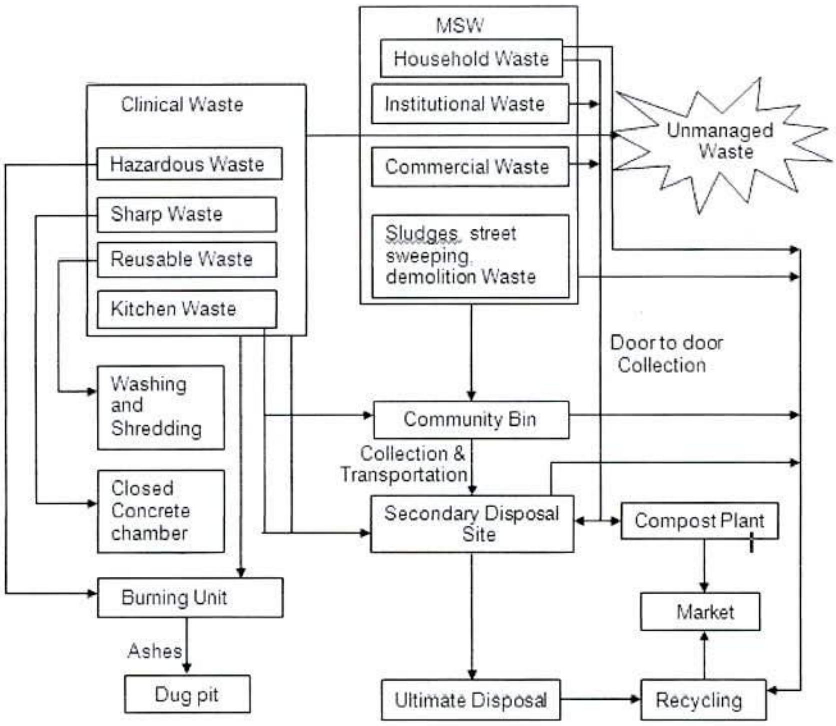


Figure 2.1 Flow path of MSW from source to ultimate disposal site in Bangladesh

Residential Sources: Residential wastes are the main sources of MSW in Bangladesh. Major portion are generated due to household activities. The types of dwellings are single family, multifamily, low, medium and high-rise apartments. These wastes include food wastes, rubbish ashes and others.

Commercial Sources: Solid wastes in commercial sources are generated from stores, restaurants, markets, hotels, service station and others. These wastes include papers, plastics packaging materials and others.

Institutional Sources: The sources of these wastes are mainly universities, schools, hospitals clinics, pathological laboratories, prisons, government and private centers/offices/institutions these wastes include mainly paper, plastics, office articles and medical waste.

Street Sweepings: These wastes are mostly generated in open areas such as streets, alleys, parks, highways, vacant lots, playgrounds, beaches, terminals, recreational areas, etc. Street sweepings include dust, rubbish and others.

2.3.3 Generation of Solid Waste

Table 2.1 Sources and locations of waste generation

Sources	Locations where wastes are being generated
Residential	Single family & multifamily, low medium & high rise apartment, typical town houses, slum etc.
Commercial	Stores, restaurants, markets, hotel, motel, garage etc.
Institutional	Schools, hospitals, prisons, medical facilities, governmental and private offices/centers/institutions, etc.
Industrial	Small and large industries, rice mill, bakery & biscuit, poultry firm, seed processing, cold storage, etc.
Municipal Services	Street sweeping, drain cleaning, park, landscaping, beach, other recreational areas, etc.
Treatment plant sites	Sludges from water treatment plant.
Public facilities	Bus terminal, launch terminal, rail station, bus stoppage, air port, inside the vehicles such as bus, train, launch, airplane, cinema hall, theatre, recreational areas, etc.
Agricultural	Paddy land, vegetable field, nursery of plants, etc.

Source: Alamgir et al., (2005)

The term generator means any person, by site or location whose act or process, produces solid waste or first causes it to become regulated. The locations of generators of MSW according to different sources are given in Table 2.1.

2.3.4 MSW generation in major six cities of Bangladesh

Bangladesh, like most of the developing countries, is facing a serious environmental problem due to huge amount of municipal solid waste (MSW) generation and its management. The generation rate is very close in each major city. Overall, the generation varies from house to house depending on the economic status, food habit, age and gender of household members and seasons. Contribution of different sources in total generation of MSW in the six major cities is given in Table 2.2. The generation of MSW in six major cities of Bangladesh is given in Table 2.3.

Table 2.2 Contribution of different sources in total generation of MSW in six major cities of Bangladesh

Sources	MSW generated daily from different sources (%)					
	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Residential	75.86	83.83	85.87	77.18	79.55	78.04
Commercial	22.07	13.92	11.60	18.59	15.52	18.48
Institutional	1.17	1.14	1.02	1.22	1.46	1.29
Municipal Services	0.53	0.51	0.55	1.24	1.15	0.80
Others	0.37	0.60	0.96	1.77	2.32	1.40
Total	100	100	100	100	100	100

Source: Alamgir et al. (2005)

Municipal solid wastes are the heterogeneous composition of wastes, organic and inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non-hazardous, generated in various sources due to human activities. The various types of waste generated in various sources are shown in Table 2.3

Table 2.3 Generation of MSW in six major cities of Bangladesh

MSW Generation	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Population(Millions)	11	3.65	1.5	0.45	0.40	0.50
MSW generation(tons/day)	5340	1315	520	170	130	215
MSW generation rate (kg/capita/ day)	0.485	0.360	0.346	0.378	0.325	0.430

Source: Alamgir et al. (2005)

2.3.5 Characteristics of solid wastes in Bangladesh

A total of 7690 tons of municipal solid waste generated daily at the six major cities of Bangladesh, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet, as estimated in 2005. The composition of the entire waste stream was about 74.4% organic matter, 9.1% paper, 3.5% plastic, 1.9% textile and wood, 0.8% leather and rubber, 1.5% metal, 0.8% glass and 8% other waste. The per capita generation of municipal solid waste was ranged from 0.325 to 0.485 kg/cap/day while the average rate was 0.387 kg/cap/day as measured in the six major cities. The potential for waste recovery and reduction based on the waste characteristics are evaluated and it is predicted that 21.64 million US$/yr can be earned from recycling and composting of municipal solid waste (alamgir et al.,2007).

Physical characteristics

The important physical characteristics of MSW are pH, moisture content, volatile solid content and ash residue; bulk density and particle size distribution. Table 2.4 shows the average value of some important physical characteristics representing six city corporation areas of Bangladesh. Moisture content and volatile solids data differ seasonally and generally has very high value in rainy season. The experimental results show that the moisture content ranges from 56 to 70% for six major cities of Bangladesh as shown in Table 2.4. Bulk densities were determined in 3 states of compactness as described earlier. In loose state, bulk density ranges from 549 to 669 kg/m^3, while in medium state, it ranges from 764 to 951 kg/m^3 and for compacted state 875 to 1127 kg/m^3 (Table 6) as evaluated by laboratory experiments. However, it ranges from 578 to 621 kg/m^3 as obtained through field test in loose state. Although source reduction, reuse, recycling and composting can divert large portions of MSW from disposal, some waste still must be placed in landfills. Bulk density in loose and compact state indicates that the volume can be reduced 50% by normal compaction.

Table 2.4 Physical characteristics of MSW in six major cities of Bangladesh

Physical characteristics	DCC	CCC	KCC	RCC	BCC	SCC	Weighted average
pH	8.69	8.23	7.76	7.72	7.70	7.71	8.50

H2O (% FM)	70.00	62.00	68.00	56.00	57.00	69.00	68.00
Volatile solid (% DM)	71.00	54.00	56.00	48.00	43.00	65.00	66.00
Ash residue (% DM)	29.00	46.00	44.00	52.00	57.00	35.00	34.00
BD^a (loose) (kg/m^3 FM)	578.00	605.00	610.00	588.00	621.00	609.00	587.00
BD^b (loose) (kg/m^3 FM)	621.00	549.00	556.00	568.00	577.00	669.00	604.00
BD^b (medium) (kg/m^3 FM)	951.00	865.00	764.00	921.00	926.00	899.00	921.00
BD^b (compact) (kg/m^3 FM)	1127.00	994.00	875.00	1052.00	1048.00	1037.00	1082.00

Note: DCC=Dhaka city corporation. CCC=Chittagong city corporation. KCC=Khulna city corporation. RCC=Rajshahicity corporation. BCC=Barisal city corporation. SCC=Sylhet city corporation.
FM = Fresh matter. DM = Dry matter. BD = Bulk density.
[a] By field test. [b] By laboratory test.

Source: Alamgir et al. 2007

Chemical characteristics of MSW

The nutrient contents in organic component of MSW were carbon (C), nitrogen (N), phosphorous (P) and potassium (K), signify here as chemical characteristics were determined by chemical analysis in the laboratory and the results are shown in Table 2.5. The test shows that the highest C/N ratio was 17.22 while the lowest value was 10.17 as obtained in Chittagong and Dhaka city, respectively. The concentration of phosphorous and Potassium were ranged from 0.23 to 0.41% and 0.42 to 1.37% (Table 7) as measured for organic waste of MSW

Table 2.5. Chemical characteristics of organic component of MSW in six major cities of Bangladesh

	Chemical characteristics			
City	C/N	N_{total} (% DM)	P (% DM)	K (% DM)
Dhaka	10.17	0.89	0.31	0.62
Chittagong	17.22	0.17	0.23	0.57
Khulna	16.08	1.62	0.41	1.37
Rajshahi	12.15	0.56	0.31	0.38

Barisal	12.44	1.23	0.40	1.18
Sylhet	11.96	0.90	0.32	0.42
Weighted average	11.91	0.82	0.30	0.66

Note: DM = Dry matter. % P as P_2O_5 = % P × 2.29. % K as K_2O = % K × 1.20.

(Alamgir et al. 2007)

2.3.6 Ultimate Disposal Practices of Solid Wastes in Bangladesh

World Bank has categorized some countries as Least Developed Countries (LDCs) in terms of the following criteria: low-income, human resource weakness, and economic vulnerability. At present, 50 countries are designated as LDCs, out of which 8 countries are from Asia - Afghanistan, Bangladesh, Bhutan, Cambodia, Laos PDR, Maldives, Myanmar & Nepal. These countries have a number of priority issues pertaining to the country's development. Among those, management of municipal solid waste is one of the priority urban issues. Common problems for MSW management in LDACs include institutional deficiencies, inadequate legislation and resource constraints. Long and short term plans are inadequate due to capital and human resource limitations. There is a need for financing equipment for MSW management, training specialists and capacity building. The governments have formulated policies for environmental protection, but they were only implemented in the national capital cities. In most urban areas, open dumping is still considered the most popular method of solid waste disposal. Only Dhaka City Corporation has converted the Matuail dump site into an engineered sanitary landfill. The Dhaka City Corporation is set to inaugurate its first-ever sanitary landfill site at Matuail with an aim to reduce the risks of health and environmental hazards.

The landfill site had been constructed as per the master plan on solid waste management, formulated in 2005 with the technical assistance from the Japan International Cooperation Agency aiming at making the city clean by 2015. Generally, significant amount of the solid waste generated in urban centers are uncollected and either burned in the streets or end up in rivers, creeks, marshy areas and empty lots. Waste that is collected is mainly disposed off in open dump-sites, many of which are not properly operated and maintained, thereby posing a serious threat to public health. The collection rate varies from city to city and collection facilities are either inadequate or inefficient in almost all of the cities (Alamgir et al. 2005).

Heavy rainfall during the monsoon is very conducive to the generation of leachate at the dumping sites. Leachate has the potential of slowly moving downwards and eventually reaching the aquifer used for the city water supply, thus contaminating this precious resource. Other problems related to un-organized waste dumping are the spread of waste by wind, run-off and flood waters, and the easy accessibility by persons to potentially hazardous or infectious materials. While waste reduction and reuse efforts may diminish the per capita quantity of waste generated in industrialized nations, there is no doubt that landfills will remain an important method for the safe disposal of municipal solid wastes for the foreseeable future due to their simplicity and cost-effectiveness (wastesafe 2007).

2.3.7 Institutional Arrangement for Solid Waste Management

Presently, the solid waste management system in Bangladesh in not well organized. However, efforts are under way to improve the organizational structure for solid waste management in different cities/towns. For instance, Dhaka City Corporation has recently established a Solid Waste Management Department to improve the waste management services in the city. In most of the city corporations and municipalities there is no separate department for solid waste management. Solid waste management is organized and run by conservancy section of the urban local bodies, whose prime responsibility is maintenance of the sanitation system. The organizational structure of conservancy section is shown in Figure- 1.2. (Only in City Corporations)

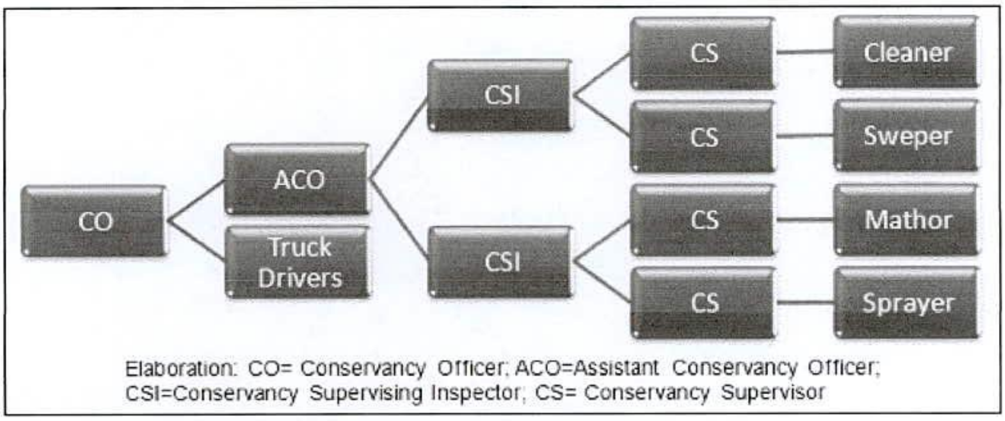


Figure 2.2 Organizational Structure of Conservancy Section in Urban Local Bodies in Bangladesh.

The number of staff for conservancy varies from city to town depending upon the size of the city and the workload. Some of the cleaners and sweepers are hired on temporary basis. Although, the organizational structure presented in Figure 2.2 deals with the collection and storage of waste as well as street sweeping, separate department in the city corporations and municipalities does transportation of waste. The chief conservancy officer or the conservancy officer in the pourasahavs has to coordinate with the transport department to get the waste transferred from collection points to designated waste disposal sites. Generally in most of the urban local bodies have insufficient number of staff involved in waste management activities. In addition to the shortage of personnel, the staffs are handicapped with relatively small amount of resources available to them for management of solid waste in their particular area of operation.

2.3.8 Laws and Regulations

There is no independent law in Bangladesh to address the problems of solid waste. In Bangladesh, solid waste management is entrusted with the local government bodies. The responsibility of removing MSW and disposing of it lies with the City Corporation. The Dhaka City Corporation Ordinance 1983 is the only local law that gives some idea on disposal of municipal waste. Dhaka Municipal Ordinance 1983 has a provision for the removal of refuse from all public streets, public latrines, urinal drains, and dustbins and for collection and disposal of such refuse. Moreover, due to shortage of funding, due to almost no direct user charges as well as insufficient subsidies, and other institutional constraints, the local government has not been able to effectively collect and dispose off the waste properly Most of the waste is visible on the streets and in the drains and Only DCC converted the Matuail open dumping site to a engineered sanitary landfill with the help of JICA (source, http://kitakyushu.iges.or.jp/docs/demo/dhaka_bangladesh).

The government is going to impose strict regulations on the healthcare facilities for safe disposal and proper management of medical waste. The Ministry of Health and Family Welfare is formulating the Medical Waste Management Regulations, which is now in the final stage, under The Bangladesh Environment Conservation Act, 1995. Sources at the Directorate General of Health Services (DGHS) said the draft of the regulations has been prepared and it is currently with the Ministry of environment and Forest for suggestions. Finally it will be sent to the law ministry for vetting.
(Source, http://www.thedailystar.net/pf_story.php?nid=24105)

Since there is no separate policy or handling rules for solid waste management in Bangladesh. Ministry of Environment and Forest is currently preparing a comprehensive solid waste management handling rules for the country. The existing legal aspects relating to solid waste management can be classified into two groups, which are given below (www.icmab.org.bd):

a) National Level Framework

Environment Conservation Act, 1995 requires that before establishment of industrial enterprise as well as undertaking of projects environmental aspects must be given due consideration and prior environmental clearance is obtained. As such, for the purpose of environmental clearance, the Environment Conservation Rules 1997 made under the Act. Apart from Environment Conservation Rules 1997, to improve the waste disposal system the Government has recently formulated some policies and plans, which are as:

(i) National Environmental Management Action Plan (NEMAP) has been prepared for a 10-year period (1995-2005), by the Ministry of Environment and Forest (MoEF) of the Government of Bangladesh in consultation with people from all walks of life (GoB, 1995).

(ii) Urban Management Policy Statement, 1998, prepared by the Government of Bangladesh has clearly recommended the municipalities for privatization of services as well as giving priority to facilities for slum dwellers including provision of water supply, sanitation and solid waste disposal (GoB, 1998a).

(iii) National Policy for Water Supply and Sanitation 1998 prepared by the Local Government Division of the Ministry of Local Government Rural Development & Cooperatives gives special emphasis on participation of private sector and NGOs in water supply and sanitation in urban areas through proper collection of wastes, use and recycling.

(iv)National Clean Development Mechanism (CDM) Strategy 2004 prepared by the Ministry of Environment and Forest (MoEF) has identified waste sector as one of the potential sectors for attracting CDM finance in the country. The waste sector options for Bangladesh can be landfill gas recovery, composting, poultry waste, and human excreta management using eco-sanitation and wastewater treatment.

b) Local Level Legal Framework

In Bangladesh, solid waste management is entrusted with urban local government bodies. The responsibility of removal and disposal of municipal solid waste lies with the City Corporations and municipalities. The six City Corporation Ordinances and Pourshava Ordinance 1977 are the only local law that gives some idea about disposal of municipal waste. These ordinances contain identical provisions relating to solid waste management, which are as follows:

- The pourshava or city corporation shall be responsible for sanitation of the municipality/city corporation area and for the control of environmental pollution.
- A pourashava or city corporation shall make adequate arrangements for removal of refuse from all public streets, public latrines, urinals, drains, and all buildings and land vested in the pourshava or city corporation and for collection and proper disposal of such waste.

- Subject to the general control and supervision of the pourashava/city corporation, the occupiers of all other buildings and land shall be responsible for removal of refuse from such buildings and lands.
- The poursahava/city corporation may, and if so required by the governments shall provide public bins or other receptacles at suitable places and by public notice, require that all refuse accumulating in any premise or land shall be deposited by the owner or occupier of such premises or land in designated bins or receptacles.
- All refuse removed and collected by staff of pourashava/city corporation or under their control and supervision and all refuse deposited in the bins and other receptacles provided by the poursahava/city corporation shall be the property of the pourashava/city corporation.
- A pourashava/city corporation shall provide adequate public drains in the municipality/city area and all such drains shall be constructed, maintained, kept cleared, and emptied with due regard to health and convenience of the public.

2.3.9 Current Practice of SWM in Khulna

Khulna City Corporation (KCC) is responsible for the operation and maintenance of municipal services, including solid waste management. The City Corporation is headed by an elected Mayor and operates through 41 elected Ward Commissioners one for each of the 31 Wards with an additional 10 women Ward Commissioners. It is made up of eight functional departments and the conservancy department is responsible for solid waste management, street sweeping, public latrines and urinals, cleaning of drains, etc. The solid waste management service organizes waste collection from approximately 1,200 City Corporation masonry bins, located on roadsides throughout the city. Households are expected to dispose of their waste in the masonry bins. The waste is then transported to its final disposal site (approximately 8 km from the city) by City Corporation trucks. Heaps of waste remains uncollected in many parts of the city; KCC trucks only pick up waste from the roadside bins while waste is frequently disposed in open drains, free land and around the waste bin sites (http://ekh.unep.org). It is estimated that of the 520 tons of waste generated daily, between a third and a half remains uncollected. Uncollected waste blocks drains, causes water logging and spills over on to roads, often resulting in increased traffic congestion. These problems are acute during the rainy season especially in poor neighborhoods which are frequently located in relatively low lying areas and have narrow alleys through which municipal trucks cannot pass. The problem of solid waste management is too extensive for the City Corporation to manage and they are heavily dependant on grants from the central government. The conservancy tax (4% of holding tax) is insufficient to fund the current level of service. In 2008-2009 financial year income from the tax was only Taka 256.52 million (1 US$ = Taka 70) while expenditure by the conservancy department was Taka 65.5 million.

The Current SWM System in Khulna is discussed below (CDIA 2009):

- SWM in Khulna, and in many other Bangladeshi cities, is hampered by the absence of adequate national or local legislation relating to municipal SWM and the treatment and disposal of hazardous waste. In particular, there are no mandatory regulations or performance standards for city corporations (e.g. KCC) to establish and manage an effective SWM system; nor are there any sanctions to prevent littering and indiscriminate dumping.
- As a result SWM in Khulna has developed in a piecemeal and unintegrated manner with NGOs, CBOs, informal recyclers and private enterprises being involved along with KCC. Apart from one ward where KCC operates Door to Door (DtD) collection, its main responsibilities are the transport of waste from 130 Secondary Disposal Sites (SDS) and 1,200 roadside Dustbin Points (DBP) to a landfill site at Rajband about 8km to the west of the city, which it operates. NGOs and CBOs, along with a KCC contracted private company, collect household waste door to door on a daily basis, using rickshaw vans, in parts of several wards and then transport it to the SDS (Figure 2.3). These are considered to be effective operations, although only a minority of city dwellers receives this service. For the most part, householders take the waste to the SDS themselves or dispose of it indiscriminately.

- Informal recyclers collect and dispose of the great majority of recyclable materials (e.g. plastics, glass and paper) but this waste only constitutes a minority (around 20% by weight) of the total daily generated household waste. The great majority of household waste is bio-waste. Although there are some composting initiatives, their total output is negligible, 20-25 tons per month when compared to the average daily household waste generation of just less than 300 tons for the KCC area.

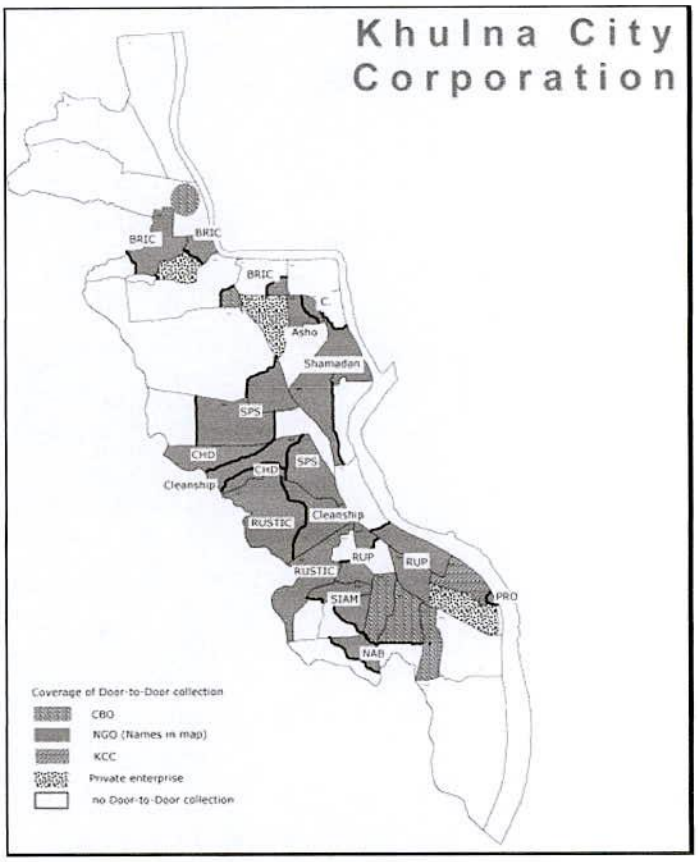


Figure 2.3 Coverage of Wards by Door to Door Refuse Collection

- In 2000, it was estimated that fewer than 30% of KCC households had access to waste disposal facilities. While this situation has improved due to the increased involvement of NGOs and the private sector, currently only 50-60% of household waste is collected with most of the remainder being disposed of indiscriminately in drains, at roadsides and into vacant areas. A substantial proportion is also used for land reclamation, sometimes through the diversion of KCC trucks going to the landfill site.
- Commercial wastes amount to 65-70 tons daily, all of which is disposed of by the enterprises themselves. Hospital wastes amount to under 1 ton per day, around

86% of which is non-hazardous. Despite attempts by NGOs to establish an incineration plant for hazardous waste, this is no longer functioning and there is now no mechanism for hazardous waste disposal. NGO Prodipan does however operate a system of collecting separated hazardous waste from around 1/3rd of Khulna's health facilities.

- The general operational inadequacy of the system is exacerbated by the inadequate management and maintenance of the SDS by KCC, the poor maintenance of KCC trucks (up to 40% are off the road at any one time), indiscriminate dumping, scavenging at SDS and DBPs which results in waste being dispersed around these sites, and the absence of engineered sanitary land fill cells and associated lack of emissions control at Rajband.
- The major reasons for Khulna's poor SWM system are 1) The low managerial, technical and financial resources available to KCC to operate an effective SWM system and 2) The lack of public awareness and commitment by a large proportion of the population which leads to indiscriminate dumping of waste exacerbated by a resistance to NGO operated DtD services for which payments additional to the conservancy charges levied by KCC need to be made.

- Quite apart from the negative impacts on health and the urban environment in general, the failure to operate an effective SMW system exacerbates the flooding that occur during the rainy season (see preceding section). The poor SWM system therefore also contributes to the adverse economic, environmental and social impacts arising from frequent flooding.

