Geoenvironmental Assessment of Ultimate Disposal Sites of Municipal Solid Waste in Some Major Cities of Bangladesh

by

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Declaration

This is to certify that the thesis work entitled as "Geoenviromental Assessment of Ultimate Disposal Sites of Municipal Solid Waste in Some Major Cities of Bangladesh" has been carried out by Kazi Abu Bakar Mohammad Mohiuddin 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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To

my parents who taught me morality

and

my beloved wife

ABSTRACT

The disposal site, termed as landfill can pose a long term threat to the human health and environment if not designed properly. This study aims to describe the present status and site potentiality of four ultimate disposal sites (UDS) receiving municipal solid waste (MSW) from the four major cities of Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal through field survey, impact analysis, laboratory tests. Physical, Environmental and geotechnical parameters are considered for the assessment of these UDS.

The study reveals that there is no controlled/engineered/sanitary landfill in the Dhaka, Khulna, Rajshahi and Barisal city of Bangladesh, the disposal sites are simply uncontrolled open dump. However, recently, Dhaka city has taken some practical initiatives to convert Matuail open dumping site into controlled landfill. The physical and technical facilities are almost absent in all sites. The leachate samples were collected from the studied sites and the laboratory analyses reveal wide variation of magnitudes as pH (6.2 to 8.2), Chloride (7.5 to 3000 mg/l), Iron (0.4 to 55 mg/l), TDS (260 to 8652 mg/l), BOD_5 (40 to 2550 mg/l), COD (110 to 5550 mg/l), Pb (0 to 0.425), Ni (0.001 to 0.46) and Cd (0 to 0.105). The ratio of BOD/COD ranges from 0.01 to 0.46 which shows biodegradability of leachate is very low. Leachate Risk Factors (LRF) was derived for identifying sites that may pose significant risk to the environment. It is depicted that the leachate poses significant risk to the environment and it requires treatment to ensure safety before discharge to the receiving environment.

This study also presents an estimation of methane (CH_4) emissions from the four actively functioning UDS by using the methodology developed by the Intergovernmental Panel on Climate Change (IPCC) which provides the baseline information of the contribution of MSW sector to global worming potential and waste-to-energy facilities. The total CH_4 emissions from the four studied sites were estimated as 31.18 Gg in the year of 2006. The ratio of CH_4 emitted to the amount of waste generated in four cities of Bangladesh varies from 0.008 to 0.015 which is analogous to the other developing countries of the world.

The sub-soil investigation was carried out at the close vicinity of landfill sites to identify the soil strata, physical and engineering properties and mineralogical compositions. Boring to a depth of 60 ft revealed that the fine sediment forms to a depth of about 5 ft followed by clay more than 30 ft thick having clay content ranges from 30 to 50% and hydraulic conductivity varies from $1.05x10^{-9}$ to $11.50x10^{-9}$m/s. Clay minerals account for more than two-thirds of the overall mineralogical composition in which non-swelling clay minerals, quartz varies from 20 to 60% and illite/muscovite ranges from 20 to 45%, while small amounts of kaolinite and feldspar also exist. Swelling clay minerals present in varying amounts of 10 to 25% of the composition and the CEC ranges from 13 to 25 meq/100g as estimated. Especially, the sub-soil formation of Dhaka, Khulna and Rajshahi appears to have suitable composition required for the construction of geologic clay liner (GCL). However, the soil samples from Barisal site exhibit low CEC values due to the existence of low amount of swelling clay minerals. The characterization of clay of selected shallow layer from the studied sites is suitable as compacted clay liner (CCL) for the construction of sanitary landfill.

CONTENTS

List of Tables

List of Figures

List of Photographs

Abbreviations

ADB	:	Asian Development Bank
BBS	:	Bangladesh Bureau of Statistics
BCAS	:	Bangladesh Centre for Advanced Studies
BCC	:	Barisal City Corporation
BCSIR	:	Bangladesh Council of Scientific and Industrial Research
BOD	:	Biochemical Oxygen Demand
BS	:	British Standard
BUET	:	Bangladesh University of Engineering and Technology
C	:	Carbon
CCL	:	Compacted Clay Liner
CEC	:	Cation Exchange Capacity
COD	:	Chemical Oxygen Demand
C/N	:	Carbon Nitrogen Ratio
DCC	:	Dhaka City Corporation
DOC	:	Degradable Organic Carbon
DS	:	Disposal Site
EPA	:	Environmental Protection Agency
FOD	:	First Order Decay
GCL	:	Geologic Clay Liner
GOB	:	Government of Bangladesh
GPS	:	Geographical Positioning System
HCl	:	Hydrochloric acid
HNO_3	:	Nitric acid
IHS	:	Indian Health Service
IPCC	:	Intergovernmental Panel on Climate Change
ISWM	:	Integrated Solid Wastes Management
JICA	:	Japan International Cooperation Agency
K	:	Potassium
KCC	:	Khulna City Corporation
KDA	:	Khulna Development Authority
KUET	:	Khulna University of Engineering and Technology
LDACs	:	Least Developed Asian Countries
LFG	:	Landfill Gas
LRF	:	Leachate Risk Factor
MAV	:	Maximum Acceptable Value

MC	:	Moisture Content
MLS	:	Matuail Landfill Site
MSW	:	Municipal Solid Waste
MSWL	:	Municipal Solid Waste Landfill
N	:	Nitrogen
NDS	:	North Kawnia Disposal Site
NGO	:	Non Govermental Organization
NIMBY	:	Not in My Back Yard
OEL	:	Occupation Exposure Limit
P	:	Phosphorous
RCC	:	Rajshahi City Corporation
RCRA	:	Resource Recovery and Conservation Act
SDS	:	Secondary Disposal Site
SH	:	Shomobay Housing
SPDS	:	Shishu Park Disposal Site
SRDI	:	Soil Resource Development Institute
SWDS	:	Solid Waste Disposal Site
TDS	:	Total Dissolved Solid
TOC	:	Total Organic Carbon
TK	:	Taka
UDS	:	Ultimate Disposal Site
UNDP	:	United Nations Development Programme
USCS	:	Unified Soil Classification System
VOC	:	Volatile Organic Compound
VS	:	Volatile Solid
WHO	:	World Health Organization

Units of Measurement

Gg	:	Giga gram
gm	:	Gram
kg	:	Kilogram
km	:	Kilometer
km^2	:	Square Kilometer
Kg/m^3	:	Kilogram per Cubic Meter
KJ/kg	:	Kilojoule per Kilogram
kg/day	:	Kilogram per Day
kg/cap/day