2.4 Sanitary Landfill

Landfill is a term used to describe the physical facilities for disposal of solid wastes and Solid waste residuals in the surface soil of the earth. Landfill may be classified into three categories-

Class I: Hazardous waste Landfill

Class II: Designated waste Landfill

Class III: Municipal Solid waste (MSW) Landfill

Based on the physical infrastructures and other associated facilities landfill is classified as-

i) Sanitary landfill

ii) Monofills

iii) Secure landfills

iv) Uncontrolled land disposal sites

2.4.1 Definition of Sanitary Landfill

- Wastes those are susceptible to contaminate air, ground water and surface water are needed to contain in an engineered safe containment system, known as engineered or sanitary landfill.
- Sanitary landfill may be defined as the operation in which wastes to be disposed of are compacted in layers and covered with a layer of earth at the end of each day's operation.
- In a word Sanitary landfills are sites where waste is isolated from the environment until it is safe. A real sanitary landfill is shown in Figure 2.4

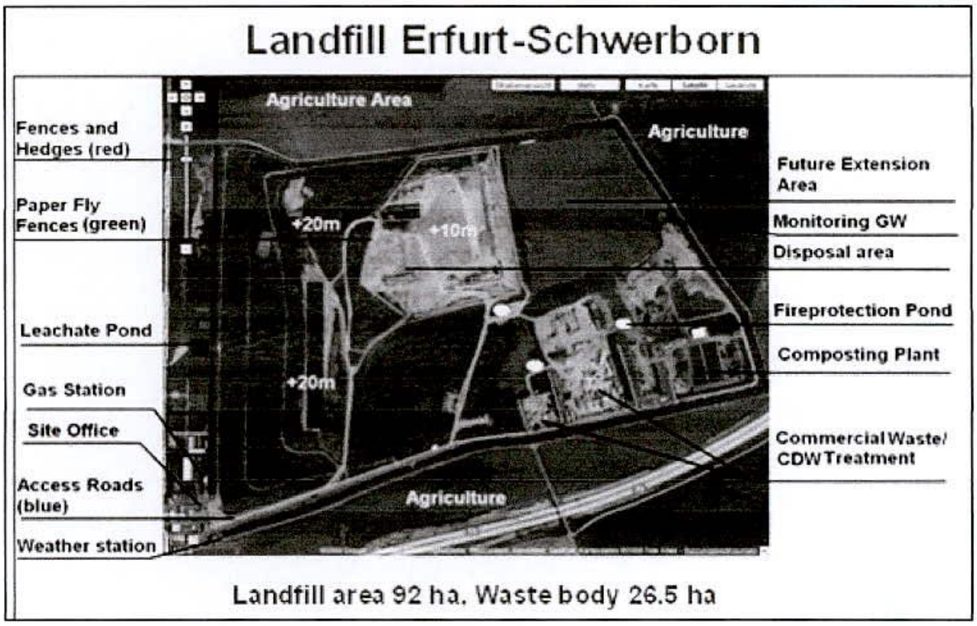


Figure 2.4 Top view of a real sanitary landfill in Germany

2.4.2 Purpose of Landfill Disposal

The purpose of landfill disposal is to stabilize the solid waste and to make it hygienic through proper storage of waste and use of natural metabolic function. Sanitary landfilling is generally preferred over other alternatives, because there is less handling and processing of materials. However, a landfill may not be the most economical or environmentally preferred method. The rapid filling of available sites, and outdated containment systems of existing landfills have forced authorities to consider alternative disposal methods. A combination of the options may be the best solution, but may depend on several factors at the installation, including: the type of refuse, availability of land for site selection, incinerator accessibility, economic feasibility for recycling usable materials, suitable locations for large quantity composting, and possible contractual arrangements that would combine several of these methods. The main advantage of a sanitary landfill is that handling and processing of refuse is kept to a minimum. Handling is limited to the pickup and transport of the waste, the spreading of refuse, and covering with a suitable cover material. Composting requires more handling before it is stored to decompose, and may only be suitable for disposing of organic matter such as yard waste. Therefore, composting may not be a viable alternative for a majority of the situations. Recycling requires that only specific materials be processed, and requires more handling than most other methods, but can reduce solid wastes in a landfill by as much as 30% (UFC 2004).. After the material is collected, it may go through various changes and processes, at a substantial expenditure of energy, before it results in a reusable form. Recyclable materials include paper, plastics, glass, metals, batteries, and automobile tires. Incineration with energy recovery has been used for some time, but has come under increased scrutiny because of new laws and regulations aimed at reducing air pollution and the resulting products of incineration may be even more dangerous than originally thought. Clean air laws, and negative public sentiment may require additional expense and waste treatment that can make incineration the least favored alternative. Ash residue and bulky refuse which are not burned during incineration will still require disposal. The main advantage of incineration is the capability to reduce landfill use by 70-80% (UFC 2004).. The critical factors which must be considered include: the possibility of surface and ground water contamination, explosions from gases generated by waste decomposition, airborne ash from incineration, odors from the composting process, and the lack of suitable sites with the capacity for long term use are critical factors which must be considered. Design authorities must make decisions which are critical to the areas surrounding the proposed sanitary landfill. Selecting a method for proper and complete disposal can be a very intricate process (UFC 2004).

2.4.3 Solid Waste Stabilization in a Sanitary Landfill (UFC 2004)

Alternatives:

While past designs required that landfills receive extended maintenance after closure, increasingly stringent regulations and the shrinking availability of suitable sites for landfills may force the designer to consider some of the new technologies that can speed up solid waste stabilization. Stabilization is achieved by the degradation of the deposited refuse, mainly through decomposition, which reduces the pile volume and can lead to surface subsidence. Landfill designs offer two options: dry or sealed landfills; and wet landfills.

Dry Landfills:

Dry landfills are designed to seal off the solid waste in hopes of reducing leachate production, therefore decreasing the possibility of leachate leakage outside of the landfill system. Unfortunately, studies show that solid waste stabilization is limited with the "dry" system. Archaeological investigations have found 20 years old refuse in existing landfills which was preserved from the elements. Because the waste was sealed off, it was protected from the rotting influences of air and moisture. While this method may require low maintenance, it could possibly require maintenance for several decades, with little actual stabilization or decomposition of the solid waste.

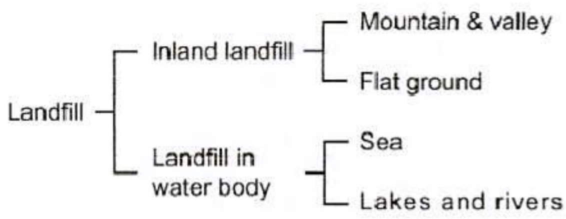
Wet landfills:

(1) Biodegradation: Current studies have shown that wet systems, or landfills that use leachate recirculation, are becoming the favored option when considering solid waste stabilization as a priority for the landfill. Since most biodegradation results from complex interactions of microbial bacteria, these "wet landfills" may also require the addition of air along with the recirculation of leachate. Lined landfills that have been properly designed and constructed provide leachate containment with a low risk of leakage.

(2) Gas Generation: Methane gas generation is considered to be a problem at some landfills. Therefore, the production of methane and other gases should be considered in the design. The economics of extracting methane gas as an energy source makes accelerated methane gas production a benefit of wet landfill designs. This may require that containing and recovering the methane gas be made part of the landfill design.

(3) Stabilization Time: The main advantage of a wet landfill is the increased rate of stabilization of the solid waste in the landfill. Studies show that the process of leachate recirculation can speed up the rate of waste decomposition, by an active biological process in a landfill from 50 or more years for a dry landfill, to just 5 or 10 years for a wet landfill. Long term financial savings through eliminated or reduced maintenance and long term monitoring may outweigh the initial start-up costs and requirements for leachate recirculation, and should be considered in the design of the sanitary landfill.

2.4.5 Classification of Landfill Site



2.4.6 Classification of Landfill Structure

Landfill sites are classified into 5 types according to structure as shown in Table 2.6. In terms of quality of leachate and gases generated from landfill site, either semi-aerobic or aerobic landfill method is desirous.

Table 2.6 Classification of Landfill Structure(www.menlh.go.id)

Anaerobic landfill	Solid wastes are filled; in digged area of plane field or valley. Wastes are filled with water and in anaerobic condition
Anaerobic sanitary landfill	Anaerobic landfill with cover like sandwich shape. Condition in solid waste is same as anaerobic landfill.
Improved anaerobic sanitary	This has leachate collection system in the bottom of the landfill site. Others are same as anaerobic sanitary landifll. The conditions is still anaerobic and moisture content is much less than anaerobic sanitary

landfill (Improved sanitary landfill)	landfill.
Semi-aerobic landfill	Leachate collection duct is bigger than the one of improved sanitary landfill. The opening of the duct is surrounded by air and the duct is covered with small crushed stones. Moisture content in solid waste is small. Oxygen is supplied to solid waste from leachate collection duct.
Aerobic landfill	In addition to the leachate collection pipe, air supply pipes are attached and air is enforced to enter the solid waste of which condition becomes more aerobic than semi-aerobic landfill.

2.4.7 Evolution of Sanitary Landfills

Since the turn of the last century, the use of landfills, in one form or another, has been the most economical and environmentally acceptable method for the disposal of solid wastes throughout the world. Landfills, in various forms, have been used for many years. The first recorded regulations to controls municipal solid waste are implemented during the Minoan civilization, which flourished in Crete (Greece). From 3000 to 1000 B.C.E. Solid wastes from the capital, Knossos, were placed in large pits and covered with layers of earth at intervals (Tammemagi, 1999). This basic method land filling has remained relatively unchanged right.Up to the present day, the summary of the evolution of municipal landfills is given in the Table 2.7.

Table 2.7 Summary of municipal landfill evolution (after Bouzza et al., 2002)

Period	Development	Problems	Improvements
1970s	Sanitary landfills	Health/nuisance i.e. odor, fires, litter	Daily cover, better compaction, engineered approach to containment
Late 1970-early 1990s	Engineered landfills recycling	Ground and ground water contamination	Engineered liners, covers, leachate and gas collection system, increasing
Late 1980s-early 1990s	Improved sitting and containment,	Stability, gas migration	Incorporation of technical, socio-political factors into sifting process, development of new

	waste diversion and re-use	lining materials, new cover concepts, increased post-closure use
2000s	Improved waste Treatment	Increasing emphasis on mechanical and biological waste pretreatment, leachate recirculation and

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
6,500 BC	North America	Archeological studies shows a clan of Native Americans in what is now Colorado produced an average of 5.3 pounds of waste a day.
500 BC	Athens Greece	First municipal dump in western world organized. Regulations required waste to be dumped at least a mile from the city limits.
New Testament of Bible	Jerusalem Palestine	The Valley of Gehenna also called Sheoal in the New Testament of the Bible "Though I descent into Sheol, thou art there." Sheoal was apparently a dump outside of the city of that periodically burned. It became synonymous with "hell."
1388	England	English Parliament bars waste dispersal in public waterways and ditches.
1400	Paris France	Garbage piles so high outside of Paris gates that it interferes with city defense.
1690	Philadelphia	Rittenhouse Mill, Philadelphia makes paper from recycled fibers (waste paper and rags).
1842	England	A report links disease to filthy environmental conditions -

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
		"age of sanitation" begins.
1874	Nottingham England	A new technology called "the Destructor" provided the first systematic incineration of refuse in Nottingham, England. Until this time, much of the burning was accidental, a result of methane production.
1885	Governor's Island NY	The first garbage incinerator was built in USA (on Governor's Island in NY)
1889	Washington DC	Washington DC reported that we were running out of appropriate places for refuse (sound familiar?).
1896	United States	Waste reduction plants arrive in US. (for compressing organic wastes). Later closed because of noxious emissions.
1898	New York	NY has first rubbish sorting plant for recycling (are we reinventing the wheel?).
Turn of Century		By the turn of the century the garbage problem was seen as one of the greatest problems for local authorities.
1900		"Piggeries" were developed to eat fresh or cooked garbage (In the mid-50's an outbreak of vesicluar exenthama resulted in the destruction of 1,000s of pigs that had eaten raw garbage. Law passed requiring that garbage had to be cooked before it could be fed to swine).
1911	New York City	NYC citizens were producing 4.6 pounds of refuse a day (remember the Native Americans from 6500 BC mentioned above?).
1914	United States	there were about 300 incinerators in the US for burning trash.
1920's		Landfills were becoming a popular way of reclaiming

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
		swamp land while getting rid of trash.
1954	Olympia Washington	Olympia Washington pays for return of aluminum cans.
1965	United States	The first federal solid waste management laws were enacted.
1968		By 1968 companies began buy back recycling of containers.
1970	United States	The first Earth Day was celebrated, the Environmental Protection Agency EPA created and the Resource Recovery Act enacted.
1976	United States	In 1976 Resource Conservation and Recovery Act (RCRA) was created emphasizing recycling and HW management. This was the result of two major events: the oil embargo and the discovery (or recognition) of Love Canal.
1979	United States	The EPA issued criteria prohibiting open dumping.
Today		The list goes on and on.

2.4.8 Elements of a Sanitary Landfill

Sanitary landfill are consists of some elements that are essential to prevent any environmental hazard. These elements are provided at different steps of construction and daily operation. Various elements of a sanitary landfill are described as below:

Cell: The term cell is used to describe the volume of material placed in a landfill during one operating period, usually 1 day.

Daily cover: Daily cover usually consists of 6 to 12 in of native soil or alternative materials such as compost, foundry sand, or auto shredder fluff that are applied to the working faces of the landfill at the end of each operating period.

Lift: A lift is a complete layer of cells over the active area of the landfill.

Bench: A bench is typically used where the height of the landfill will exceed 50 to 75 ft. Benches are used to maintain the slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping.

Landfill liners: Landfill liners are materials that are used to line the bottom area and bellow grade sides of a landfill.

Landfill Cover: The final landfill cover layer is applied over the entire landfill surface after all land filling operations are complete.

Monitoring wells: It is designed and placed to define groundwater flow and water quality below the surface of a solid waste facility. Properly designed and placed wells will also ensure that groundwater samples and water level measurements are representative of the groundwater below the site. Placed individually or as clusters, each individual well is installed in its own boring. The above elements are shown in Figure 2.5.

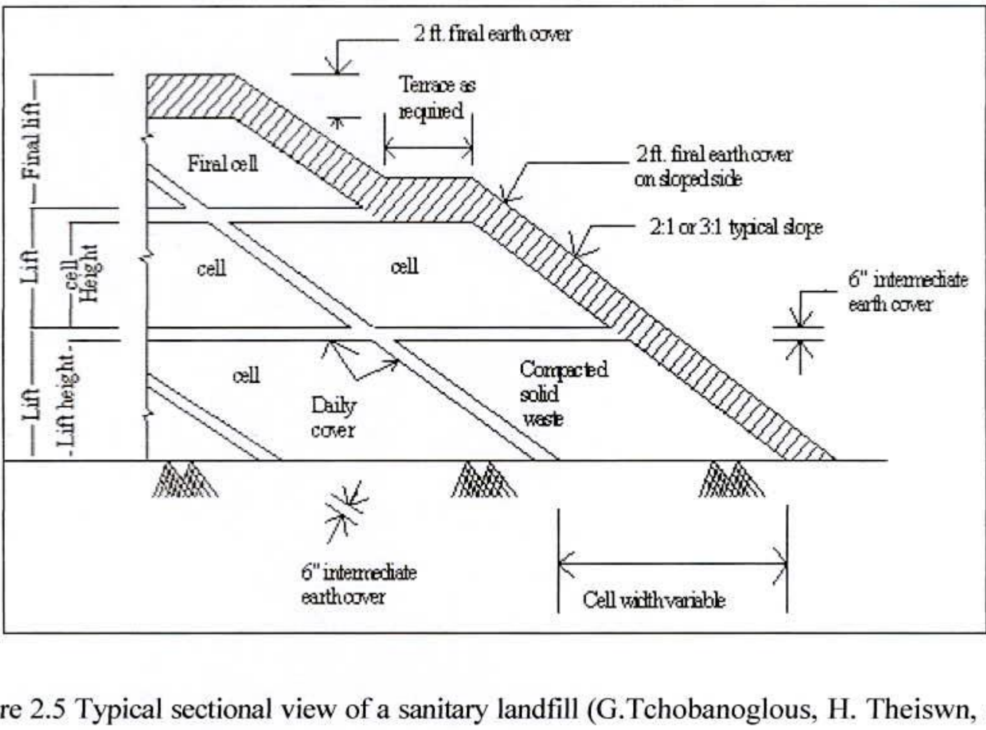


Figure 2.5 Typical sectional view of a sanitary landfill (G.Tchobanoglous, H. Theiswn, & S. Vigil, 1993)

2.5 Sanitary Landfill in Bangladesh

Despite a Pilot Scale Sanitary Landfill (PSSL), this is the second experience in Bangladesh after the Matuail's one (Ahmed 2008), where the Dhaka City Corporation has been developing an engineered landfill in semi aerobic method by converting the existing open dumping site as shown in figure 2.6. A semi-aerobic landfill system has been adopted to reduce the polluting load on the environment and speed up the stabilization of the disposed waste. A perforated pipe network for leachate collection and gas venting arrangement are installed for proper collection of the leachate and provision of air supply system. Periodical monitoring of the environmental parameters of the ground and surface water, leachate quality and landfill gas is introduced as part of the operational measure of the sanitary landfill. Under this semi-aerobic system, the lifetime of the landfill is estimated to be 20 years at the present rate of incoming waste of around 1,700 tons/day (www.citynet-ap.org).

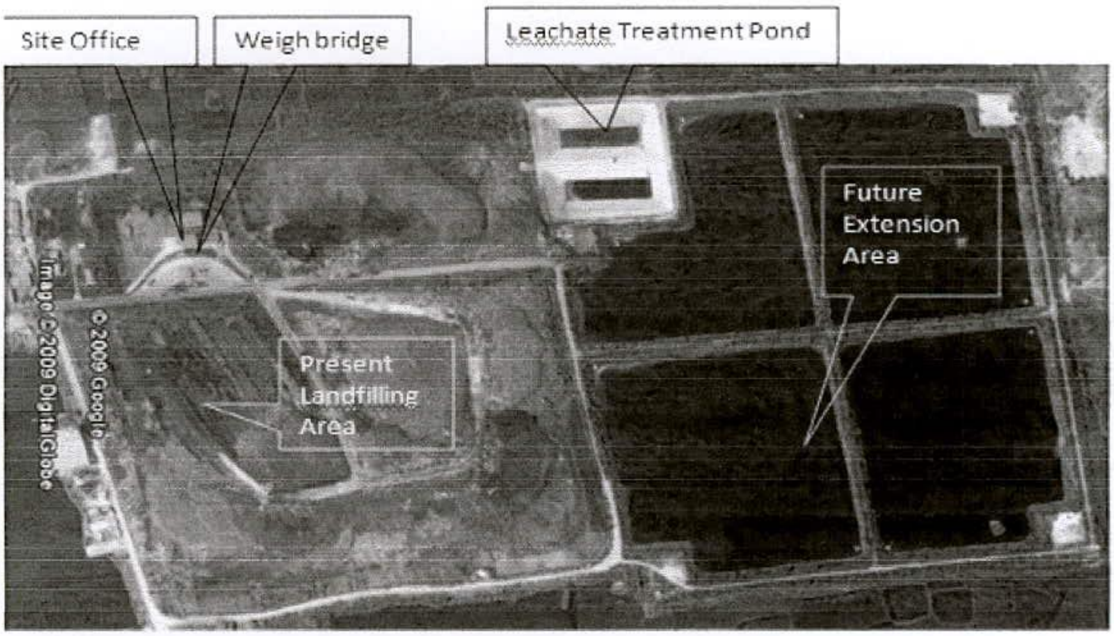


Figure 2.6 Matuail Sanitary Landfill of DCC, Bangladesh (www.google earth.com)

KUET and KCC jointly have been constructing the PSSL in Rajbandh, Khulna to establish appropriate construction technology for Bangladesh conditions using local building materials, technical capabilities and the available technology. The pilot scale sanitary landfill is designed and constructed during the first-half of 2008. In the design and construction, very simple approach relevant to the condition of LDACs is considered; the details are discussed in the following chapter.

CHAPTER THREE

PILOT SCALE SANITARY LANDFILL STUDIES AT KHULNA

3.1 General

Proper design is vital to the successful operation of a landfill disposal facility in even the most suitable location. All technological alternatives which meet requirements of the proposed landfill should be reviewed prior to incorporation into the design. The design should produce a landfill capable of accepting given solid waste materials for disposal. To serve as a basis for design, the types and quantities of all refuse expected to be disposed of at the landfill should be determined by survey and analysis.

3.2 Feasibility Investigation

The feasibility study of PSSL site is summarized the findings from an investigation of several factors are discussed herein including advantages and costs.

i) Ownership/Acquisition: The present ownership of the property is KCC which is the Local Government Authority as a single owner, rather than multiple.
ii) Zoning: The site is within an area that is currently zoned by the local government for this type of land use.
iii) Road Access: The existing roads and access to the site is considered. It is easily accessible from a main highway and has an access road that is presently maintained year-round.
iv) Topography: The topography of the site is suitable for the efficiency of the cut and fill operations as well as equipment movement at the landfill.
v) Site Capacity: The capacity of PSSL is estimated for one year based on the site's size, shape, and topography.
vi) Soils: Deep deposits of clay soils are ideal for a landfill site.

vii) Depth to Groundwater: As the depth to groundwater is increased, the probability that the groundwater quality will be contaminated by leachate will be decreased.

viii) Proximity to Wells: The landfill site is over 500 meters up gradient of water supply wells.

ix) Surface Water: The site is more than 300 meters away from a stream, but allows closer distances with engineering measures.

x) Flood Hazard: The site is located outside of a 100-year floodplain.

xi) Airport Safety: The landfill site will must not pose a bird hazard to aircraft.

xii) Holocene Fault: The landfill site is located more than 100 meters from a fault that has experienced displacement during the present Holocene Epoch.

xiii) Seismic Impact Zone: The siting of a landfill will not occur in a seismic impact zone.

xiv) Site Stability: The stability of site is considered in the site evaluation. It has no slope stability problems, no expansive soils, or no subsurface instabilities.

xv) Run-on/Run-off Controls: Both run-on and run-off will be controlled.

xvi) Landfill Gas Control: The potential for landfill gas to migrate off the site and the impacts of the gas migration is considered.

xvii) Land Use: The site will located at Rajbandh where residential, industrial, or recreational land uses are improbable.

xviii) Agricultural Land: The site has with little agricultural value that will be viewed more favorably.

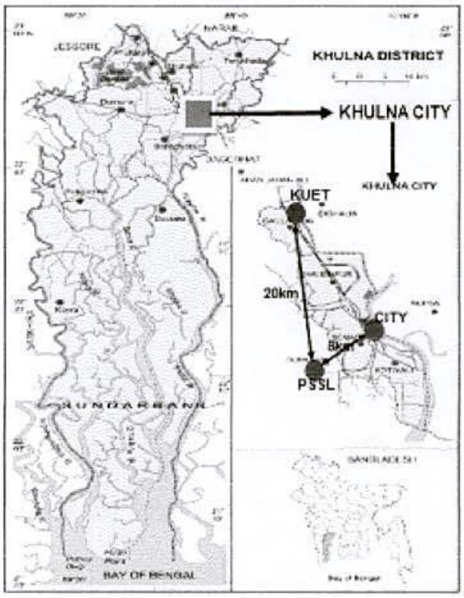
xix) Habitat Value: The site is ideal because landfill development will have little or no impact on wildlife or plant habitat.

xx) Visual Impacts: It is preferable that landfill operations will be kept out of view from present or future residences near the site.

xxi) Downwind Impacts: The impact to residences downwind will be minimized by siting the landfill further upwind of residences.

3.3 Site Characteristics

3.3.1 Location and Site Selection



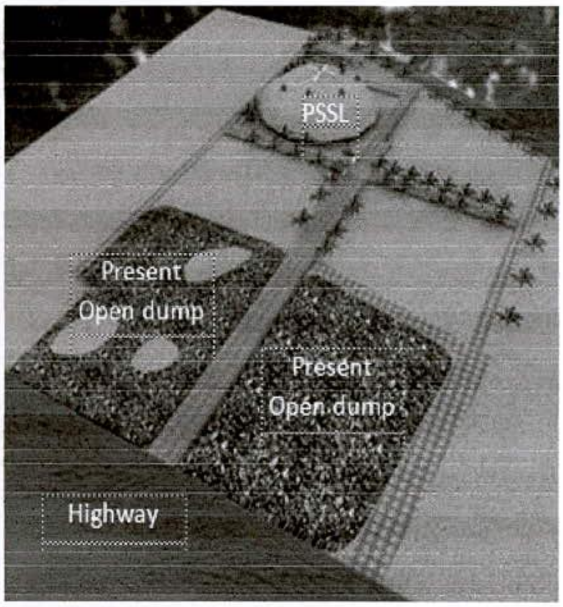


Figure 3.1 Location of PSSL with respect of Khulna city map.

Figure 3.2 Layout of the PSSL at new Rajbandh.

Finally it was decided by the WasteSafe II Team member to select a site in the ultimate disposal site (UDS) of KCC at Rajbandh for the construction of PSSL. In the Rajbandh, there are two sites used as UDS by KCC as crude open dumping of solid waste generated in the Khulna city, one is known as 'Old Rajbandh' and the other is 'New Rajbandh'. The Old Rajbandh having an area of 20 acres is located about 8km far from the city centre i.e. 'Royal-Castle Salam Square' of Khulna city and situated along the North-side of Khulna-Satkhira highway as shown in Figure 3.1. The New Rajbandh the second UDS site of MSW of KCC, having an area of 5 acres is just 700m west from the Old Rajbandh. KCC started to dump waste in Old Rajbandh in 1977. Later, KCC acquire this land for UDS and later converted to Children Park.

The New Rajbandh consists of 5 cells (shallow depth pond) surrounded by earthen embankment, where paddy plantation and fish cultivation were continued till the waste deposition started. However, still it has significant capacity to accommodate the solid waste. Despite the Old Rajbandh filled-up partially with solid wastes, KCC started to dump wastes in the New Rajbandh since January 2007 and first two cell cells along the Khulna-Satkhira Highway were started to fill as shown in Figure 3.2. The site of the PSSL is located at the north-west corner with an area of 1.1acres. This location for PSSL was selected based on the series of site visit and the discussion with KCC team members. Since, the wastes deposition as open dumping was already started in the first two cells (Shallow ponds), the last corner was selected to avoid all the possible interferences due to open dumping. The corner pond is surrounded by earthen embankment and located at distance of 122m from the Khulna-Satkhira Road. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 64mx55m. There is a public natural stream in the North side and private paddy land in the west.

3.3.2 Topography of the Site

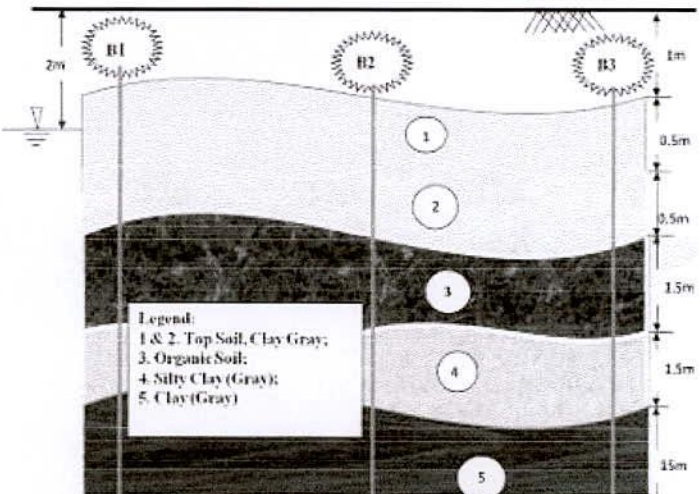


Figure 3.3 Sub-soil strata of the site of PSSL at Rajbandh, Khulna

The site is not a deep valley with a gentle slope. A small stream channel of about 8 m wide, flows beside the site from east to west and joins Dumuria River at about 1.5 km in the down stream. The valleys with undulating terrain present depths of 10 to 15 m (appx.)

respectively, at two different locations. It is evident that the performance of all the Geo-environmental structures such as landfill liners, covers, impoundments of vertical barriers, settlement and side stability depends mainly on the sub-soil conditions and the basic characteristics of the soils. The geotechnical characteristics of the sub-soils were determined in the laboratory using conventional test methods after collecting the soil samples through a sub-soil exploration by wash boring method up to a depth of 15m. The three boreholes were executed and the values of soil parameters were evaluated. The existing ground surface exists at a depth of 1m from the road level, while the ground water table is encountered at a depth of 2m as shown in the sub-soil strata presented in Figure 3.3.

3.3.3 Subsoil Investigation

Table 3.1 Geotechnical properties of the landfill site (Akhter, 2007)

Depth (m)	Liquid limit W_L (%)	Plastic limit PL (%)	Plasticity index IP (%)	Hydraulic conductivity ($x10^{-5}$ cm/s)	Void ratio e_0	Porosity n (%)	Specific Gravity ,Gs	Dry Density (kN/m^3)
0-1	51.20	31.80	19.40	0.217	1.026	50.64	2.72	16.9
1-2	55.06	48.09	6.97	0.481	1.303	56.58	2.72	14.93
2-3	54.43	29.29	25.14	0.252	2.229	69.03	2.72	10.68
3-4	88.23	31.46	56.77	0.728	5.464	84.53	2.25	4.4
4-5	53.21	31.78	21.43	1.34	0.901	47.40	2.15	14.3
5-6	112.88	70.49	42.39	1.01	3.804	79.20	2.15	5.66
6-7	47.05	31.31	15.73	0.622	1.079	51.90	2.74	16.66
8-9	25.40	13.90	66.40	0.20	1.091	52.18	2.73	16.5
9-10	41.40	24.39	17.01	0.994	0.939	48.43	2.70	17.6
10-11	41.81	32.63	8.77	0.8	--	--	--	--

The sub-soil investigation was carried out at the Pilot Scale Sanitary Landfill site to identify the soil strata, physical and engineering properties. Boring to a depth of 17m revealed that the gray clay minerals with organic forms to a depth of 1.5m followed by silty clay having clay minerals content ranges from 23 to 30% and hydraulic conductivity varies from $2.45x10^{-6}$ to $2.5x10^{-8}$ cm/sec at different molding water content. Swelling clay minerals are present in varying the amount of 0 to 11% of the composition. The soil quality analysis at the proposed site shows that the soil is acidic with pH ranging from 4.42 to 5.50 and the soil density ranges from 1.1 to 1.4 gm / cc. The geotechnical properties of the Rajbandh landfill site is shown in Table 3.1.

3.3.4 Mineralogical Composition of Clay

Table 3.2 The mineralogical composition of the PSSL site
(after Roehl 2007)

Major type	*Name of the Minerals*	*Minerals (by % of weight)*	
		Sample I (0 to 0.6m)	*Sample II (1.2 to 2.0m)*
Non-clay minerals	Quartz	19	17
	Feldspars	< 1	< 1
	Carbonates	< 1	< 1
Non-Swelling clay minerals	Illite	~50	~50
	Kaolinite	~10	~10
	Chlorite	1	1-1
Swelling clay minerals	Smectite	20	19

The mineralogical composition of clay which to be used as CCL is one of the most deciding factors. The mineralogical composition of clay collected from the depth of 0 to 0.6m (Sample I) and 1.2 to 2.0m (Sample II) are shown in Table 3.2 as measured in the laboratory of the department of Applied Geology, Karlsruhe University, Germany (Roehl, 2007). The samples collected from the site were shifted to Germany and their mineralogical composition was analyzed using the X-ray Diffraction Equipment. From the result, it is observed that the clay minerals account for more than two-thirds of the mineralogical composition. The amount of swelling clay minerals is as high as 20% dominated by highly-swelling smectite. In the non-swelling clay minerals, the amount of illite is very high and found as 50%, while kaolinite is around 10% with insignificant amount of chlorite. In general, fine-grained sediments in Bangladesh appear to constitute a valuable material for geological and technical barrier for landfill. The mineralogical findings of the clay collected from New Rajbandh site have proved such postulation.

3.4 Environmental Parameters

3.4.1 Meteorological Conditions

Bangladesh is called the land of six seasons. It has a tropical climate because of its geological location. The Bangla calendar year is traditionally divided into six seasons. Each season on average two months lasting, some seasons merge into another seasons, while others are short. More broadly, Bangladesh has three distinct seasons such as the hot and dry pre-monsoon season, from March to May; the rainy season, from June to October, the cool and dry winter season, from November to February. Rainfall which takes place during this time accounts for 10 to 25% of the annual total. This rainfall is caused by thunderstorms. This rainy season coincides with the summer monsoon. Rainfall of this season accounts for 70 to 85% of the annual total. The maximum rainfall is recorded in July and August as shown in Table 3.3. There is a hydrograph shape of rainfall in Khulan region which start from April to November as shown in Figure 3.4. This is caused by the tropical depression that enters the country from the Bay of Bengal. In regard to the study of meteorological condition of the PSSL site Table 3.3 shows for five years precipitation data from 2004 to 2008 and up to August in 2009. The seasons of Bangladesh regulate its economy, communications, trade and commerce, art and culture and, in fact, the entire lifestyle of the people. The influence of the tropical monsoon climate is clearly evident in Bangladesh during the rainy season. April & May are usually the hottest month in the country caries low humidity as shown in Table 3.4.

Wind direction changes from time to time in this season, especially during its early part. January is the coldest month in Bangladesh. However, the cold winter air that moves into the country from the northwestern part of India loses much of its intensity by the time it reaches the northwestern corner of the country.

Table 3.3 Monthly Average Precipitation from 2004 to 2009 in Khulna

(Khulna Weather Station 2009)

Month	Precipitation (mm) in Year					
	2004	2005	2006	2007	2008	2009
January	000	015	000	000	067	001
February	000	000	000	054	036	006
March	007	148	005	014	048	010
April	085	047	019	092	036	023
May	180	215	246	119	151	137
June	383	103	262	392	187	233
July	253	435	522	591	301	347
August	266	194	371	160	203	570
September	621	363	603	397	379	
October	182	420	105	198	187	
November	000	000	004	113	000	
December	000	000	000	000	000	
Total	1977	1940	**2137**	2130	1595	
Average	165	162	178	177.5	132.91	

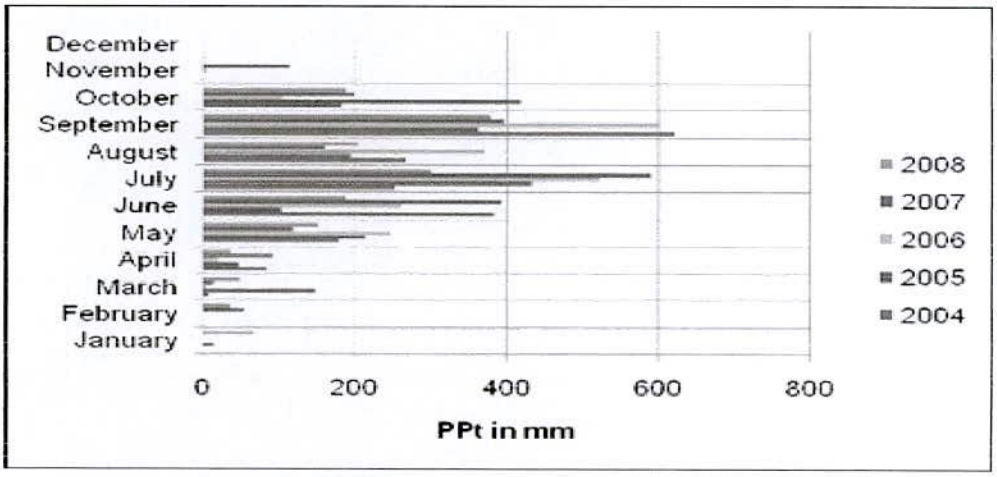


Figure 3.4 Distribution of precipitation over the year (2004 to 2008)

Average temperature in January varies from 13 to 25^{0}C in this region of the country. The minimum temperature in the Khulna City in late December and early January can be as low as 12^{0}C to 14^{0}C as shown in Table 3.5. As the winter season progresses into the pre-monsoon hot season, temperatures rise, reaching the maximum in April, which is the middle of the pre-monsoon hot season. Average temperatures in April vary from about 25^{0}C to 35^{0}C. After April, the temperature decreases slightly during the summer months, which coincides with the rainy season. Average temperatures in July vary from about 26^{0}C to 32^{0}C (Weather Station, Khulna 2008).

Table 3.4 Monthly mean humidity from 2006 to 2008 (all units are in %)

(Khulna Weather Station 2008)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2006	77	74	69	71	77	84	87	87	86	84	80	79
2007	78	77	70	75	78	82	87	84	91	89	86	80
2008	80	74	77	74	75	81	89	86	86	84	79	85

Figure 3.4 shows the distribution of rain fall throughout the year of Khulna city. Table 3.4 and 3.5 shows the monthly mean humidity and monthly mean temperature for Khulna respectively. All data are collected from weather station, Gallamari, Khulna.

Table 3.5 Monthly Temperature data from 2004 to 2008 (Khulna Weather Station 2008)

Year	2004		2005		2006		2007		2008		Average	
Month	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max**	**Min**
January	23.8	13.2	25.2	13.5	25.9	12.8	24.9	12.3	25.1	13.8	25	13.1
February	27.8	14.8	30	17.3	31.8	18.8	27.6	16.9	26.8	15.3	28.8	16.6
March	33	21.9	32.6	22.1	33.3	21.1	30.2	19.9	32.3	22.4	32.3	21.5
April	33.9	25	34.9	25.2	35	24.9	34.1	25.5	35	24.5	34.6	25
May	35.8	26.2	35.1	25.3	34.5	25.7	34.8	26.2	35.9	25.3	35.2	25.7

June	33.2	26.2	34.9	27.3	33.6	26.9	33.6	26.2	32.7	26.2	33.6	26.6
July	32.1	26.4	31.5	26.3	32.4	26.4	30.9	26.7	31.5	26.3	31.7	26.4
August	32.6	26.3	32.4	26.9	32.2	26	32.2	27.1	32.4	26.6	32.4	26.6
September	31.9	26.6	32.7	26.3	32.4	26.1	31.4	26.6	32.8	26.2	32.2	26.4
October	30.8	24.2	30.8	24.6	32.4	24.9	31	24.4	31.8	23.8	31.4	24.4
November	29.8	18.4	29	18.9	29.6	20.1	29.1	20.5	29.6	19.6	29.4	19.5
December	27.2	15.8	26.8	15.1	26.9	15	25.7	14.4	26.1	16.4	26.5	15.3

3.4.2 Air and Surface Water Quality

There is natural air in the site and the other pollutants like Respirable Particulate Matter (RPM), SO_2 and NO_2 are well within the permissible limits. A small channel of 8 m width originates beside the proposed landfill site and tangent through the site before joining the nearby River Kya flowing at about 3 km in the down stream. The residents of village and other people utilize the stream water for domestic uses, fishing and cattle washing.Critical parameters such as total dissolved solids (1560 mg/l), BOD (20 mg/l), COD (335mg/l), Total Coliforms (>600 per 100 ml), Lead (0.001 mg/l) and Cadmium (0.01 mg/l) were all found to be above the permissible limits. Further in the down stream, the quality of water in the River at the point of confluence of the stream indicates no significant levels of pollution. However, Coliforms were found in the samples, which indicate organic pollution in the river body.

3.4.3 Ground Water Hydrology and Quality

The geology of the proposed site is characterized as tropical weathered and organic aquifer and the depth of water table ranges from 2 m to 3 m. The quality of ground water in the project area (based on sample analysis beside the proposed site) indicates the presence of iron, chloride and traces of heavy metals. The downstream ground water is however acidic in nature (pH of about 6.3).

3.4.4 Ecological Environment

Coconut plantations are the predominant types of vegetation found at the proposed landfill site. The ecological inventory of the site indicated no endangered species at the proposed site. There are approximately various species of vascular plants belonging to the botanical families, of which about major species represent Angiosperms and some species represent Pteridophytes. Poaceae, Leguminosae, Asteraceae, Moraceae, Euphorbiaceae, Rubiaceae, Amaranthaceae, Apocynaceae, Malvaceae, Arecaceae, Labiatae, and Verbenaceae are the top 10 families in the order of dominance. With regards to fauna, four species of amphibians, ten species of reptiles, seven species of mammals, ten species of birds and many species of insects can be found at the site and its influence area.

3.5 Health and Safety

The design has produced a pilot scale sanitary landfill which does not threaten the health and safety of nearby inhabitants and which in general precludes the following:

a. Pollution of surface and ground-waters from landfill generated leachate.

b. Air pollution from dust or smoke.

c. Infestation by rats, flies or other vermin.

d. Other nuisance factors such as odors and noise.

e. Fires and combustion of refuse materials.

f. Explosive hazards from methane gas generated within the landfill.

3.6 Volume Minimization

Reducing the need for a landfill should be a priority for all installations. The type and extent of compaction should be considered in design to reduce landfill volume. Recycling and other methods of reducing landfill volume are discussed elsewhere in this report.

3.7 Conceptual Designs of Landfill Components

In the cities of Least Developed Asian Countries (LDACs), city authorities have been facing the challenges to run a sustainable integrated management of municipal solid waste (MSW). The challenges have become unattainable despite the huge demand from the city dwellers due to poor governmental policy and response, lack of political will, inadequate economic and human resources, weak local institutions and the absence of appropriate management system. As a result the generated MSW remains unmanaged and unsafe and poised serious threat to human health and nature. In a consequence, the environmental sustainability in most of the cities of LDACs could not be achieved. Due to very high population density in the cities of Bangladesh and huge gap between the existing and the appropriate systems of MSW management, in the recent time waste management becomes one of the most striking environmental issues which need to address properly.

In the existing MSW management of Bangladesh, no engineering approach is followed for the ultimate disposal of waste. Crude open dumping of all types of solid waste in low-lying areas is the common practiced. However, recently the relevant stakeholders including city authority have realized the need of the construction of engineered landfill to replace the open dump. In Bangladesh, except Matuail Engineered Landfill at Dhaka in which the open dumping was converted engineered landfill with help of JICA (Japan International Cooperation Agency), there is no experience of the construction, daily operation and performance evaluation of sanitary landfill. In the footsteps, a pilot scale sanitary landfill have been constructing in Khulna Bangladesh as part of research project, WasteSafe II, at Khulna University of engineering & technology, Bangladesh co-financed by EU-Asia Pro Eco II Programme of the European Commission. In the main aim of this field research work is to establish the landfill standard for Bangladesh condition.

To this endeavor, a Pilot Scale Sanitary Landfill (PSSL) was designed and hence constructed at New Rajbandh, Khulna (Alamgir et al. 2008, Alamgir and Islam 2009). A simple version of sanitary landfill was design ensuring minimum basic technical requirements. In the design emphasis has been given to use the locally available construction techniques, equipments and building materials. In earth excavation, construction of various components of the landfill such as approach road, site office, base liner and leachate collection system, leachate holding tank, leachate treatment pond etc. the above principle was fully accomplished (WasteSafe II 2007 and 2008). Moreover, in every phase of PSSL construction such as material processing, maintaining of slope, placement, remolding and compaction work of earth, manual labors were used where female participant was viewed a focus because 70% of labors were female. In every steps of construction, closing monitoring was given to ensure the quality control of the works. During the daily operation, composition and quantity of MSW, the amount and quality of leachate generated from MSW have been recorded. A small scale leachate treatment system has also been introduced in the site to identify the suitable technique. It is expected that the PSSL will be closed at the middle of 2009 and the post closure monitoring will be conducted accordingly.

Despite a PSSL, this is the second experience in Bangladesh after the Matuail's one (Ahmed 2008), where the Dhaka City Corporation has been developing an engineered landfill in semi aerobic method by converting the existing open dumping site. In case of PSSL, it is observed that using of locally available construction materials, methods and manual labor intensively, the landfill can be constructed successfully with major necessary components such as base liner, leachate detection and collection system, ground water monitoring well and the small scale leachate treatment installation. Experiments have also been conducting to see the performance of CCL used in base liner and the small scale leachate treatment facilities. The field experience acquired in the construction of this PSSL depict that sanitary landfill in full scale can be constructed using local building materials and present technological capabilities by satisfying the first hand technical requirements. Moreover, this attempt will build the confidence among the local consultants, engineers and authorities to go ahead with full scale replication of the employed technique to build a sanitary landfill with accomplishment of necessary modification.

3.7.1 Overview of Pilot Scale Sanitary Landfill

A suitable location for the construct of PSSL has been selected. The overview of the site, location, sub-soil conditions and the nature of solid waste to be deposited in the PSSL are discussed here in the following sections. It was decided by the WasteSafe II Team member to select a site in the ultimate disposal site (UDS) of KCC at Rajbandh for the construction of PSSL. In the Rajbandh, there are two sites used as UDS by KCC as crude open dumping of solid waste generated in the Khulna city, one is known as 'Old Rajbandh' and the other is 'New Rajbandh'. The Old Rajbandh having an area of 20 acres is located about 8km far from the city centre i.e. 'Royal-Castle Salam Square' of Khulna city and situated along

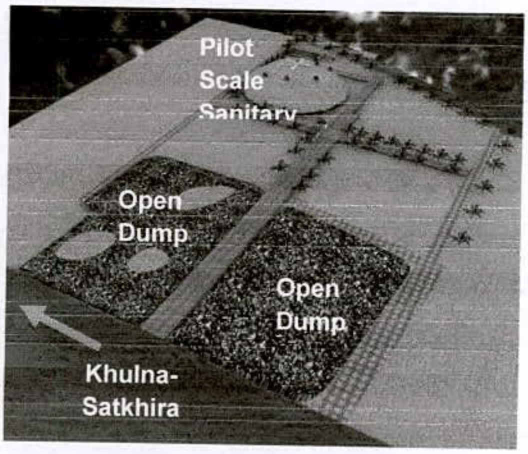


Figure 3.5 Layout of PSSL at New Rajbandh

the North-side of Khulna-Satkhira highway. The New Rajbandh the second UDS site of MSW of KCC, having an area of 5 acres is just 700m west from the Old Rajbandh. KCC started to dump waste in Old Rajbandh in 1977. Later, KCC acquire this land for UDS and later converted to Children Park.

The New Rajbandh consists of 5 cells (shallow depth pond) surrounded by earthen embankment, where paddy plantation and fish cultivation were continued till the waste deposition started. However, still it has significant capacity to accommodate the solid waste. Despite the Old Rajbandh filled-up partially with solid wastes, KCC started to dump wastes in the New Rajbandh since January 2007 and first two cell cells along the Khulna-Satkhira Highway were started to fill as shown in Figure 3.5. The site of the PSSL is located at the north-west corner with an area of 1.1acres. This location for PSSL was selected based on the series of site visit and the discussion with KCC team members. Since, the wastes deposition as open dumping was already started in the first two cells (Shallow ponds), the last corner was selected to avoid all the possible interferences due to open dumping. The corner pond is surrounded by earthen embankment and located at distance of 122m from the Khulna-Satkhira Road. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 64mx55m. There is a public natural stream in the North side and private paddy land in the west (Islam and Alamgir et. al.,2009).

3.7.2 Design Criteria

To establish an appropriate construction technology of landfill for Bangladesh conditions using local building materials and available technological capabilities and facilities, the pilot scale sanitary landfill has designed at New Rajbandh, Khulna. Analysis and design of PSSL was completed by WasteSafe II Team members within December, 2007 (WasteSafe II, 2008). Despite a pilot scale sanitary landfill cell, the WasteSafe II Team decided to consider all the relevant aspects of a standard sanitary landfill while designing the cell and the components. Emphasis is also given for the best use of locally available building materials and construction techniques. However, scientific an technical considerations, guided by field experiences, are given while fixing up the dimensions and materials specification of the various components of the landfill. The PSSL consists of the main components of a standard landfill such as (i) Waste deposition cell, (ii) Compacted clay liner on a geological barrier with a drainage layer on top (iii) Top Cover with compacted clay liner, drainage layer, top soil as vegetation cover, surface run-off and percolated water collection system, (iv) Gas measurement and management facility, (v) Leachate detection and collection system with leachate holding tank, (vi) Leachate pond with leachate treatment facility, (vii) Vehicle inspection and washing facility, (viii) Access Road and Site office, (ix) On-going and post closure monitoring facilities.

Analysis and Design of the PSSL was completed by WasteSafe Team members by December 2007 guided by field experiences, local condition and project provision while fixing up the dimensions and materials specification of the various components of the landfill. The MSW collected from Khulna city will be deposited in shortest possible time with moderate compaction efforts. It is decided to follow the standard landfill operation system with local perspectives will be followed during the construction, waste deposition and operation, and monitoring phases. Post closure monitoring will be conducted till the end of the project, which will be continued by KUET till the active period of the landfill The size of the waste containment is 50mx50mx6m, which is 3m below and 3m above the ground surface with a side slope of 26° the schematic diagram is presented in Figure 5.2. The base liner, the most important component, includes a leak detection sump system, compacted clay liner, leachate collection pipe system with a leachate collection layer. It is designed considering hydrological data of the site, the size of landfill, suitability of construction and locally available of material. The base liner has a 400mm thick of CCL just above the geological barrier of 15m clay deposits, over which 200mm thick sand layer as drainage layer. Leachate collection pipe is placed in the drainage layer, while the leachate detection pipe is placed just below the CCL. The generated leachate will be stored in leachate holding tank of 2mx2mx4m and later transfer to the leachate treatment pond of 10mx20mx3.5m. The system is designed in such a way so that the leachate can be collected and thus stored in the tank through gravity flow. The leachate detection pipe is also designed and connected in the leachate holding tank by ensuring gravity flow. From tank the leachate will be transferred to the pond using pump.

The final cover of PSSL as shown in Figure 4.16, consists of top soils, percolation water collection layer, compacted clay liner and gas collection pipe system with gas collection layer. The inclusion of biofilter for methane oxidation is kept as possible inclusion in the top cover. The top has gas collection layer at the top of 0.20m thick just over the waste, then 0.30m CCL, 0.15m fine sand and 0.15m sand plus brick aggregates as percolation and drainage layer which is followed by 0.60m top soil. The combination of fine sand layer and then sand and brick aggregates is given to ensure capillary rise of water for the keeping CCL wet as much as possible to prevent possible desiccation and cracking. Top soil layer of 0.60m thick will help to support and maintain the growth of vegetation by retaining moisture and providing nutrients. There is a Leachate Recirculation System that will maintain moisture and enhance degradation of waste. To control possible soil erosion, mild slope is maintained at the top cover, which is 15° at the edge to middle and then 7° from middle to top (Alamgir et. al., 2009).

3.7.3 Capacity of PSSL

The land available at the Rajbandh site for development of the landfill is approximately 5 acres and one acre of land is accepted for PSSL site. The foot print of the site is shown in figure 3.6.With 40 ton of trash to fill daily, the life of the landfill has been estimated at 6 months. The landfill area has been divided into 3 parts as indicated figure 3.7 below:

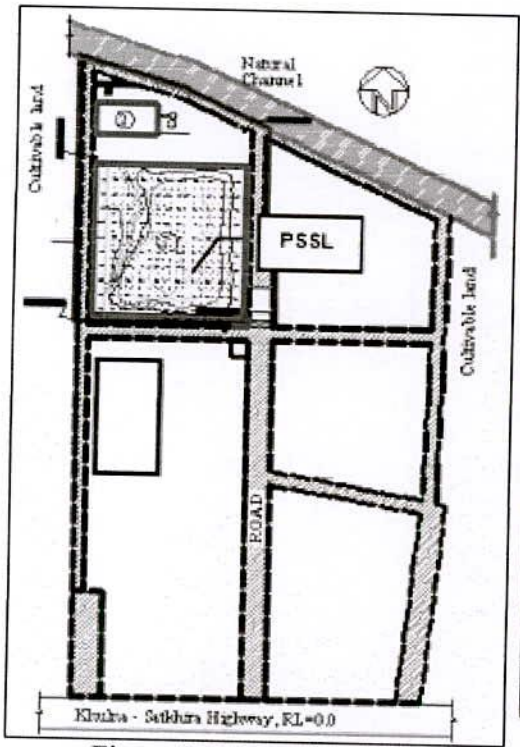


Figure 3.6 Foot print of the site

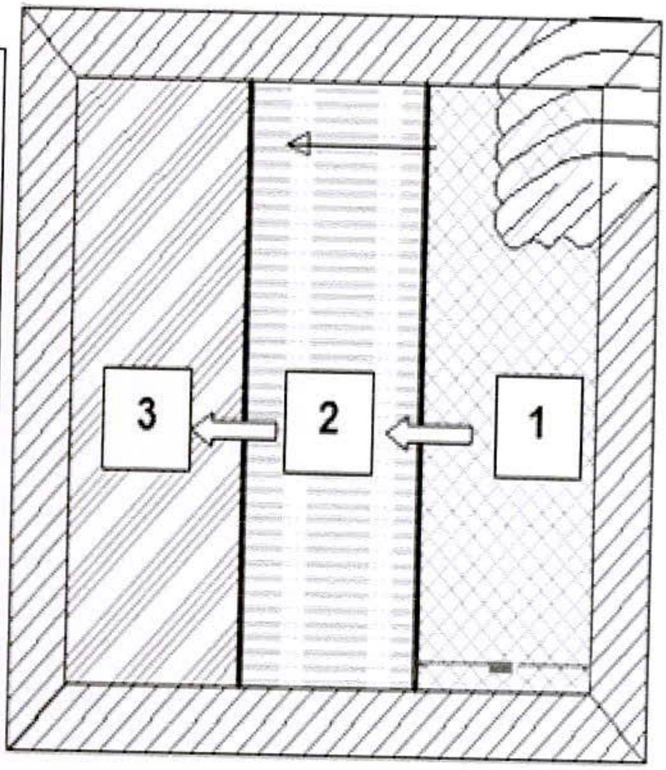


Figure 3.7 Parts of landfill

3.7.4 Cross Section of Pilot Scale Sanitary Landfill

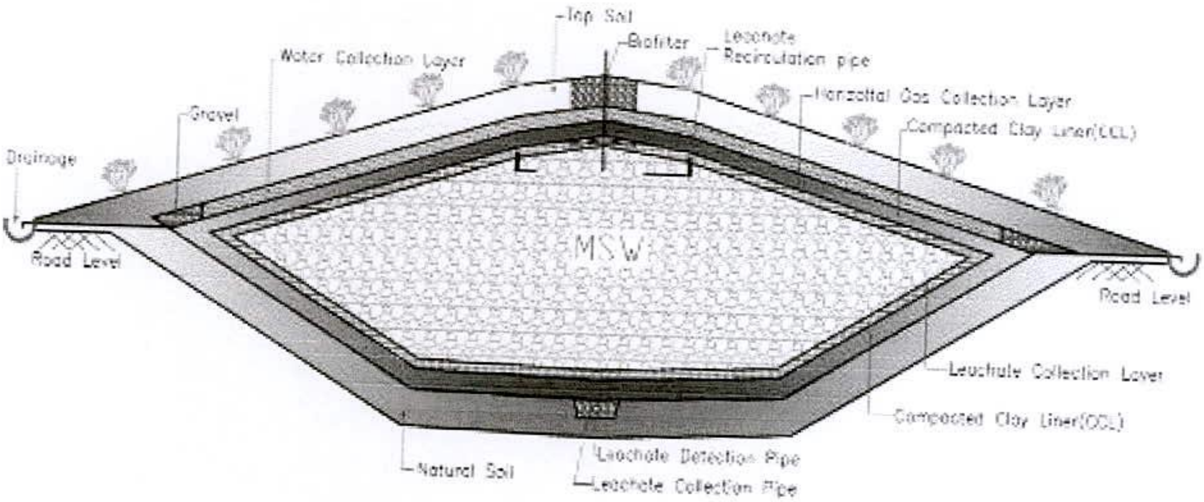


Figure 3.8 Schematic diagram of the containment of pilot scale sanitary landfill

In the experimental study, the size of containment is control by several physical and technical factors. The factors can be listed as: (i) land availability, (ii) time frame of the study, (iii) fund, (iv) technical capacity, (v) daily waste streams, etc. Considering the above mentioned aspect, the team decided to construct a waste containment is 50mx50mx6m, which is 3m below and 3m above the ground surface with a side slope of 26^{o}, which gently maintained a horizontal distance of 4.25m and following a mild slope till the middle of the cell. The schematic diagram is presented in Figure 3.8. In the top cover, to control possible soil erosion, two slopes are introduced, at the edge a slope of 15^{o} from the edge to the half of the top.

CHAPTER FOUR

PILOT SCALE SANITARY LANDFILL OPERATION

4.1 Introduction

The Pilot Scale Sanitary Landfill has constructed and being operated to establish landfill construction technology in Bangladesh. Locally available construction techniques, equipments and building materials were used for the excavation of earth, construction of various components of the landfill such as approach road, site office, base liner and leachate collection system, leachate holding tank, leachate treatment tank etc. In every phase of PSSL construction such as material processing, maintaining slope, placement, remolding and compaction work manual labors are used where female participant was viewed a focus because 70% of labors were female. The deposition of waste has been monitoring and other necessary aspects have been controlling to ensure the quality management of daily operation. In spite of a pilot scale sanitary landfill, this is the second experience of the construction of sanitary landfill in Bangladesh. It is observed that using locally available construction materials and methods using manual labor intensively, the sanitary landfill can be constructed successfully with necessary components such as compacted clay liner, leachate detection and collection system. This small scale but real experience using indigenous method will provide confidence to the city authority and the concerned stakeholders about landfill technology in the contrast of presently practicing crude open dumping.

This PSSL is the first of this kind of construction in Bangladesh. The construction works have been conducted based on the design ensuring close monitoring by the project engineer. Another important aspect is that the locally available construction techniques, equipments and building materials were used for the earth excavation, construction of various components of the landfill such as inspection point, base liner, leachate collection and detection systems, leachate holding tank, leachate pond and the small scale leachate treatment option.

4.2 Inauguration Ceremony of PSSL Operation

An open tender for the construction of the PSSL was published on January 03, 2008 by KCC in the major local and national both the English and Bengali newspapers. It also launches in the website: www.wastesafe.org. The tender documents kept available both in KCC and KUET for the interested bidder. The closing date for the submission of document was 27 Jan., while the opening date was 28 Jan. 2008. Meeting of Technical Evaluation Committee was held at KCC Bhaban, Khulna on 22nd February 2008. Among the four bidders for the construction of pilot scale sanitary landfill, considering all the relevant aspects, it was decided to select the lowest bidder for the construction works. None of the firm has the experience of the construction of sanitary landfill. However, acknowledging the reality and the volume of works, selection was made. The work order was given to the selected construction company on March 12, 2008 and the construction works started on March 19, 2008. Then the construction works was completed as per the schedule and prepared for waste deposition. The operation of Pilot Scale Sanitary Landfill has began 11th July 2008 in presence waste safe ii research persons and KCC authority person (Figure 4.1).

Figure 4.1 Inauguration ceremony of PSSL operation

4.3 Plan Layout, Site Preparation and Construction Steps

Operating procedures at a sanitary landfill are determined by many factors, which vary from site. The landfill operational plan prepared as a part of the design procedure serves as the primary resource document, providing the technical details of the landfill and procedures for constructing the various engineered elements. Figure 4.2 has shown layout plan of Pilot Scale Sanitary Landfill. Operating procedure must be noted so that an accurate record is maintained. Site preparation and construction steps are given below:

1. Clear site.
2. Remove and stockpile topsoil.
3. Construct berms.
4. Install drainage improvements
5. Excavate fill areas.
6. Stockpile daily cover materials.
7. Install environmental protection facilities
   a. landfill liner with leachate collection system,
   b. groundwater monitoring system, gas control equipment and gas monitoring equipment.
8. Prepare access roads.
9. Construct support facilities:
   a. Service building,
   b. Employee facilities,
   c. Weigh scale, and
   d. Fueling facilities.
10. Install utilities:
    a. Electricity
    b. Water
    c. Sewage, and
    d. Telephone

11. Construct fencing:
    a. Perimeter
    b. Entrance
    c. Gate and entrance sing, and
    d. Litter control
12. Prepare construction documentation

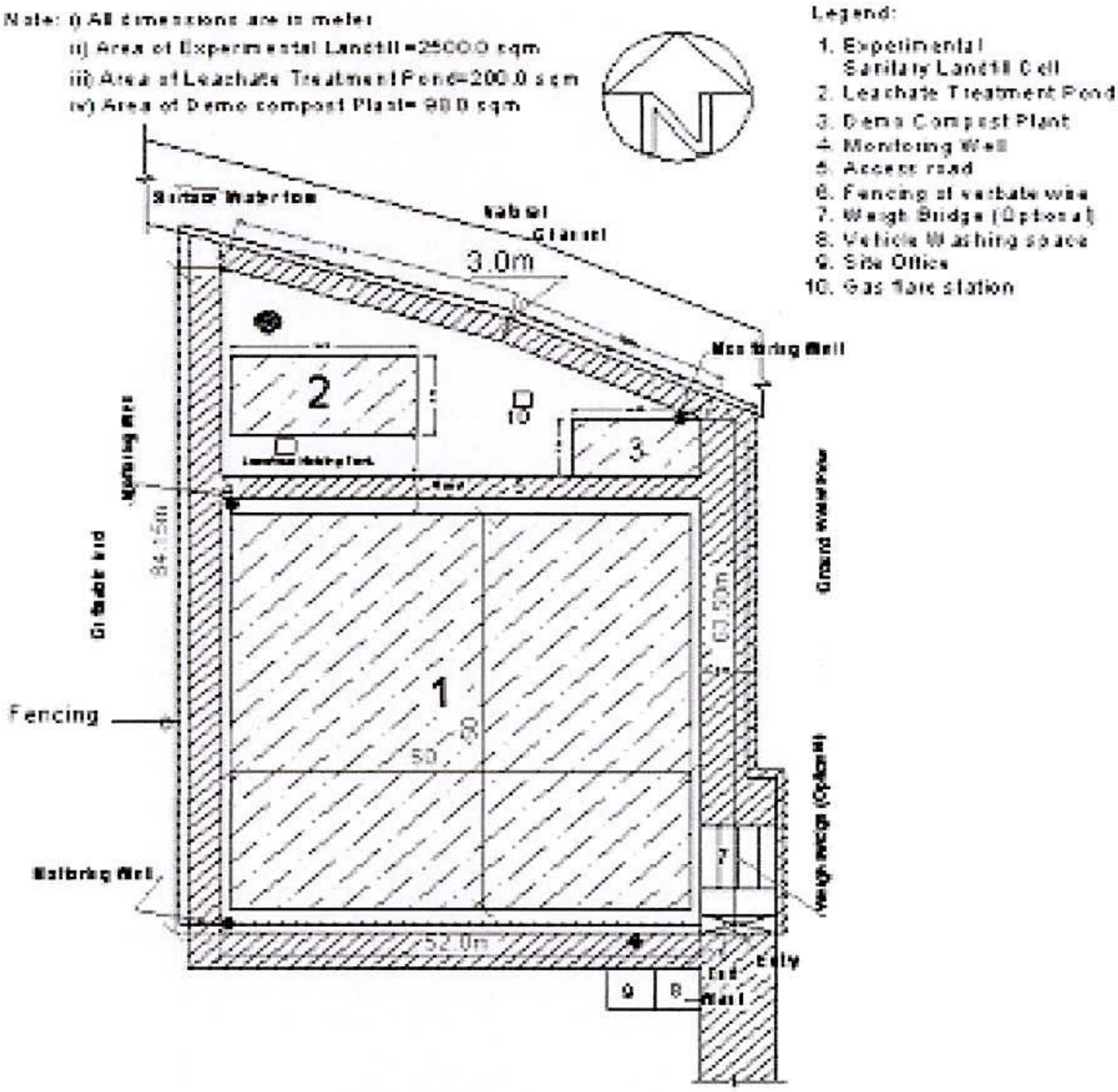


Figure 4.2 Lay out Plan of Pilot Scale Sanitary Landfill

4.4 Action Plan of PSSL Operation

Operation procedures of a sanitary landfill are determined by many factors, which vary from site to site. The plan of landfill operation is prepared as a part of the design procedures serve as the primary resource document, providing the technical details of the landfill and procedures for constructing the various engineered elements. While landfills may outwardly appear simple, they need to operate carefully and follow specific guidelines that include where to start filling, wind direction, the type of equipment used, method of filling, roadways to and within the landfill, the angle of slope of cell, controlling contact of the waste with ground water, and the handling of equipment at the landfill site. In the operation of PSSL, the local conditions are considered in every stage. However, it is also intended to follows the standard landfill operation aspects. The major components of landfill operation as followed in the PSSL are discussed in the following section.

4.4.1 Inspection of Incoming Waste and Vehicle Recording

MSW generated in KCC areas has been deposited in the PSSL. The incoming waste carrying vehicles are being counted; volume of waste measured roughly and then weight measured indirectly unit weight method, and hence recorded properly in the site office of PSSL. The plan area of the site office is 54 m^2 as shown in Figure 4.3 constructed using locally available materials and located just beside of control gate. Waste carrying vehicle which is entered in the PSSL has inspected and a registered book is maintained for recording all the vehicles. There are different types of waste carrying vehicles entered into the PSSL. It can be divided three categories; small, medium and large by volume of waste carrying as 3.00 to 4.5, 6.44 to 6.80 and 7.94 m^3 respectively. Control gate of vehicle and inspection of waste in the PSSL has shown in Figure 4.4 which is maintained manually by using as colored bamboo

Figure 4.3 Site office beside the PSSL

stick placed transversely to the entrance road. The sample of the site office record keeping which has maintained in the site office is shown in table 4.1.

Figure 4.4 Control and inspection of waste in the PSSL

Table 4.1 Example data of the site office record keeping

Date	Vehicle information		Waste in % of vehicle vol.	Vehicle Vol.(m^3)	Unit weight (k.g./m^3)	Amount of waste (kg)	Remarks
	Sl.No.	Vehicle No.					
11.07.2008	1	SA-110020	100	7.94	600	4764	
	2	SA-110008	100	6.75	600	4050	

4.4.2 Waste Weighting

Waste weighting is important part of landfill operation, because the capacity of landfill has designed. Waste weighting can be easily done by Weigh Bridge. But there is no facility of Weigh Bridge. It has done in eye inspection and some procedure maintained. At first it has recorded the volume waste carrying vehicle. In Table 4.2 has shown vehicle volume specification in the landfill used.

Table 4.2 Vehicle volume specifications

Vehicle Type	Dimension			Volume (m^3)
	Length (m)	Breath (m)	Height (m)	
TATA-01, TATA-02	3.66	2.14	0.76	5.95
TATA-03, TATA-04	3.46	2.13	0.61	4.50
HINO-01, HINO-02, HINO-03	4.10	2.28	0.76	7.08
SA-110013 SA-110014 SA-110017 SA-110023 SA-110027	3.96	2.14	0.76	6.44
SA-110015 SA-110016	3.40	1.85	0.48	3.00
SA-110019 SA-110020	4.27	2.27	0.82	7.94
SA-110021 SA-110022	3.05	1.98	0.61	3.70
SA-110024	4.57	2.44	0.61	6.80
SA-110006 SA-110008 SA-110009 SA-110010	Carrying a Deck which is trapezoidal. Volume of the Deck = 0.5*(3.05+2.20)*3.00*0.86 = 6.75 m^3			6.75
SA-110025 SA-110026	Carrying double Deck which is trapezoidal. Volume of each Deck = 0.5*(3.05+2.89)*2.87 = 6.50 m^3			13.00

Landfill operator has supervised the waste carrying vehicle and it has recorded the volume of waste in eye view. The unit weight of waste has measured under every fifteen days which has shown in Annex c. Finally it has measured weight of waste by multiplying unit weight of waste and the volume of waste. The record file has maintained in the site office.

4.4.3 Compaction and Waste Plantation

In the beginning of waste deposition in the PSSL, waste was spreading manually, latter KCC's vehicle such as Back-Wheel Compactor Cum Excavator and Chain-Dozer has employed. In some instances, for convenience, manual labor and compactor worked together for waste spreading and compaction. The spreading and compaction of waste in the PSSL has shown in Figure 4.5. It is observed that due the presence of high moisture content, bio-degradable nature of waste, waste volume decreased noticeably. It is also observed that waste spreading and subsequent compaction becomes very difficult due to the presence of high water content. The movement of mechanized vehicle is difficult due to smaller plan area and the presence of very soft soil beneath the adjacent approach road. Moreover, smooth spreading is not possible. Therefore, difficulties arrive during the waste spread and compaction process, which eventually developed the waste deposition activities.

Figure 4.5 Waste spreading and compaction operation at the PSSL

4.4.4 Vehicle Washing Facilities

After waste deposition in the landfill, the vehicle has gone over washing platform. Then it has washed manually. The size of the platform is 6mx7.5m constructed using very rich RCC pavement. It has done the out going vehicle to prevent any possible littering of waste while running out in the street. The vehicle washing during PSSL operation is shown in Figure 4.6.

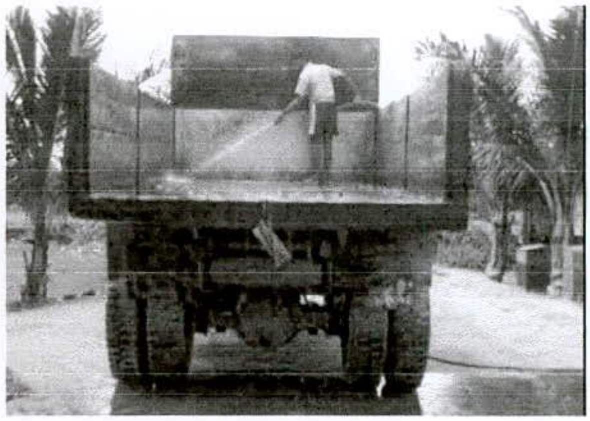


Figure 4.6 Vehicle washing practices during PSSL operation

4.4.5 Daily Waste Cover

Daily cover material has applied in the PSSL, as necessary to minimize fire hazards, odors, blowing litter, vector food and harborage; control gas venting and infiltration of precipitation; discourage scavenging; and has provide an aesthetic appearance. At the beginning of PSSL, Polythene sheet has used as temporary daily cover during monsoon and later, local sand is used as daily cover. Sand has also convenience for the movement of waste transport vehicles and compaction machinery. The practice of covering the waste is shown in Figure 4.7. However, the use of polythene does not work as expected.

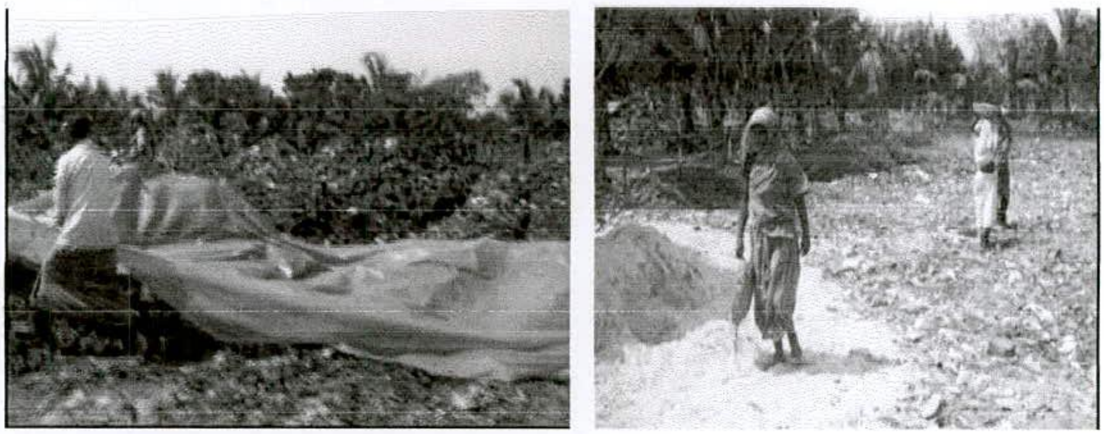


Figure 4.7 Daily Cover: (a) Polythene sheet and (b) Sand layer.

4.4.6 Waste deposition

Figure 4.8 First minute of MSW deposition

Waste deposition in the PSSL site is steeply dipping un-compacted layer. Later spreading of waste and compaction has done together. The deposition of waste in a landfill has a major influence on the chemical reaction and conditions in the landfill. It has high permeability, there is rapid infiltration and percolation of water, and prevails an aerobic condition. The first minute of MSW deposited in the PSSL has shown in Figure 4.8. During 14 months landfill operation, 11790 tons of waste has already been deposited in the landfill.

4.4.7 Physical Characteristics of Waste

Municipal Solid Waste (MSW) is the heterogeneous composition of wastes, organic an inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non hazardous, generated in various sources in urban area due to human activities. Its composition, characteristics and generation largely depends on geographical location, socio-economic settings, living standards, and food habits and peoples awareness. The type of waste has determined by physical characteristics of waste. It has done manually under every month. The physical characteristics data of waste has shown in Annex D. The typical composition is shown in Figure 4.9, which represents the percentage of solid waste as food, vegetable & bio waste 89%, plastics 3%, demolition 6% and others 2%.

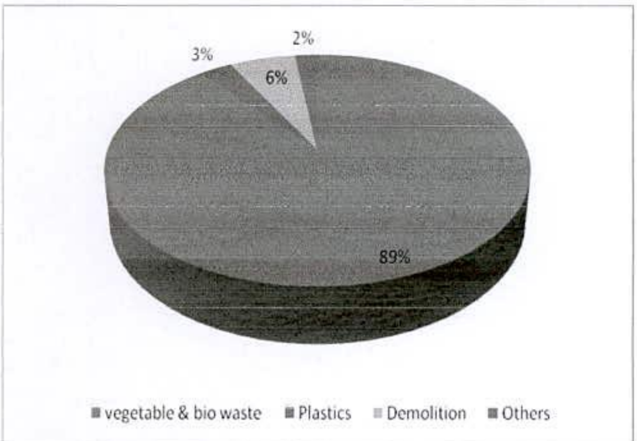


Figure 4.9 Composition of MSW in landfill

4.5 Operation Maintenance

A safe design of landfill is barely enough to ensure the safety of the public and the environment protection, it requires a well-managed operation.

4.5.1 Waste Identification and Restriction

Landfill operators have identified different type of waste that is entering the landfill. This is to prevent hazardous waste from being delivered and co-disposed with other municipal solid waste at the landfill. They have been authorized to reject any waste until it is identified to be safe and acceptable at the landfill site.

4.5.2 Approach Road Maintenance

Approach road is very important for safe waste deposition. Heavy vehicles are utilized in the landfill site during waste deposition and compaction. For being this purpose approach road of landfill site is partially damaged. End of daily waste deposition approach road has maintained by the site office labor. Here is utilized a lots of bats and sand which has stocked in the landfill site.

4.5.3 Safety

The operation has implemented in a way that not threaten the workers' health and safety. They are well informed with the risks and associated symptoms due to exposure to various types of waste especially hazardous waste. Protective equipment has provided to the site workers and public access is restricted in order to minimize the risks.

4.5.4 Tools

In the PSSL operation different types of equipments used as safety measure, landfilling and compaction, operational maintenance purpose. Also different types locally made equipment used for convenience. It is necessary to maintain landfill equipment for safe and undisturbed disposal and also cost effective purpose. A different type of maintaining operation has done as cleaning, washing and repairing of equipments at the end of daily operation.

4.5.5 External Infrastructures and Landfill Infrastructures

Landfill internal and external infrastructure has maintained under daily supervision work. Site office, monitoring well, leachate pond and the landfill area are the main internal infrastructures which also a component of PSSL. For safe of the landfill and worker it has maintained carefully. External infrastructure, such as fencing of the PSSL site is important for protect excavengers, animals etc. has maintained by the site office workers for environment safe landfilling.

4.5.6 Litter and fire control

Litter does not seriously damage the environment, yet it is perhaps the most persistent operational problem cited by surveys. Lt's seriousness is due, in part, to bad public image. Waste discharging procedures, orientation of the working face to the wind, existence or absence of nearby wind shielding features, and waste type and preparation all play a role in solving the litter control problem. Unloading wastes at the bottom of the working face can help. Here the wind cannot pick up materials as easily as when wastes are deposited at the top of the working face. Portable fences are often used to catch the litter, followed by manual cleaning of the litter fence and the area downwind of the working face Dust also a nuisance at landfills, both to employees and neighbors. Water has used to control dust. Fires within the waste are best controlled by digging out the combusting material and covering it with dirt. Fire control equipment has readily available in the site office. Water wagon equipment can also be used for fire control.

4.5.7 Control of Scavenger and Vectors

Scavenging are conducted most of the open dumping sites in Bangladesh by the poor street children, which looks very difficult to control even in the PSSL through strong inspection. However, attempts have been taken to discourage people for such kind of unhygienic works.

Figure 4.10 Locally made sound system and kaktadua used in the PSSL

Another difficult task is to prevent birds, dogs and other vectors to enter into the site. A local traditional system, known as Kaktadua and a sound system is for controlling animal and birds (Figure 4.10). This is concern for spreading germs and different types of disease. Fencing of the PSSL site is also to prevent entry of general people.

4.6 Leachate Management and the Monsoon

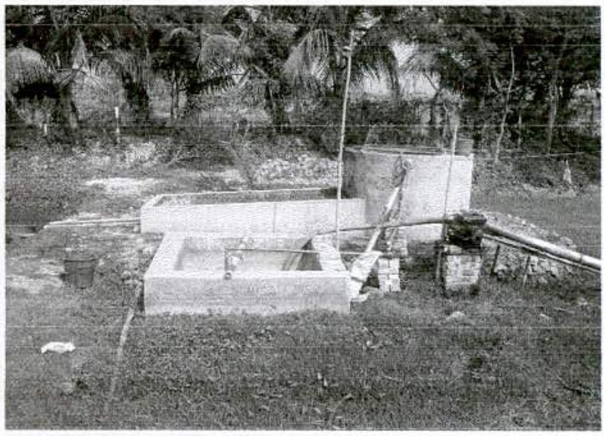


Figure 4.11 Leachate holding tank beside the PSSL

Leachate is considered to be a contaminated liquid; it contains many dissolved and suspended materials. Good management techniques that can limit adverse impact of leachate on ground and surface waters include control of leachate production and discharge from a landfill, and collection of leachate with final treatment and/or disposal. The leachate which is generated in the PSSL is stored in the leachate holding tank (Figure 4.11) through the leachate collection pipe and then it has transferred to the leachate pond (Figure 4.12). During heavy rain in monsoon, a huge amount of leachate is generated that is pumped out in the nearby reservoir ponds of PSSL because of the difficulties of the operation has shown in Figure 4.13. The leachate has generated in the PSSL is about 70,00000 liters due to heavy rain which is measured as pumping hour and then convert into liters. The pumping hour of 0.5 cusec pump is about 147 hour. For that reason landfill operation is greatly hampered and delayed. Only a small scale treatment plant was made for partial treatment but it was not enough to treat that huge leachate. In this field experiences, it has revealed that adequate drainage system is required to

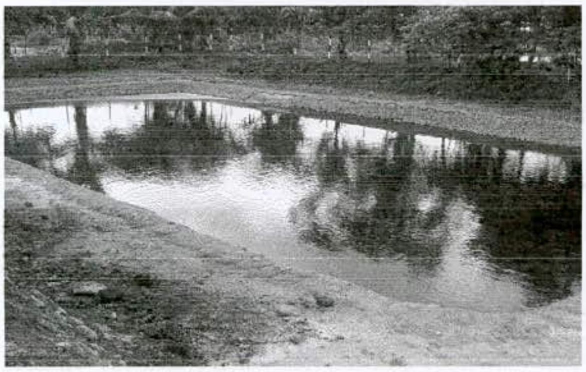


Figure 4.12 Leachate pond in the PSSL

Figure 4.13 Leachate reservoir during monsoon

control the heavy monsoon rain and to protect the direct rain infiltration in the PSSL. The experience reveals that in the landfill (constructed in Bangladesh) special cell should be considered to accommodate precipitation only in the rainy season just to avoid the enter of huge amount of rain water in the Landfill, otherwise it would be very difficult and hence expensive also to manage and treat the large volume of leachate. This can be a very interesting further research works.

4.7 Supervision and Monitoring

a. General.

Monitoring is an essential activity in establishing, operating, and closing a solid waste landfill disposal facility. Monitoring has coordinated with local environment office management activities. Landfill disposal facilities has monitored as follows for the purpose of determining if and when a contingency remedial action plan should be implemented to correct an environmental problem. All enclosed structures at a landfill disposal facility is monitored regularly to detect accumulations of explosive gassed such as methane.

b. Ground-water.

A ground-water monitoring well is installed at all landfill disposal facilities for checking contamination of leachate which have the potential for generating substantial quantities of leachate in the landfill. Samples from monitoring wells have collected and analyzed in order to obtain baseline data on existing ground water conditions. Figure 4.14 has shown ground water monitoring well. Samples have collected from all monitoring wells and analyzes at least every six months. Monitoring well water and leachate has examined in the laboratory which has shown in Appendix F.

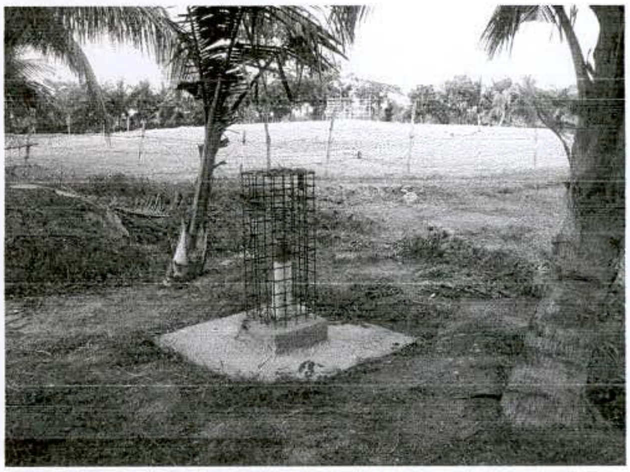


Figure 4.14 Ground water monitoring well

d. Landfill gas monitoring

When final covering of the landfill site it is installed a gas ventilating pipe which is capped. After completion of the landfill site it is monitored gas production in the landfill cell in every three months. Landfill gas monitoring pipe has shown in Figure 4.15.

Figure 4.15 Landfill gas monitoring pipe

4.8 Top Covering of PSSL operation

Finally when the landfills are full, it is covered with a low permeable cap in order to prevent the rainwater from filtering through and mix with the waste which would lead to more leachate production. A final cover or cap is important in landfill design too. In the landfill site's soil is used for final cover, it is suitable to prevent infiltration and promote runoff and evaporation. In Figure 4.16 has shown in schematic diagram of top covering of PSSL. Gas ventilation pipe set up with top covering of PSSL has shown in Figure 4.17.

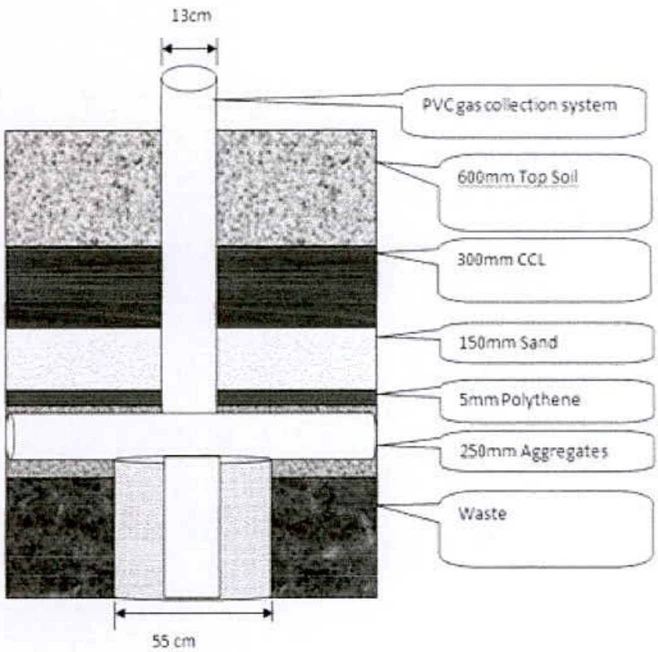


Figure 4.16 Schematic diagram of the Top Cover

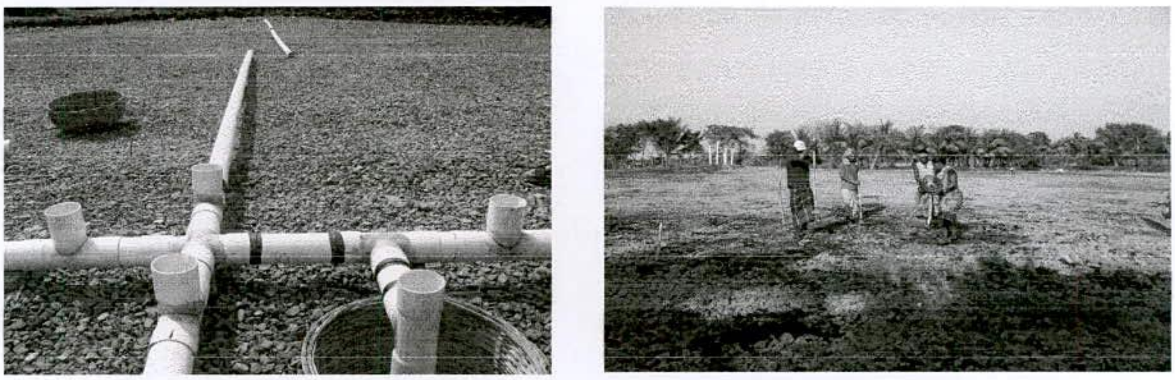


Figure 4.17 Top covering of PSSL with Gas Ventilation Pipe

4.9 Complete Landfill Use

After completion of Landfill, it is prepared for agriculture. Labor is utilized to culture vegetable in the landfill and trees are planted. The landfill site office man watered it regularly. In Figure 4.18 has shown the PSSL used for agriculture and Landscaping.

Figure 4.18 PSSL use for agriculture and landscaping

4.10 Post-closure Maintenance of Completed Areas

a. Inspection of Completed Areas

The landfill supervisor inspects completed areas of the landfill once a month for signs of cracks and depressions due to settlement.

b. Cracks and Depression

Cracks and depressions are filled with compacted soil when it is noticed.

4.11 Labor

In landfill operation it is used ten labors for maintenance of access road, landfill infrastructures, waste spreading along with chain dozer and compacter, vehicle washing etc. Safety measure is used during landfill operation and they are well informed about sanitary measures of landfill operation. In landfill operation it is noticeable that seventy percent of labors are women.

4.12 Equipment

Equipment has used at PSSL into four functional categories: waste movement and compaction, cover transport, placement and compaction, and support functions. Coordination of equipment is essential for proper operation of sanitary landfill. Conventional earth moving equipment, including scrapers, bulldozers, excavators, trucks, and other supporting instrument has employed at PSSL. Equipment maintenance is clearly an important task. Regular maintenance can reduce repair problems before more costly and time consuming repairs are needed. The equipments are used in the PSSL is shown in table 3.

Table 4.3 List of equipments during operation of the PSSL.

Name of equipment	Quantity	Owner
Truck	Avg.10 to 15 nos	KCC
Pay loader cum excavator	1 no	KCC
Chain dozer	1 no	KCC
Motor	1 no	PSSL
Scraper	10 nos	PSSL
Scales	1 set	PSSL
Safety gloves	50no.	PSSL
Gumboot	15 pairs	PSSL
Tube well	1 no	PSSL
Basket	10 nos	PSSL
Polythene	2 roles	PSSL
PVC Pipe	50m	PSSL

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

Landfills are part of an integrated system for the management of MSW. When carefully designed and well managed within the context of the local infrastructure and available resources, landfills can provide safe and cost-effective disposal of a city's MSW. Nevertheless, municipal landfills, whether controlled dumps or sanitary landfills, should not be treated as panaceas for deficiencies in the region's overall waste management needs. Landfills are not designed for the routine disposal of industrial or hazardous waste, used oil, or other special wastes. If they are consistently pushed beyond their design limits, landfills, like any other engineered system, will fail. Such failure can have dire consequences for human health and the environment as the landfill then degrades into a potentially toxic open dump.

An integrated MSWM system may prioritize its waste management options according to waste minimization, materials recovery/recycling, composting, incineration, and landfilling. Incineration is only a sound management practice under particular conditions. At present, these generally do not occur in MSWM systems with limited capital and technical resources. All the other components of the integrated approach can improve landfill operations and extend the life of the facility.

Waste minimization or source reduction focuses on reducing the quantity and potential toxicity of MSW destined for the landfill. This means less material to be handled throughout the MSW system with less risk.

Materials recovery and recycling reduces the amount of material to be disposed of and extends the life of the landfill. It also provides the additional benefit of reducing the consumption of raw materials.

Composting diverts organic matter from the landfill. This can reduce gas and leachate risks at the landfill and extend the life of the facility.

It is more cost-effective to perform these operations close to the site of waste generation. This reduces the cost of transporting the materials to the landfill and minimizes the difficulty of separating mixed wastes at the landfill.

Finally, as noted earlier, successful MSWM depends on adequate financing, enabling legislation, and a supporting institutional and policy environment. In many cases this will require changes in the way government institutions currently operate and will necessitate recognition of the importance of effective MSWM for a city's and country's sustainable development.

5.1.1 What facilities had in PSSL

- Service building
- Employee facilities
- Electricity
- Water supply
- Mobile Phone facilities
- Leachate pond
- Gas ventilation system
- Leachate collection system
- Safety equipments
- Fire extinguisher
- Excavenging control facilities
- Vehicle washing facilities
- Access road
- Monitoring facilities
- Vehicle recording facilities
- Waste characterization

- Monitoring well
- Fencing of landfill site

5.2 Results and Discussion

5.2.1 Records keeping

A daily log have been maintained by the sanitary landfill supervisor to record operational information, including the type and quantity of refuse received, and the portion of the landfill used and any deviations made from the plans and specifications. A copy of the original plans and specifications, a plan of the completed landfill has filed with in the site office of the PSSL for maintaining waste disposal. Example data of record keeping has shown in Table 4.1

5.2.2 Routine inspections and evaluation

Routine inspections and evaluations of landfill operations has made by the PSSL site

Waste Safe II
Pilot Scale Sanitary Landfill Operation
Weekly Monitoring Checklist

[Use Yes, No or number in applicable cases]

1	Is the record keeping properly at the PSSL site?	Yes / No
2	Is Physical Characteristics and Unit Weight of MSW measured schedule time at the site?	Yes / No
4	Is the waste deposited in a proper place at the site?	Yes / No
5	Is compaction of waste done properly at the site?	Yes / No
6	Is access road maintained regular at the site?	Yes / No
7	Are landfill workers used safety equipment?	Yes / No
8	Is leachate removed from leachate holding tank to the leachate pond appropriately?	Yes / No
9	Checked any clogging in leachate collection system?	Yes / No
10	Is waste covering material used end of the daily operation?	Yes / No
11	Are the excavengers controlling in the PSSL?	Yes / No
12	Is the designated waste deposited in the PSSL?	Yes / No
13	Has fire extinguisher of fire extinguishing material keep in the landfill site?	Yes / No

General Comments and Recommendations: (Implementation procedures, work quality, any deviation, Things working well, Challenge faced and others)

Monitor Name, Signature and Date

Figure 5.1 Example data of routine inspection in the PSSL supervisor. A notice of any deficiencies, together with any recommendations for their correction, have provided to the PSSL resource person for the landfill operation. PSSL resource person has inspected and evaluated the landfill operation every week. The sample of the site office routine inspection has shown in Figure 5.1.

5.2.3 Characteristics of cover material

The soil used as cover material is such character that it has compacted to provide a tight seal, does not crack excessively when dry, and is free of putrescible materials and large objects. In the PSSL, the clayey soils collected from the depth of 0 to 2m of the site, was used for cover material. The characteristics of cover material are plasticity index >20% and hydraulic conductivity $\leq 1x10^{-7}$cm/s.

5.2.4 Waste Deposition, Placing and Compaction

(a) Refuse are spread and compacted in shallow layers approximately three feet to four feet of compacted material, it has been compacted by the compaction equipment. Additions of refuse have been spread evenly by repeated passages of landfill equipment.

(b) The refuse fill have continued to the total depth of lift. Individual lifts in sanitary landfills is not greater than eight feet in depth.

(c) A compacted layer of at least three inches of suitable cover material have placed on all exposed refuse by the end of each working day.

(d) Final cover layer of suitable cover material compacted to a minimum thickness of two feet have placed over the entire surface of each portion of the final lift not later than one week following the placement of refuse within that portion. Final cover has graded as provided on the approved plan and to prevent ponding, the surface of the final cover have maintained at the plan elevation at all times by the placement of additional cover material.

(e) Upon completion of the landfill, the entire surface of the final cover has been inspected monthly and all cracked, eroded and uneven areas repaired.

5.2.5 Ground Water Pollution and Protection

(a) It has indicated that suitable provisions to prevent water pollution have been provided. It has implemented a ground water monitoring system of determining the sanitary landfill's impact on the quantity of ground water underlying the sanitary landfill. In the landrfill site subsoil structure has such that there is reasonable assurance that leachate from the landfill will not contaminate the groundwater or surface waters in the area.

(b) Site located in floodplain that is subject to overflow is protected by impervious dikes. Pumping facilities has provided for the removal of seepage and surface waters.

(c) The landfill site has operated in a manner that is control surface water erosion and percolation into the landfill. The surface contour of the ground (area) has graded so that surface runoff is not flow into or through the operational or completed fill area. Grading, diking, terracing, diversion ditching or tilling is acceptable procedures for accomplishing this objective.

5.2.6 Equipment

Adequate numbers, types and sizes of equipment have available for operating the landfill in accordance with good engineering practice. Suitable shelter for the landfill equipment has provided. In order to provide for occurrence of major equipment failure, arrangement has made to have standby repair equipment quickly for smooth operation and also with help of city corporation mechanics.

5.2.7 Access Roads

An all-weather access road, negotiable by loaded collection vehicles, have provided to the entrance of the landfill where a public road does not exist. Access roads to the entrance of the landfill has paved or surfaced with such materials as asphalt, bats or soil cement and has provided with a base capable of withstanding anticipated load limits. Such access road has extended from the gate of the landfill to the unloading area. Necessary measures have taken to access road to the unloading area during inclement weather. When necessary, operational roads within the site have treated to control dust.

5.2.8 Employee Facility

Suitable shelter and sanitary facilities have provided for operating personnel. Chemical toilets have used. Necessary measures have taken for safe drinking water and hand washing.

5.2.9 Communications

Telephone or mobile communications have provided at the sanitary landfill site.

5.2.10 Fire Protection

(a) Fire protection measures have taken to control fires and to regulate and prohibit loads that may fire hazards. An adequate supply of water under pressure is available at the site, or a stockpile of sand has maintained reasonably close to the working face of the fill at about 5m far from landfill cell.

(b) Fire extinguishers, maintained in working order, have kept on the equipment in site office.

5.2.11 Limited Access

(a) Access to a sanitary landfill is limited and it is accept those times when an attendant is on duty and only to those authorized to use the site for the disposal of refuse.

(b) The gate has opened only when an attendant or equipment operator is on duty and it is locked at all other times.

(c) Hours of operation and other limitations on access has displayed prominently at the entrance gate.

(d) An attendant is on duty during operating hours to prevent trespassers or unauthorized persons from entering the area, or, on small landfills, the equipment operator is aware for preventing trespassers or unauthorized persons from entering the area.

5.2.12 Vector and Dust Control

Conditions unfavorable for the production of insects and rodents has maintained by carrying out routine landfill operations promptly and in a systematic manner. Supplemental vector control measures have performed, when necessary. Suitable control measures have taken wherever dust is a problem. End of every day waste deposition daily cover has used.

5.2.13 Accident Prevention and Safety

An operational safety program has conducted for all sanitary landfill personnel. A first-aid kit equipped with sterile bandages, antiseptic solutions, tourniquets, splints and other necessary supplies have kept at the site. All permanent employees at the site are familiar with the location of these supplies and have instructed in their proper use.

5.2.14 Inspection, bond and maintenance after completion

(a) An inspection of the entire site has made by a representative of the site office of PSSL before the earthmoving equipment is removed from the site. Necessary corrective work has performed before the landfill project is accepted as completed.

(b) Arrangements have made for the repair of all cracked, eroded and uneven areas in the final cover during completion of the fill.

5.2.15 Leachate Collection, Removal and Treatment System

Leachate is considered to be a contaminated liquid; it contains many dissolved and suspended materials. Good management techniques that can limit adverse impact of leachate on ground and surface waters include control of leachate production and discharge from a landfill, and collection of leachate with final treatment and/or disposal.

The leachate which is generated in the PSSL has stored in the leachate holding tank (Figure 11) through the leachate collection pipe and then it has transferred to the leachate pond (Figure 12). During heavy rain in monsoon, a huge amount of leachate has generated that pumped out in the nearby reservoir ponds of PSSL because of the difficulties of the operation has shown in Figure 13. For that reason landfill operation is greatly hampered and delayed. Only a small scale treatment plant was made for partial treatment but it was not enough to treat that huge leachate. In this field experiences, it has revealed that adequate drainage system is required to control the heavy monsoon rain and to protect the direct rain infiltration in the PSSL. The experience reveals that in the landfill (constructed in Bangladesh) special cell should be considered to accommodate precipitation only in the rainy season just to avoid the enter of huge amount of rain water in the Landfill, otherwise it would be very difficult and hence expensive also to manage and treat the large volume of leachate.

5.2.16 Effect of Climate on Sanitary Landfill

Adverse climate can severely limit the capability of the sanitary landfill, but this can be partially overcome by preplanning and operational techniques. Operational problems at PSSL are associated mainly in wet season and the limitation of proper equipment.

(a) Wet weather

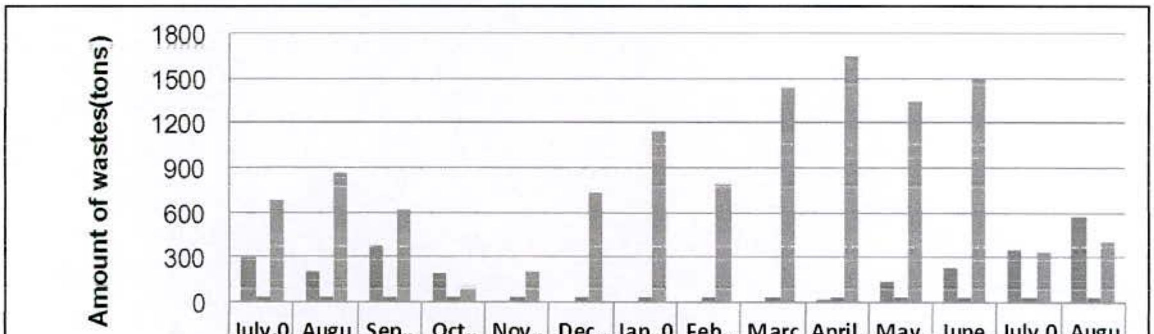
The major problems are in wet seasons maintaining maneuverability of the refuse delivery vehicles and equipment. Heavy rainfall during monsoon created special problem to operate the landfill properly, such as damage of approach road, movement of vehicle on the wastes, difficulties of waste plantation and compaction and generation of huge amount of leachate. Control of storm water runoff at a landfill disposal facility is necessary to minimize the potential of environmental damage to ground and surface waters. Direct surface water contamination can result when solid waste and other dissolved or suspended contaminants are picked up and carried by storm water runoff that comes into contact with the working face of the landfill. Uncontrolled surface water runoff can also increase leachate production, thereby increasing the potential for ground water contamination. Surface drainage can usually be diverted from open excavations by careful grading. Operational practices can also reduce the effect of this problem. This can be provided in the design by selecting a site that is well drained and with soil that has adequate trafficability when wet condition.

(b) Dry Weather

Dry weather problems at PSSL are mainly operational such as blowing dust or paper. A certain amount of moisture is needed for the biological activity in the refuse; however, it is unusual to have to add for this purpose. Control of blowing refuse can be accomplished by prompt covering and by the use of portable fences downwind of the open face of the fill.

5.2.17 Waste Deposition and the Climate

There is no wye bridge in the PSSL, for that reason waste weight has not measured directly. It has done indirectly unit weight method. Limitation of compactor and chain dozer has hampered the waste deposition in the PSSL. It is required necessary equipment for proper operation. During 14 months landfill operation, 11790 tons of waste has already been deposited in the landfill. The figure 8 shows that waste deposition in month wise at different climate condition. From Figure 8 it has seen that in the beginning of waste deposition during monsoon, waste deposited 720tons (avg.) from July to September, 2008 and then it has dropped to 147tons (avg.) in next two months. This is because of huge amount of leachate generated during this monsoon and it has created an adverse condition to landfill. After disposal of these huge amounts of leachate, the environment has come in favor to waste deposition and the operation runs in full swing from December, 2008 to June, 2009. It has reached the record amount of landfill on average 1227 ton/months. After that the monsoon has come again and the situation is repeated. It was planned that the period of land filling was six



	July,08	August,08	Sep., 08	Oct., 08	Nov., 08	Dec., 08	Jan.,09	Feb., 09	March,09	April, 09	May, 09	June, 09	July,09	August,09
PPt(mm)	301	203	379	187	0	0	1	6	10	23	137	233	347	570
Max.Temp(0C)	31.5	32.5	32.8	31.8	29.6	26.1	26.2	29.8	33.2	36.6	35.6	34.8	32.3	32.6
Landfilling(ton)	680	867.	614.	87.9	205.	736.	1142	784.	1434	1644	1342	1507	343.	408.

Figure 5.2 Waste depositions into the PSSL month wise at different climate conditions

month by 50tons/day but due to the climate condition only 28 tons/day of waste is possible to fill in the PSSL. Later, the operation period is extended to few months for fulfill the operation.

5.2.18 Unloading of Refuse

(a) Unloading of refuse have continuously supervised. Appropriate signs have posted to indicate clearly where vehicles are to unload. An attendant is on duty during operating hours to direct unloading of refuse. On small landfills, the equipment operator is direct unloading of refuse.

(b) Unloading of refuse has confined to as small an area as possible. Blowing paper has controlled by providing a portable fence near the working area. The entire area has policed regularly.

5.2.19 Working Face

The size of the working face has confined to as small as possible for easily compacted daily with the available equipment. The width of the working face is small for consistent with the size of the compacting equipment.

5.2.20 Animals

Domestic animals have excluded from the site. Where fencing is used for prevent entering animals.

5.2.21 Landfill Gas Monitoring

After completion of landfill cell, it has monitored gas production of cell. After one year it has seen a noticeable gas production for undergoing decomposition of the waste. And it has checked that the gas which is produce in the landfill cell is ignitable. A routine gas monitoring has conducted to the landfill cell. If the energy recovery technique is applied, methane gas should be processed to produce bio-fuel.

5.3 The requirements for the PSSL

- Weigh bridge
- Weather measuring instruments
- Light wheel compactor/ Chain dozer
- Protection against direct fall of rain water into the landfill

5.4 Appropriate Operation Approach for Sanitary Landfill in Bangladesh

There are different opinions about the sustainability of landfill. Some scholars hold the opinion that if landfills are constructed and maintained in a proper manner and with resources recovery facilities available, landfilling is a sustainable method in handling municipal solid waste. According to them even the best engineered landfills will somehow pose some environmental threats to the ecosystem. If these effects are not shown at this time period, they will be left for future generation to deal with. In the human society, whether it is a modern economic of subsistence economic, production and consumption are inevitable. And solid waste is the by-product of these activities. When the production and consumption increase, this will increase the municipal solid waste. The magnitude of change in municipal solid waste will be influenced by different factors such as population, per capita income, industrialization, urbanization, living standards, seasons, etc. When the municipal solid waste accumulates, the local authorities must find a way to dispose it. The easiest, simplest and most probably the most thrifty way to dispose municipal solid waste is to dump it at crude dumping landfills. Dumping all municipal solid waste in landfill without any recovery will cause the natural resources deplete and will in a way have negative effects on usage, productions and ultimately lower consumption which might in turn lower the living standard. On the other hand, haphazard dumping municipal solid waste at the landfill will lead to various negative environment and socio-economic impacts such as ground water and surface water pollution, air pollution, health hazard and so on. These impacts will have severe chain reactions which will cause the degeneration of public welfare. In realizing that crude dumping is not the only solution of handling the increasing municipal solid waste problems, the local authorities or the landfill managers will bring in new landfill technologies in order to prevent or at least to minimize the negative impacts that crude dumping landfills will lead to. Lining system, leachate collection and treatment and gas venting facilities will be installed in the landfill. By doing so, the socio-economic and environmental impacts will be reduced and thus indirectly public welfare will increase as compared to the situation where crude dumping is practiced. Even with the new installed technologies, problems still exist. As long as the production and consumption activities are going on, the municipal solid waste will still increase and the public welfare will still be threatened. They will, via various channels, complain to the authorities and this will lead to legislation to tackle the municipal solid waste problems. A legislation that brings to source reduction and resources recovery can reduce the municipal solid waste being sent to landfill in two different ways. Firstly, the source reduction policy will reduce the production and consumption which will reduce the municipal solid waste from being generated and of course the municipal solid waste that will be sent to landfill for disposal. The second solution is resources recovery where the municipal solid waste will first be sent for pre-treatment such as recycling, composting and incineration in order to recover as much resources as possible. These recovered resources will be added up to the resources availability to produce more goods. The ideal disposal methods should be environmental friendly with optimum recycling, economically less demanding and socially acceptable. As to volume reduction issue, incineration might be able to solve the problem in the sort –term but it is not a permanent cure. It is essential to go back to the root cause of the solid waste problems and tackle them from there. Thus, there is an emerging need for the local authorities to tackle these problems by looking for a more efficient and environmentally sound disposal method where sanitary landfill has been identified to be one of the options. With its proper design, maintenance and post closure monitoring, sanitary landfill offers a sustainable way in handling the ever-increasing municipal solid waste.

5.4.1 Waste Receiving and Recording

It should have observe the wastes being dumped to spot and prevent unauthorized materials such as flammable, explosive, or other hazardous material from being deposited within the waste cell. If unauthorized material is dumped, the laborer should notify the Equipment Operator so it can be safely removed. Waste receiving and recording is important part of landfill operation. Waste weighting can be easily done Weigh bridge. It is essential because the capacity of the landfill has designed.

5.4.2 Waste Deposition

While landfills may outwardly appear simple, they need to operate carefully and follow specific guidelines that include where to start filling, wind direction, the type of equipment used, method of filling, roadways to and within the landfill, the angle of slope of each daily cell, controlling contact of the waste with groundwater, and the handling of equipment at the landfill site.

A sanitary landfill does not need to be operated by using only the area or trench method. Combinations of two are possible, and flexibility is, therefore, one of sanitary landfilling's greatest assets. The methods used can be varied according to constraints of a particular site.

1. One common variation is the progressive slope or ramp method, in which the solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste. In this way, a small excavation is made for a portion of the

next day's waste. This technique allows for more efficient use of the disposal site when a single lift is constructed than the area method does, because cover does not have to be imported, and a portion of the waste is deposited below the original surface.

2. Both methods might have to be used at the same site if an extremely large amount of solid waste must be disposed of. For example, at a site with a thick soil zone over much of it bur with only a shallow soil over the remainder, the designer would use the trench method in the thick soil zone and use the extra spoil material obtained to carry out the area method over the rest of the site. When a site has been developed by either method, additional lifts can be constructed using the area method by having cover material hauled in. The final surface of the completed landfill should be so designed that ponding of precipitation does not occur. Settlement must, therefore, be considered. Grading of the final surface should induce drainage but not be so extreme that the cover material is eroded, side slopes of the completed surface should be 3 to 1 or flatter to minimize maintenance.

5.4.3 Waste Plantation

Two types of road are required for the landfill operation. One type is permanent road which is used mainly for the operation and maintenance of the site, and the other type is temporary road (working road) which is used mainly for the transportation of the waste. For proper waste deposition and plantation it has to be made two ways of the landfill cell.

To provide additional protection for the liner system, waste will be placed on the bottom and sides of the lined trench, and compacted until the liner is completely covered with at least four feet of waste and soil. Once this four-foot layer is in place, waste will be deposited in vertical cells on the end slope to form a working face which will extend across the trench and advance toward the berm. Daily and intermittent cover should be obtained from the adjacent cell under construction (generally using a scraper). Wastes should always be placed at the toe of the working face. Incompact waste will be spread in layers no more than 0.76m thick before compacting. Once compacted, another layer can be added and then compacted so that the waste cell will be several feet thick before the soil cover is added. The working face should have a 20 to 30 percent slope, and be as narrow as feasible to accommodate the number of trucks using the landfill.

5.4.4 Waste Compaction

A high degree of compaction extends the fill life, reduces cover material and long-term land requirements, reduces litter problems, and results in other beneficial effects. Good compaction is achieved by operating the compactor up and down the working face between 3 and 5 times on 0.30 to 0.60m layers of waste until no further compaction occurs. The top deck of the cell must also be compacted by running the landfill compactor across the top keeping it as level as possible.

5.4.5 Protection against Rain Water

Rain water protection is important for smooth operation of the landfill. Generally heavy rain occurs in the month of July, September and October respectively. During this time special waste cell will be used and covering each cell after deposition of waste so that rain water can not enter into the cell.

For better management of Landfill, two types of cell will be used, one is dry season cell which will big that means main cell and another is wet season cell which is small. Main cell can be used long time for landfill design duration. During Monsoon main cell will be closed, and it can be covered by using polythene shed. In Monsoon Waste will be deposited in wet cell and covering it after operation. Top covering of the wet cell will be finished at the end of every Monsoon. For design duration of landfill, specific number of wet cell will be prepared. Waste access road of this cell will separate.

The entire site, including the fill surface will be provided with drainage facilities to minimize run off into the fill, to prevent washing of the fill and drain off rain water falling on the fill.

Precipitation which falls on the waste will be considered contaminated. Discharges from this area will be contained temporally on the detention basin, then removed to a surface waste impoundment or managed in the facility storm water management system as appropriate.

5.4.6 Control of Birds, Insects and Animals

The three basic procedures that are carried out in sanitary landfills are: spreading the solid waste materials in layers; compacting the wastes as much as possible; and covering the waste with sand and coarse aggregates at the end of the each day. This method reduces the breeding of rats and insects at the landfill. Installations of paper trap fences around the front of the waste access road and of surrounding areas, watering of the roads to limit the proliferation of insects infested with germs and also prevent animals entering to the landfill. Birds can be controlled in to the landfill by using Kaktarua with sound system.

5.4.7 Operation of Vehicle

Steel-wheeled compactors are designed specifically for compacting solid wastes. Wheels are studded with load concentrators of various designs. This equipment gives maximum compaction of solid wastes. Steel-wheeled compactors are best suited to medium or large sanitary landfills. Truk-type tractors can be used for site preparation as will as road construction and maintenance. Truk-type loaders are similar to track-type tractors. They have the added ability of lifting and carrying soil without losing excavating and spreading ability.

Equipment maintenance is clearly an important task. Regular maintenance can reduce repair problems before more costly and time-consuming repairs are needed. Equipment manufacturers provide instructions for periodic maintenance and will provide assistance with equipment maintenance and repairs. It is imperative that a periodic preventive maintenance program be implemented and supported by a well equipped maintenance shop. Wet weather problems are especially serious with soils that have high silt or clay content. When wet, these soils become very muddy, and provision should be made to continue operation in areas of the fill that are less susceptible to problems. Wet weather plans should include measures to reduce tracking of mud from the landfill onto the road system and provisions for cleaning trucks.

5.4.8 Staff Management

The landfill staff should have technical know how about landfill operation. For safety and health consideration they have to well train. To maintain an efficient operation, employees must be carefully selected, trained, and supervised. Proper landfill operation depends on good employees. Along with equipment operators, other necessary employees may include maintenance personnel, a scale operator, labors and a supervisor. Suitable shelter and sanitary facilities shall be provided for operating personnel. Chemical toilets may have use. Provision shall also be made for safe drinking water and hand washing. Telephone communication shall be provided at the sanitary landfill site.

5.4.9 Environment Aspects

It is important to conduct landfilling in an environmental sound manner in order to protect the environment, public health and natural resources. Currently, the municipal solid waste disposal method in Bangladesh is crude dumping. Municipal solid waste is disposed improperly and resulting in health threats, damage to the environment and loss of natural resources. It is hoped that sanitary landfills that are equipped with the leachate collection and gas venting facilities, ground water monitoring, closure and post-closure care will reduce the chances of environmental degradation. There is no doubt that sanitary landfill will provide a more secure and better environmentally sound disposal system than crude dumping landfill. If the sanitary landfill is engineered according to environmental codes of practice and maintained properly, it is offered a sustainable way in handling municipal solid waste. In order to avoid any possible hazards that could occur, it is important to ensure the following conditions are present:

i) There must be pre-sorting before the waste is disposed at the landfill in order to recover materials.

ii) Hazardous waste should be forbidden to be co-disposed at the municipal solid waste landfill.

iii) An impermeable liner system should be installed together with leachate collection and treatment system. Ground water monitoring should be done from time to time to ensure no ground water contamination

iv) Gas venting and flaring system to prevent explosion or fire at the landfill site as well gas monitoring system to make sure no landfill gases be escaped freely to the atmosphere.

A landfill should not be located in areas with high groundwater tables. Waste in a sanitary landfill will decompose through biological and chemical processes that produce solid, liquid, and gaseous products. Food wastes degrade rapidly, whereas plastics, glass and construction waste do not. The most common types of gas produced by the decomposition of the waste are methane and carbon dioxide. Methane, which is produced by anaerobic decomposition of landfill materials, is hazardous because it is explosive. Depending on the landfill composition, gases can be recovered and utilized in the generation of power of heat.

Heavy clay soils should be avoided in selecting a site because operations are severely hampered by mud during inclement weather. The alternate is to stockpile suitable fill material to stabilize access roads during foul weather. This can be provided in the design by selecting a site that is well drained and with soil that has adequate trafficability when wet.

Field experience on the daily operation indicated that sanitary landfills can be and are operated under varying conditions. For most, the terrain and soil conditions determined whether the ramp, trench or area method is used or a combination of two of three methods, according to the season of year. The type of operation dictated that the type of equipment used, although in some instances the method of operation can be determined by the available equipment.

CHAPTER SIX

SUMMARY AND CONCLUSION

6.1 SUMMARY

Uncontrolled dumping of solid waste around the world becomes one of the major striking social and environmental issues. The majority of these are located in the developing countries, which generate the solid waste with high rapidly biodegradable fraction. In Bangladesh, like other Least Developed Asian Countries (LDACs), ultimate disposal sites of Municipal Solid Waste (MSW) are situated in and around the city areas at low-lying open spaces, unclaimed land, riverbanks and roadsides. Even in some city authorities do not have any specific place for ultimate disposal. Such disposal sites do not have minimum infrastructure requirements and environmental protections, as a result, present open dumping practices pose to high threat to health and environment. There are no controlled/engineered/sanitary landfills in Bangladesh; however, recently Dhaka City Corporation has taken an initiative to convert 'Matuail Open Dumping Site' into the Engineered Landfill. Due to severe financial constraints and the priorities to other sectors such as food, shelter, health and education, central and local governments are not able to address this social and environmental issue despite the realization that the only affordable disposal solution in Bangladesh for the foreseeable future – is to establish engineered landfills. So, Bangladesh needs develop as appropriate method of landfill construction considering local conditions. To this endeavor, a pilot scale sanitary (PSSL) landfill at Rajbandh, Khulna has been constructed using local clay as a base liner material. In design of the PSSL all the relevant aspects of a standard sanitary landfill is considered. Emphasis is also given for the best use of locally available building materials and construction techniques. However, scientific and technical considerations, guided by field experiences, are given while fixing up the dimensions and materials specification of the various components of the landfill. The PSSL consists of the main components of a standard landfill such as (i) Waste deposition cell, (ii) CCL on a geological barrier with a drainage layer on top (iii) Top Cover with CCL, drainage layer, top soil as vegetation cover, surface run-off and percolated water collection system, (iv) Gas measurement and management facility, (v) Leachate detection and collection system with leachate holding tank, (vi) Leachate pond with leachate treatment facility, (vii) Vehicle inspection and washing facility, (viii) Access Road and Site office, (ix) On-going and post closure monitoring facilities.

The site of the PSSL is located at the north-west corner with an area of 1.1acres. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 64mx55m. There is a public natural stream in the North side and private paddy land in the west. The sub-soil investigation was revealed that the gray clay minerals with organic forms to a depth of 1.5m followed by silty clay having clay minerals content ranges from 23 to 30% and hydraulic conductivity varies from 2.45×10^{-6} to 2.5×10^{-8} cm/sec at different molding water contents. Swelling clay minerals are present in varying the amount of 0 to 11% of the composition.

The total surface area of the landfill base including side slope is 2683m^2. The base liner consists of properly compacted clay liner of 400mm in thickness. A Leachate collection and removal system in combination with Leachate and leakage detection system has been developed intending to receive the entire surface run off and leachate. This may flow across the landfill floor to a sump through waste into a drainage media and on to the sump. The downward percolation of water is prevented by the CCL. The landfill with leak detection sump system is intending to collect water which passes or leaks through the CCL only. Both collection and sumps are perforated at definite elevations and both sumps rest in a concrete basin. The CCL was prepared applying hand compaction by locally fabricated hammer of weight 5kg in three layers and at the wet side of proctor curve to achieve the optimum hydraulic conductivity, 1×10^{-9}m/sec. The generated leachate will be stored in leachate holding tank of 2mx2mx4m through gravity flow and later transfer to the leachate treatment pond of 10mx20mx3.5m. The leachate detection pipe is also designed and connected in the leachate holding tank by ensuring gravity flow. A leachate collection layer of 0.20m and a leachate collection pipe are placed above.

During 18 months landfill operation, 11790 tons of MSW wastes was deposited in the landfill. During the deposition period huge amount of leachate generated due to inherent wastes nature and the typical monsoon season of Bangladesh and it has created an adverse condition to landfill. The amount of leachate obtained the leachate collection system and the detection systems were measured and hence monitored. It is observed that the leachate collection and detection system have worked well as no clogging was reported. To examine the performance of the CCL, the leachate collected through both the collection and detection pipes have been characterized in the laboratory through necessary routine tests. The quality of the surface water and ground water in and around the landfill cell, have been tested collecting water samples both from the constructed ground water monitoring well and the adjacent natural streams. After the completion of PSSL on last December 2009, the cover system was constructed and the post closure monitoring has been conducted by the researchers of the Department of Civil Engineering, KUET.

6.2 CONCLUSIONS

Based on this study the following conclusion can be made;

1. For proper waste deposition and plantation it has to be made two ways of the landfill cell. One type is permanent road which is used mainly for the operation and maintenance of the site, and the other type is temporary road (working road) which is used mainly for the transportation of the waste.

2. For better management of Landfill, two types of cell will be used, one is dry season cell that means main cell and another is wet season cell which is small. Main cell can be used long time for landfill design duration. In Monsoon, Waste will be deposited in wet cell and covering it after operation. Top covering of the wet cell will be finished at the end of every Monsoon. For design duration of landfill, specific number of wet cell will be prepared. Access road of this cell will separate.

3. Daily and intermittent cover should be obtained from the adjacent cell under construction (generally using a scraper).

4. High silt or clay soils should be avoided in selecting a site because operations are severely hampered by mud during inclement weather. Wet weather problems are especially serious with soils that have high silt or clay content, these soils become very muddy and for this operation of vehicle is very difficult.

5. Wastes should always be placed at the toe of the working face. Incompact waste will be spread in layers, thickness of layers keep suitable for better compaction. From daily operation of PSSL it has experienced that good compaction is achieved by operating the compactor up and down the working face between 3 to 5 times on 0.30m to 0.60m layer of waste until no further compaction occurs.

6. Steel-wheeled compactors are designed specifically for compacting solid wastes. Truk-type compactor can be used for site preparation as well as road construction and maintenance. Truck-type tractors sometimes hamper of the operation because of puncture of the wheel by glass or rods which are inherent of MSW and also by using this type tractor compaction has not done smoothly.

7. Small scale of solid waste deposition, the progressive slope or ramp method is suitable, in which the solid waste is spread and compacted on a slope. In this way, a small excavation is made for a portion of the next day's waste.

8. Cover material is obtained directly in front of the working face and compacted on the waste. This technique allows for more efficient use of the disposal site when a single lift is constructed than the area method does, because cover does not have to be imported, and a portion of the waste is deposited below the original surface.

Finally, it can be concluded that this field study will also help to establish the landfill technology for Bangladesh conditions, which can be replicable to other Least Developed Asian Countries with required refinement.

6.3 Recommendation for future research works

1. For practical application of PSSL in the existing conditions of Bangladesh, it is needed further research work for leachate management system during Monsoon.

2. It is needed future research works of Environmental Impact Analysis in the PSSL site, where leachate intrudes into the ground or contaminates the ground water or free gas diffusion from landfill cell to the atmosphere.

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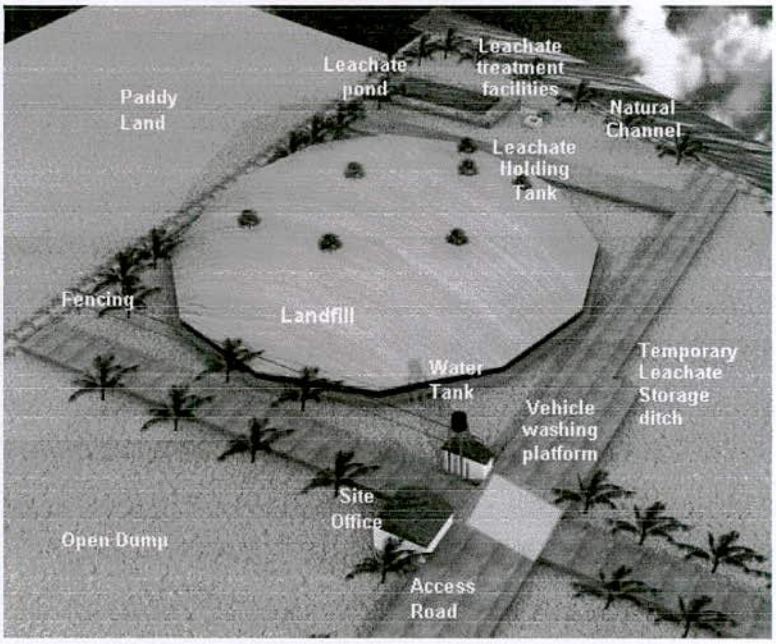
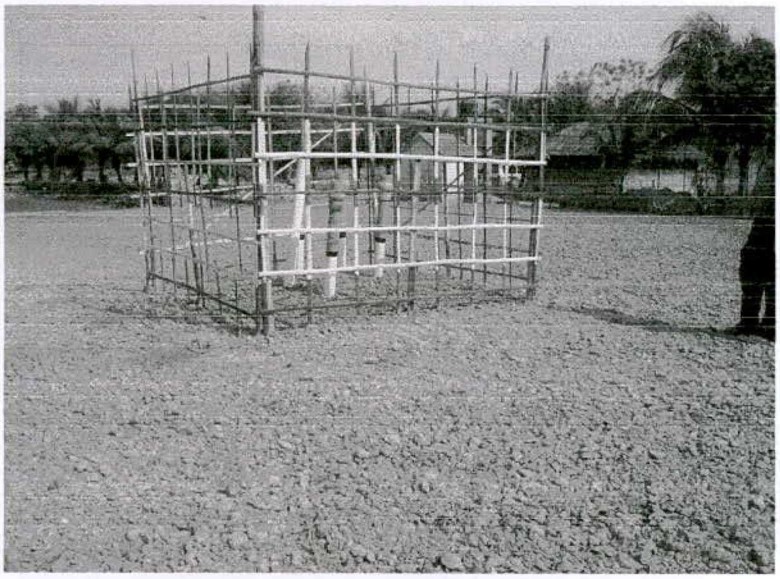
ANNEX A



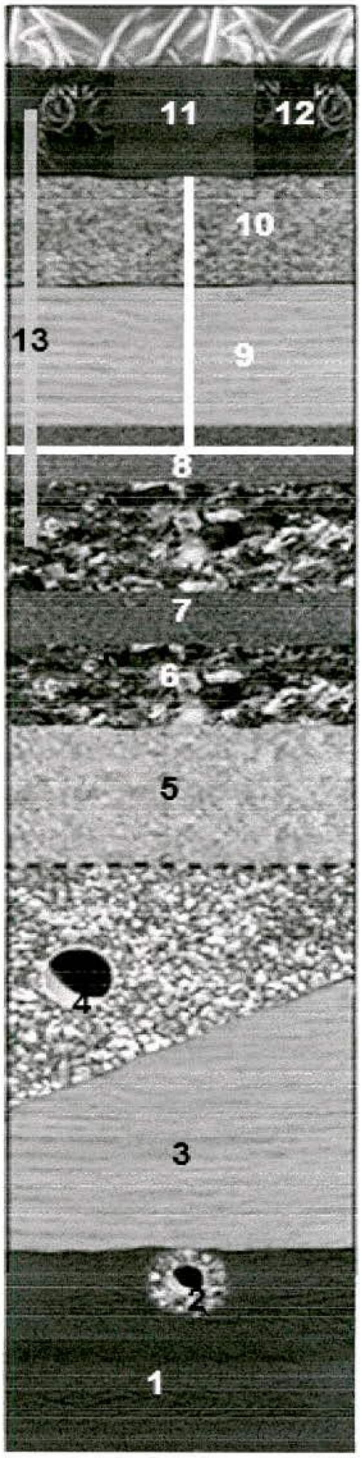
Perspective view of Pilot Scale Sanitary Landfill at the design level



Final view of Pilot Scale Sanitary Landfill with gas ventilation system

ANNEX B

Anatomy of Pilot Scale Sanitary Landfill (At design Phase)



(13) Leachate Recirculation System: It will Maintain moistuer and Enhance degradation of waste.

(10) Drainage Layer: A layer of sand and gravel drains excess precipitation from the protective cover soil to enhance stability and help prevent infiltration of water through the landfill cap system.

(8) Gas Collection Layer: Waste produces gas and that gas will be colledted by perforated pipe system sourunded by a layer of sand and gravel to check its characteristics.

(6) Waste: As waste arrives, it is compacted in layers within a small area to reduce the volume consumed within the landfill. This practice also helps to reduce odors, keeps litter from scattering and deters scavengers.

(4) Leachate Collection Pipe System: Perforated pipes, surrounded by a bed of gravel, transport collected leachate to specially designed low points called sumps. Pumps, located within the sumps, automatically remove the leachate from the landfilland transport it to the leachate management facilities.

(2) Leachate Detection System: 38mmϕPVC filter pipe surrounded by 150mm of course sand & 1% slope to the sump will detect the leachate that leave from CCL

(12) Top Soil: Helps to support and maintain the growth of vegetation by retaining moisture and providing nutrients.

(11) Biofilter: It will oxidize CH_4 in to CO_2 to protect environment

(9) Compacted Clay: It is placed to form a cap when the landfill reaches the permitted height. This layer prevents excess precipitation from entering the landfill and forming leachate and helps to prevent the escape of landfill gas, thereby reducing odors.

(7) Daily Cover: At the end of each working period, waste is covered with 150mm of compost or other approved material. Daily cover reduces odors, keeps litter from scattering and helps deter scavengers.

(5) Leachate Collection Layer: A layer of sand or gravel collects leachate and allows it to drain by gravity to the leachate collection pipe system.

(3) Compacted Clay: Is located directly below the Leachate Collection Layer and forms an additional barrier to prevent leachate from leaving the landfill and entering the environment. This layer also helps to prevent the escape of landfill gas.

(1) About 15m of clay-gray benath the Landfill will be act as Natural soil Barrier to prevent spreading of cotaminant

ANNEX C

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (14/07/08), Sample 02 (30/07/08)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	7.940	18.800	31.76	75.20
	02	Paper and Paper products	1.560	0.750	6.24	3.00
	03	Plastic/Polythene	5.925	0.500	23.70	2.00
	04	Pet Bottles/Oil container	0.320	-	1.28	-
	05	Textiles/Clothes/Rags	2.185	0.300	8.74	1.20
	06	Rubber	-	-	-	-
	07	Leather	0.665	-	2.66	-
	08	Wood	1.720	0.067	6.88	2.68
	09	Rope/Straw/Coconut	0.915	1.300	3.66	5.20
	10	Animal Bones	-	-	-	-
	11	Leaves/grass etc	-	0.325	-	1.30
Total Organic Waste			21.230	22.645	84.92	90.58
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	1.225	0.400	4.90	1.60
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	0.170	0.135	0.68	0.54
	15	Ceramic/Crockery	0.175	0.200	0.70	0.80
	16	Bricks/Concrete/Demolition	1.675	1.300	6.70	5.20
Total Inorganic Non-hazardous			3.245	2.035	12.98	8.14
Inorganic Hazardous Waste	17	Battery	0.095	-	0.38	-
	18	Liquid/Shoe Polish/Remover	0.090	-	0.36	-
	19	Personal care(Paste tube/Shampoo Bottles etc)	0.170	0.125	0.68	0.50
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	0.070	-	0.28	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0.425	0.125	1.70	0.50
System Loss			0.100	0.195	0.4	0.78
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (13/08/08), Sample 02 (30/08/08)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	13.285	9.25	53.14	37.00
	02	Paper and Paper products	2.885	4.785	11.54	19.13
	03	Plastic/Polythene	3.375	2.740	13.50	10.97
	04	Pet Bottles/Oil container	-	0.250	-	1.00
	05	Textiles/Clothes/Rags	1.490	2.050	5.96	8.20
	06	Rubber	-	-	-	-
	07	Leather	0.070	-	0.28	-
	08	Wood	-	0.190	-	0.76
	09	Rope/Straw/Coconut	0.465	0.965	1.86	3.86
	10	Animal Bones	-	-	-	-
	11	Leaves/grass etc	0.415	1.595	1.66	6.38
Total Organic Waste			21.985	21.825	87.94	87.30
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	-	0.350	-	1.40
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	-	0.250	-	0.60
	15	Ceramic/Crockery	0.125	0.500	0.50	2.02
	16	Bricks/Concrete/Demolition	2.790	2.080	11.16	8.30
Total Inorganic Non-hazardous			2.915	3.080	11.66	12.32
Inorganic Hazardous Waste	17	Battery	-	-	-	-
	18	Liquid/Shoe Polish/Remover	-	-	-	-
	19	Personal care(Paste tube/Shampoo Bottles etc)	-	-	-	-
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	-	-	-	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0	0	0	0
System Loss			0.100	0.095	0.40	0.38
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (11/09/08), Sample 02 (01/10/08)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	12.075	11.33	48.30	45.32
	02	Paper and Paper products	4.100	5.28	16.40	21.12
	03	Plastic/Polythene	2.060	2.860	8.24	11.43
	04	Pet Bottles/Oil container	-	-	-	-
	05	Textiles/Clothes/Rags	0.900	1.570	3.62	6.31
	06	Rubber	0.055	-	0.20	-
	07	Leather	-	-	-	-
	08	Wood	-	0.075	-	0.30
	09	Rope/Straw/Coconut	0.700	0.410	2.80	1.64
	10	Animal Bones	-	-	-	-
	11	Leaves/grass etc	2.245	1.425	8.97	5.70
Total Organic Waste			22.135	22.950	88.52	91.80
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	-	0.255	-	1.02
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	0.150	-	0.60	-
	15	Ceramic/Crockery	-	0.225	-	0.90
	16	Bricks/Concrete/Demolition	2.615	1.075	10.46	4.30
Total Inorganic Non-hazardous			2.765	1.555	11.06	6.22
Inorganic Hazardous Waste	17	Battery	-	0.095	-	0.38
	18	Liquid/Shoe Polish/Remover	-	0.090	-	0.36
	19	Personal care(Paste tube/Shampoo Bottles etc)	-	0.135	-	0.54
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	-	-	-	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0	0.32	0	1.28
System Loss			0.100	0.175	0.04	0.70
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (30/11/08), Sample 02 (27/12/08)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	10.42	10.70	41.67	42.80
	02	Paper and Paper products	4.56	3.435	18.25	13.25
	03	Plastic/Polythene	4.91	2.49	19.65	9.95
	04	Pet Bottles/Oil container	-	-	-	-
	05	Textiles/Clothes/Rags	0.500	1.45	2.00	5.80
	06	Rubber	-	-	-	-
	07	Leather	0.095	-	0.38	-
	08	Wood	-	-	-	-
	09	Rope/Straw/Coconut	3.185	2.815	12.75	11.25
	10	Animal Bones	-	0.560	-	2.24
	11	Leaves/grass etc	-	-	-	-
Total Organic Waste			23.67	21.45	94.73	85.79
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	-	0.325	-	1.30
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	-	0.115	-	0.46
	15	Ceramic/Crockery	-	0.575	-	2.30
	16	Bricks/Concrete/Demolition	1.20	2.125	4.85	8.50
Total Inorganic Non-hazardous			1.20	3.14	4.85	12.56
Inorganic Hazardous Waste	17	Battery	-	-	-	-
	18	Liquid/Shoe Polish/Remover	-	0.075	-	0.30
	19	Personal care(Paste tube/Shampoo Bottles etc)	-	0.125	-	0.50
	20	Blade	-	-	-	
	21	Syringe	-	-	-	
	22	Medicine Bottles	-	-	-	
	23	Tablet cover	-	-	-	
	24	Globe/coil/Globe Stand	-	-	-	
Total Inorganic Hazardous Waste			0	0.20	0	0.85
System Loss			0.130	0.210	0.52	0.84
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (24/01/09), Sample 02 (28/02/09)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	9.90	13.775	39.60	55.10
	02	Paper and Paper products	3.525	2.125	14.10	8.50
	03	Plastic/Polythene	1.840	2.065	7.35	8.25
	04	Pet Bottles/Oil container	-	-	-	-
	05	Textiles/Clothes/Rags	0.750	0.375	3.0	1.50
	06	Rubber	-	-	-	-
	07	Leather	-	-	-	-
	08	Wood	-	0.100	-	0.40
	09	Rope/Straw/Coconut	0.365	0.225	1.22	1.26
	10	Animal Bones	-	-	-	-
	11	Leaves/grass etc	5.40	4.10	21.65	16.40
Total Organic Waste			21.70	22.765	86.80	90.95
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	0.300	-	1.20	-
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	-	-	-	-
	15	Ceramic/Crockery	-	-	-	-
	16	Bricks/Concrete/Demolition	2.850	2.050	11.40	8.20
Total Inorganic Non-hazardous			3.150	2.050	12.60	8.20
Inorganic Hazardous Waste	17	Battery	-	-	-	-
	18	Liquid/Shoe Polish/Remover	-	-	-	-
	19	Personal care(Paste tube/Shampoo Bottles etc)	-	-	-	-
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	-	-	-	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0	0	0	0
System Loss			0.150	0.185	0.60	0.74
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (21/03/09), Sample 02 (25/04/09)

Waste Types	Item no.	Items	Amount (kg)		Composition (%0	
			Sample 01	Sample 02	Sample 01	Sample 02
Organic Waste	01	Food & Vegetables waste	16.625	11.585	66.50	46.35
	02	Paper and Paper products	1.45	1.865	5.80	7.46
	03	Plastic/Polythene	1.20	2.60	4.80	10.63
	04	Pet Bottles/Oil container	-	-	-	-
	05	Textiles/Clothes/Rags	0.625	2.255	2.50	9.02
	06	Rubber	-	-	-	-
	07	Leather	-	-	-	-
	08	Wood	-	0.545	-	2.18
	09	Rope/Straw/Coconut	0.465	1.050	1.85	4.10
	10	Animal Bones	0.250	-	1.00	-
	11	Leaves/grass etc	-	3.070	-	12.28
Total Organic Waste			20.615	23.278	82.50	93.11
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	-	0.150	-	0.60
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	-	-	-	-
	15	Ceramic/Crockery	0.450	0.250	1.80	1.00
	16	Bricks/Concrete/Demolition	3.55	1.050	14.20	4.20
Total Inorganic Non-hazardous			4.00	1.450	16.00	5.80
Inorganic Hazardous Waste	17	Battery	0.095	-	0.38	-
	18	Liquid/Shoe Polish/Remover	-	0.100	-	0.40
	19	Personal care(Paste tube/Shampoo Bottles etc)	0.115	-	0.46	-
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	-	-	-	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0.21	0.100	0.84	0.40
System Loss			0.175	0.172	0.70	0.70
Total Amount of Waste			25.00	25.00	100	100

Waste Safe II

Pilot Scale Sanitary Landfill Operation

25 Kg Waste Characterization Data Sheet

Sample 01 (23/05/09), Sample 02 (28/06/09)

Waste Types	Item no.	Items	Amount (kg) Sample 01	Amount (kg) Sample 02	Composition (%0 Sample 01	Composition (%0 Sample 02
Organic Waste	01	Food & Vegetables waste	11.75	7.58	47.00	30.35
	02	Paper and Paper products	6.95	9.31	27.80	37.25
	03	Plastic/Polythene	2.06	3.29	8.25	13.15
	04	Pet Bottles/Oil container	0.125	-	-	-
	05	Textiles/Clothes/Rags	0.70	0.90	2.80	3.60
	06	Rubber	-	-	-	-
	07	Leather	-	-	-	-
	08	Wood	-	-	-	-
	09	Rope/Straw/Coconut	1.375	1.60	5.5	6.65
	10	Animal Bones	-	-	-	-
	11	Leaves/grass etc	-	-	-	-
Total Organic Waste			22.960	22.74	91.84	91.00
Inorganic Non-hazardous	12	Glass Bottles/ Broken Glass	-	0.125	-	0.50
	13	Melamine	-	-	-	-
	14	Metal/Tin Can	-	-	-	-
	15	Ceramic/Crockery	0.350	-	1.40	-
	16	Bricks/Concrete/Demolition	1.50	1.960	6.00	7.84
Total Inorganic Non-hazardous			1.85	2.085	7.40	8.34
Inorganic Hazardous Waste	17	Battery	-	-	-	-
	18	Liquid/Shoe Polish/Remover	-	-	-	-
	19	Personal care(Paste tube/Shampoo Bottles etc)	-	-	-	-
	20	Blade	-	-	-	-
	21	Syringe	-	-	-	-
	22	Medicine Bottles	-	-	-	-
	23	Tablet cover	-	-	-	-
	24	Globe/coil/Globe Stand	-	-	-	-
Total Inorganic Hazardous Waste			0	0	0	0
System Loss			0.190	0.175	0.76	0.66
Total Amount of Waste			25.00	25.00	100	100

ANNEX D

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: July/08

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
14.07.	01	1.00	19.750	0.03	18.750	625.00	
08	02	1.00	18.325	0.03	17.325	577.50	595.83
	03	1.00	18.550	0.03	17.550	585.00	
30.07.	01	1.00	19.300	0.03	18.300	610.00	
08	02	1.00	18.870	0.03	17.870	595.66	601.60
	03	1.00	18.975	0.03	17.975	599.16	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: August/08

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
13.08.	01	1.00	19.375	0.03	18.375	612.50	
08	02	1.00	19.100	0.03	18.100	603.33	598.61
	03	1.00	18.400	0.03	17.400	580.00	
30.08.	01	1.00	19.100	0.03	18.100	603.33	
08	02	1.00	19.225	0.03	18.225	607.50	600.38
	03	1.00	18.710	0.03	17.710	590.33	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II
Pilot Scale Sanitary Landfill Operation
Data Sheet: September/08
Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
11.09.	01	1.00	19.450	0.03	18.450	615.00	
08	02	1.00	19.290	0.03	18.290	609.66	606.83
	03	1.00	18.875	0.03	17.875	595.83	
30.09.	01	1.00	19.120	0.03	18.120	604.00	
08	02	1.00	18.69	0.03	17.690	589.66	602.33
	03	1.00	19.40	0.03	18.400	613.33	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II
Pilot Scale Sanitary Landfill Operation
Data Sheet: October/08
Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
04.10.	01	1.00	19.05	0.03	18.05	601.66	
08	02	1.00	18.67	0.03	17.67	589.00	600.55
	03	1.00	19.33	0.03	18.33	611.00	
	01	1.00					
	02	1.00					
	03	1.00					
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II
Pilot Scale Sanitary Landfill Operation
Data Sheet: November/08
Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
30.11.	01	1.00	17.750	0.03	16.75	558.33	
08	02	1.00	16.75	0.03	15.75	525.00	547.77
	03	1.00	17.80	0.03	16.80	560.00	
	01	1.00					
	02	1.00					
	03	1.00					
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II
Pilot Scale Sanitary Landfill Operation
Data Sheet: December/08
Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
08.12.	01	1.00	17.300	0.03	16.300	543.33	
08	02	1.00	17.925	0.03	16.925	546.166	544.99
	03	1.00	17.365	0.03	16.365	545.50	
27.12.	01	1.00	16.875	0.03	15.875	529.16	
08	02	1.00	17.325	0.03	16.325	544.16	544.77
	03	1.00	17.830	0.03	16.830	561.00	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: January/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
04.01.	01	1.00	16.650	0.03	15.650	521.66	
09	02	1.00	17.300	0.03	16.300	543.33	531.00
	03	1.00	16.840	0.03	15.840	528.00	
24.01.	01	1.00	17.925	0.03	16.925	531.00	
09	02	1.00	16.425	0.03	15.425	514.16	517.27
	03	1.00	16.200	0.03	15.200	506.66	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: February/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
10.02.	01	1.00	17.240	0.03	16.240	541.33	
09	02	1.00	16.40	0.03	15.40	513.33	523.88
	03	1.00	16.51	0.03	15.51	517.00	
28.02.	01	1.00	16.875	0.03	15.875	529.66	
09	02	1.00	17.325	0.03	16.325	544.16	527.05
	03	1.00	16.22	0.03	15.22	507.33	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: March/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
08.03.	01	1.00	18.43	0.03	17.43	581.00	
09	02	1.00	17.10	0.03	16.10	536.66	553.55
	03	1.00	17.29	0.03	16.29	543.00	
21.03.	01	1.00	17.70	0.03	16.70	556.66	
09	02	1.00	17.33	0.03	16.33	544.33	547.21
	03	1.00	17.22	0.03	16.22	540.66	
	01	1.00					
	02	1.00					
	03	1.00					

Data Sheet: April/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
02.04.	01	1.00	17.90	0.03	16.90	563.33	
09	02	1.00	17.18	0.03	16.18	539.36	549.90
	03	1.00	17.42	0.03	16.42	547.31	
25.05.	01	1.00	18.38	0.03	17.38	579.33	
09	02	1.00	17.16	0.03	16.16	538.66	550.00
	03	1.00	16.95	0.03	15.95	531.66	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: May/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
04.05.	01	1.00	18.82	0.03	17.82	594.00	
09	02	1.00	19.35	0.03	18.35	611.66	601.33
	03	1.00	18.95	0.03	17.95	598.33	
23.05.	01	1.00	20.00	0.03	19.00	633.34	
09	02	1.00	18.00	0.03	17.00	566.66	598.88
	03	1.00	18.90	0.03	17.90	596.66	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: June/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
03.06.	01	1.00	19.34	0.03	18.34	612.66	
09	02	1.00	19.15	0.03	18.15	605.00	615.88
	03	1.00	19.50	0.03	18.90	630.00	
28.06.	01	1.00	19.70	0.03	18.70	623.33	
09	02	1.00	17.90	0.03	16.90	563.33	592.22
	03	1.00	18.70	0.03	17.70	590.00	
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: July/09

Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
04.07.	01	1.00	19.58	0.03	18.58	619.33	
08	02	1.00	19.00	0.03	18.00	600.00	598.90
	03	1.00	18.38	0.03	17.38	579.33	
	01	1.00					
	02	1.00					
	03	1.00					
	01	1.00					
	02	1.00					
	03	1.00					

Waste Safe II

Pilot Scale Sanitary Landfill Operation

Data Sheet: August/09

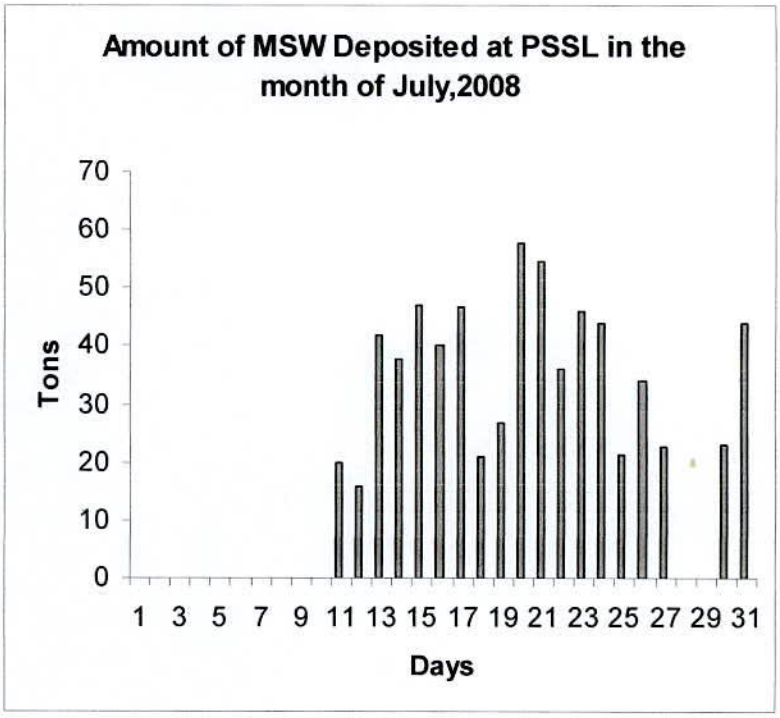
Specific Weight Data

(All Weight measurement in kg, Volume measurement in m^3, Specific Wt unit is kg/m^3)

Date	Serial No.	Weight of Container (A)	Weight of container + Waste (B)	Volume of Container (V)	Weight of Waste (W=B-A)	Specific Weight (W/V)	Average Specific Weight
09.08.	01	1.00	19.32	0.03	18.32	610.66	
09	02	1.00	18.88	0.03	17.88	596.00	601.55
	03	1.00	18.94	0.03	17.94	598.00	
26.08.	01	1.00	18.64	0.03	17.64	588.00	
09	02	1.00	19.58	0.03	18.58	619.33	604.66
	03	1.00	19.20	0.03	18.20	606.66	
	01	1.00					
	02	1.00					
	03	1.00					

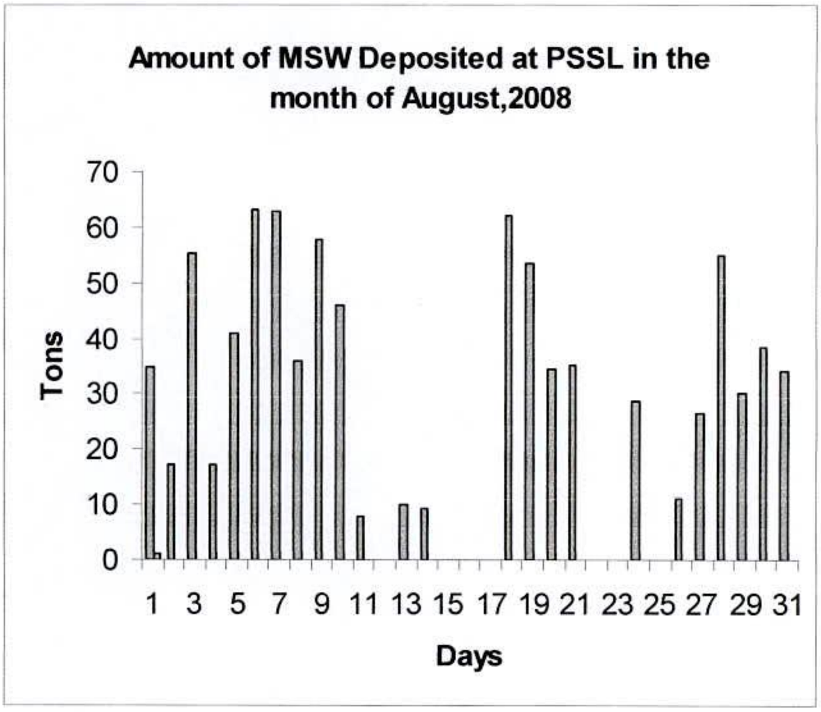
ANNEX E
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	20.059
12	15.673
13	41.943
14	37.832
15	47.175
16	40.216
17	46.524
18	21.06
19	26.78
20	57.48
21	54.403
22	36.191
23	45.858
24	43.886
25	21.266
26	34.036
27	22.591
28	0
29	0
30	22.917
31	44.072



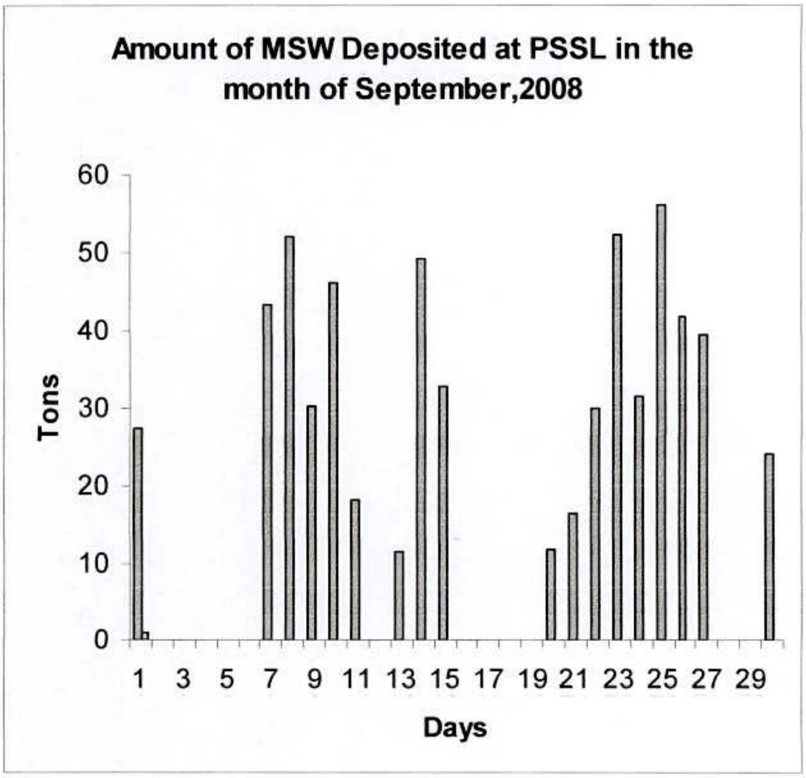
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	34.783
2	17.244
3	55.168
4	17.272
5	40.75
6	63.19
7	62.671
8	35.831
9	57.903
10	45.95
11	7.764
12	0
13	10.167
14	9.466
15	0
16	0
17	0
18	62.133
19	53.615
20	34.441
21	35.157
22	0
23	0
24	28.742
25	0
26	11.307
27	26.432
28	54.851
29	30.085
30	38.311
31	33.946



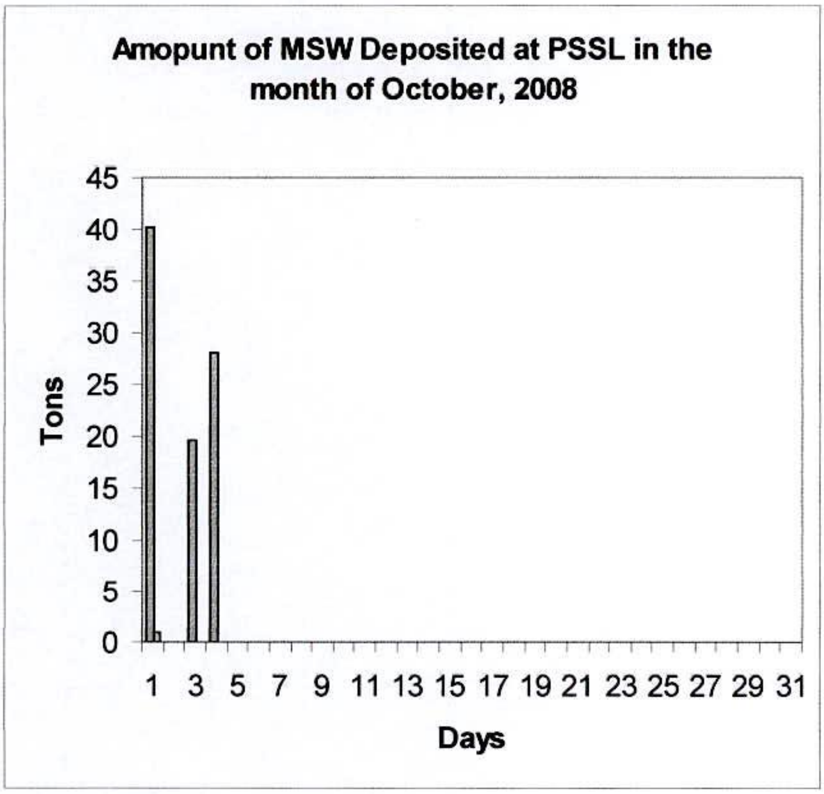
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	27.345
2	0
3	0
4	0
5	0
6	0
7	43.252
8	51.94
9	30.337
10	46.178
11	18.188
12	0
13	11.664
14	49.158
15	32.822
16	0
17	0
18	0
19	0
20	11.88
21	16.462
22	29.904
23	52.374
24	31.536
25	56.084
26	41.684
27	39.489
28	0
29	0
30	24.156



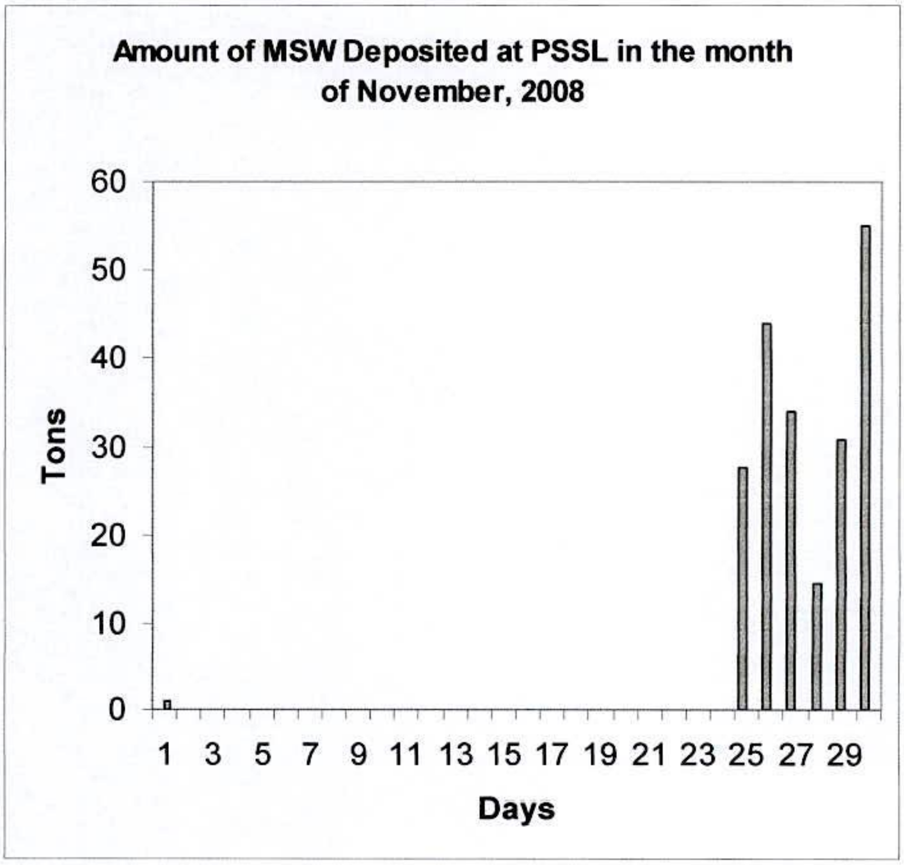
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	40.186
2	0
3	19.614
4	28.158
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0



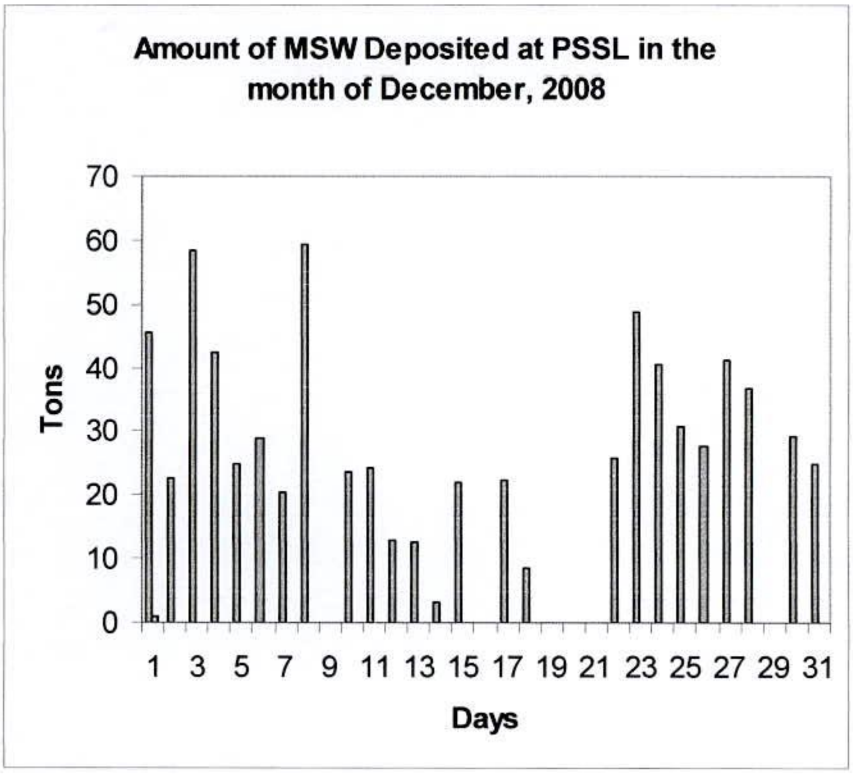
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	27.603
26	43.876
27	33.878
28	14.383
29	30.682
30	54.966



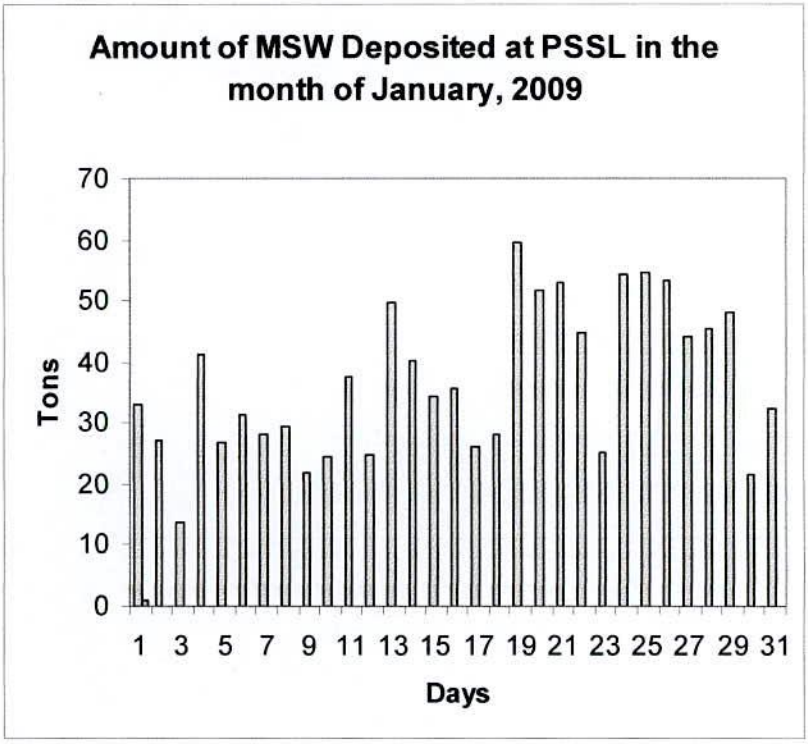
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	45.466
2	22.481
3	58.343
4	42.494
5	24.737
6	28.905
7	20.335
8	59.204
9	0
10	23.42
11	24.298
12	12.972
13	12.41
14	3.08
15	21.956
16	0
17	22.347
18	8.583
19	0
20	0
21	0
22	25.731
23	48.766
24	40.647
25	30.704
26	27.531
27	41.058
28	36.697
29	0
30	29.148
31	24.902



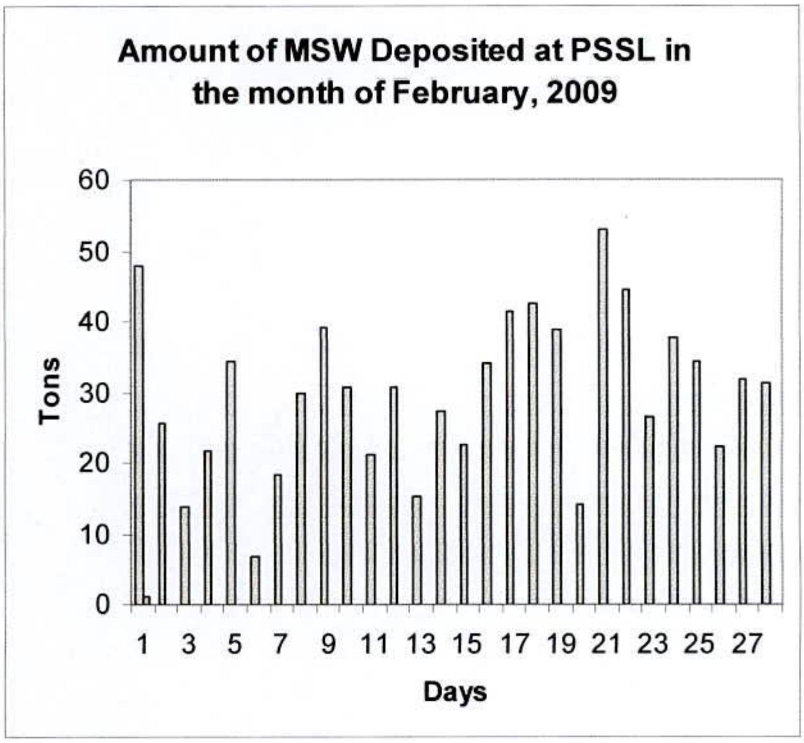
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	32.942
2	27.137
3	13.673
4	41.247
5	26.865
6	31.32
7	28.075
8	29.477
9	21.944
10	24.507
11	37.663
12	24.895
13	49.781
14	40.145
15	34.325
16	35.64
17	26.251
18	28.146
19	59.68
20	51.631
21	52.85
22	44.751
23	25.25
24	54.459
25	54.529
26	53.403
27	44.014
28	45.468
29	48.05
30	21.518
31	32.409



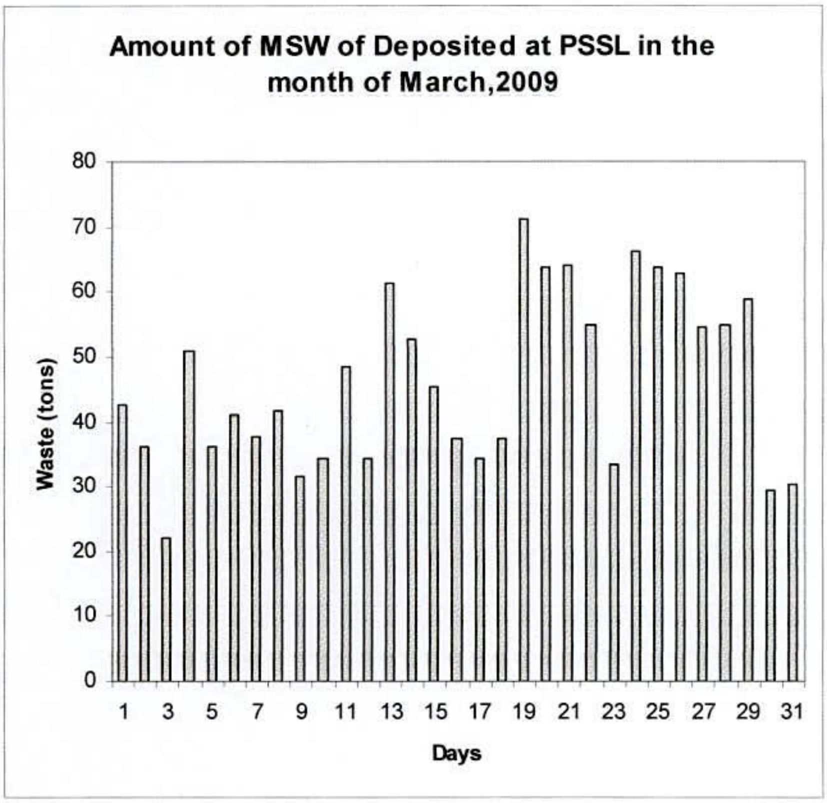
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	47.901
2	25.593
3	13.914
4	21.632
5	34.309
6	6.638
7	18.328
8	29.926
9	39.138
10	30.753
11	21.15
12	30.753
13	15.24
14	27.207
15	22.535
16	33.949
17	41.435
18	42.577
19	38.821
20	14.208
21	52.85
22	44.531
23	26.51
24	37.718
25	34.279
26	22.24
27	31.76
28	31.136



Waste Safe II
Pilot Scale Sanitary Landfill Operation

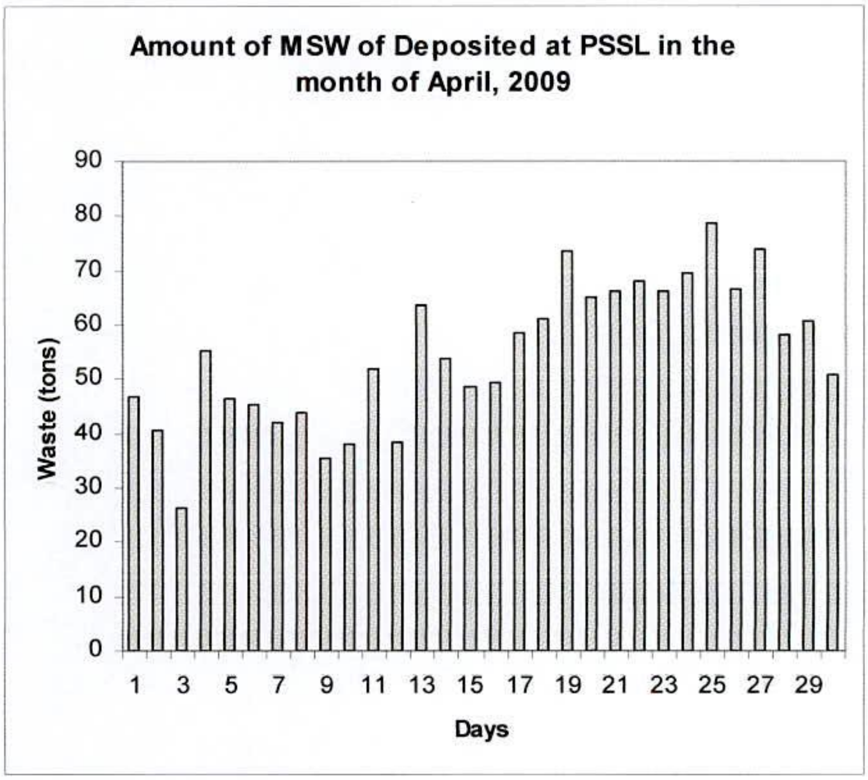
Days	Waste(tons)
1	42.473
2	36.203
3	22.095
4	50.984
5	36.104
6	41.138
7	37.56
8	41.805
9	31.569
10	34.255
11	48.349
12	34.228
13	61.451
14	52.722
15	45.483
16	37.504
17	34.364
18	37.459
19	71.065
20	63.771
21	64.041
22	54.799
23	33.406
24	66.159
25	63.763
26	62.935
27	54.546
28	54.878
29	58.73
30	29.523
31	30.276



Waste Safe II

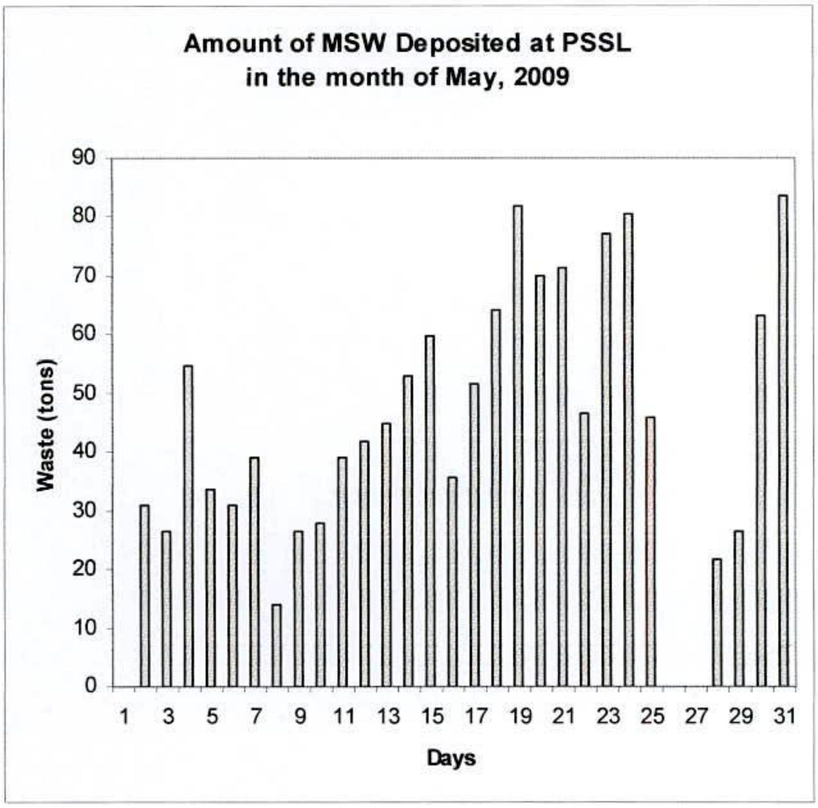
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	46.765
2	40.495
3	26.388
4	55.277
5	46.541
6	45.43
7	42.166
8	43.868
9	35.41
10	38.115
11	51.899
12	38.52
13	63.639
14	53.618
15	48.79
16	49.568
17	58.547
18	60.947
19	73.613
20	65.206
21	66.054
22	68.153
23	66.365
24	69.354
25	78.613
26	66.488
27	74.035
28	58.073
29	60.704
30	50.9



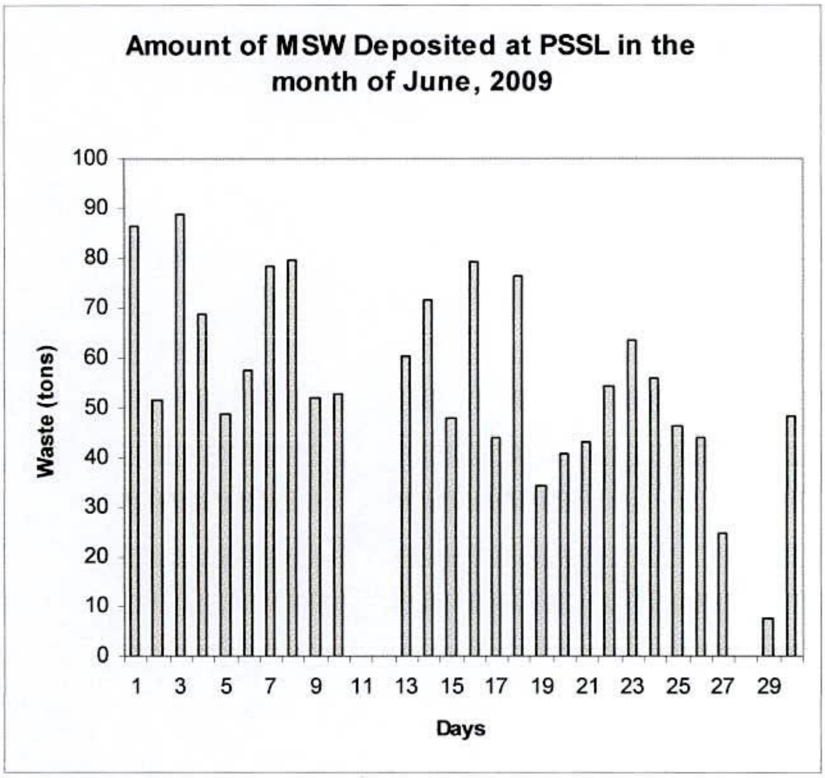
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	0
2	31.01
3	26.39
4	54.513
5	33.758
6	30.811
7	38.906
8	13.866
9	26.448
10	27.93
11	39.211
12	41.894
13	44.841
14	53.107
15	59.875
16	35.703
17	51.675
18	64.251
19	81.737
20	70.042
21	71.249
22	46.605
23	77.162
24	80.427
25	45.915
26	0
27	0
28	21.607
29	26.39
30	63.071
31	83.649



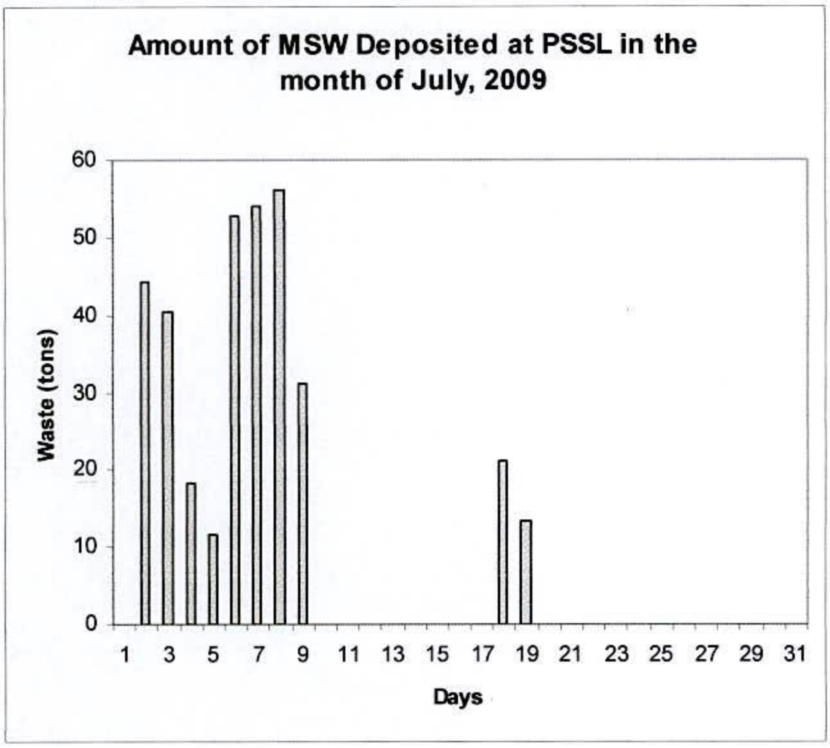
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	86.206
2	51.5
3	88.823
4	68.763
5	48.62
6	57.712
7	78.412
8	79.601
9	51.872
10	52.681
11	0
12	0
13	60.306
14	71.744
15	48.111
16	79.06
17	44.049
18	76.21
19	34.529
20	40.803
21	43.262
22	54.531
23	63.535
24	55.942
25	46.21
26	43.893
27	24.615
28	0
29	7.728
30	48.46



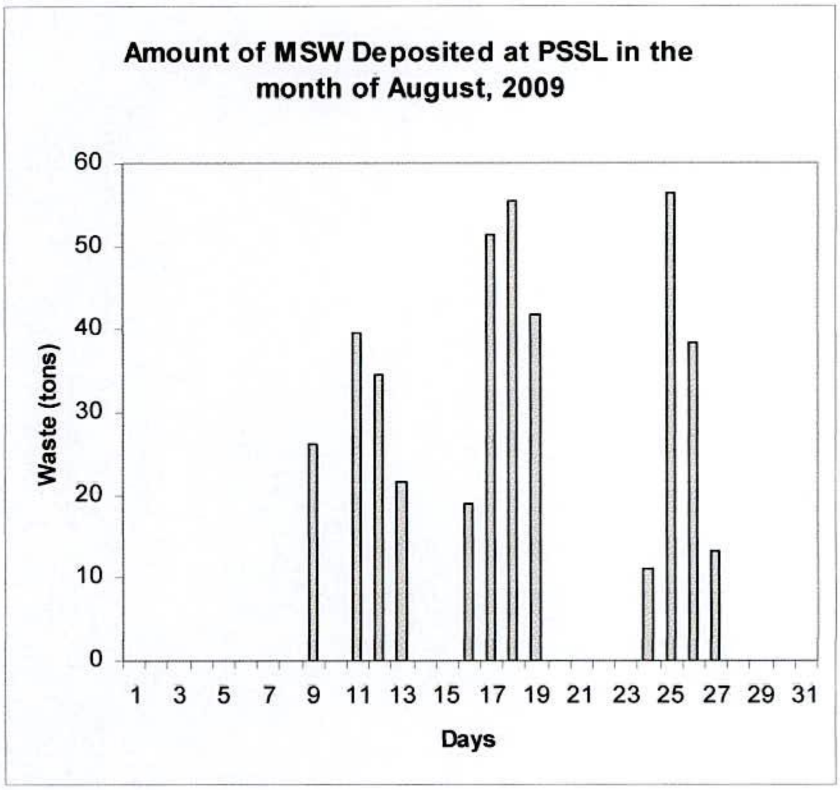
Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	44.24
2	40.366
3	18.338
4	11.558
5	52.741
6	54.182
7	56.151
8	31.033
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	21.206
18	13.495
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0



Waste Safe II
Pilot Scale Sanitary Landfill Operation

Days	Waste(tons)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	26.217
10	0
11	39.584
12	34.551
13	21.596
14	0
15	0
16	18.968
17	51.458
18	55.507
19	41.821
20	0
21	0
22	0
23	0
24	11.017
25	56.356
26	38.473
27	13.081
28	0
29	0
30	0
31	0



Annex F

Test Results of Ground Water and Leachate

Test No- 01 Date:-14/07/08

S.L No-	Test Parameter	unit	Cannel Water	Dumping Site Water
01	P^H		7.54	7.75
02	Iron	mg/l	0.1	0.9
03	Salinity	mg/l	270.0	240.0
04	DO-1	mg/l	5.31	6.87
	DO-5	mg/l	4.84	4.1
05	TDS	mg/l	1750.0	2410.0
06	Alkalinity	mg/l	100.0	435.0
07	Hardness	mg/l	424.0	370.5
08	COD	mg/l	1600.0	640.0

Test No- 02 Date:-25/11/08

S.L No-	Test Parameter	unit	Cannel Water	Dumping Site water
01	P^H		7.17	7.75
02	Iron	mg/l	0.0	6.02.1
03	Salinity	mg/l	487.5	812.5
04	DO-1	mg/l	1.54	3.55
	DO-5	mg/l	0.86	1.7
05	TDS	mg/l	3750.0	2730.0
06	Alkalinity	mg/l	1170.0	445.0
07	Hardness	mg/l	1083.42	1685.32
08	COD	mg/l	736.0	1800.0

Test No- 03 Date:-28/03/09

S.L No-	Test Parameter	Unit	Cannel Water	Landfill water	Leachate
01	P^H		8.29	7.75	7.82
02	Iron	mg/l	0.06	6.6	7.2
03	Salinity	mg/l	157.5	372.5	602.5
04	DO-1	mg/l	4.69	0.31	0.32
	DO-5	mg/l	3.18	0.27	0.28
05	TDS	mg/l	870.0	3090.0	3540.0
06	Alkalinity	mg/l	115.0	330.0	840.0
07	Hardness	mg/l	1833.48	750.0	916
08	COD	mg/l	1120.0	4800.0	6400.0

Test No- 04 Date:-14/09/09

S.L No-	Test Parameter	unit	Cannel	Dumping	Leachate
01	P^H		8.03	8.32	6.93
02	Iron	mg/l	0.06	0.33	0.45
03	Salinity	mg/l	105.0	500.0	350.0
04	DO-1	mg/l	1.16	1.07	1.06
	DO-5	mg/l	0.85	0.63	0.92
05	TDS	mg/l	200.0	1290.0	1460.0
06	Alkalinity	mg/l	160.0	300.0	150.0
07	Hardness	mg/l	138.9	648.2	1018.6
08	COD	mg/l	288.0	1408.0	256.0

Test No- 05 Date:-21/01/10

S.L No-	Test Parameter	unit	Treatment Pond	Cannel	Landfill
01	P^H		7.89	7.58	7.18
02	Iron	mg/l	6.0	1.77	0.0
03	Salinity	mg/l	375.0	426.0	225.0
04	DO-1	mg/l	4.68	3.35	2.38
	DO-5	mg/l	1.56	1.08	0.46
05	TDS	mg/l	1160.0	520.0	2340.0
06	Alkalinity	mg/l	800.0	300.0	1250.0
07	Hardness	mg/l	463.0	324.1	926.0
08	COD	mg/l	2080.0	1440.0	2240.0

Test No- 06 Date:-14/05/10

S.L No-	Test Parameter	unit	Cannel	Holding Tank	Landfill
01	P^H		6.32	6.8	7.5
02	Iron	mg/l	0.1	1.2	0.8
03	Salinity	mg/l	125	1300	425
04	DO-1	mg/l	4.90	0.98	0.90
	DO-5	mg/l	2.56	0.48	0.45
05	TDS	mg/l	820	3050	2310
06	Alkalinity	mg/l	200	900	750
07	Hardness	mg/l	277.8	1018.6	6694.5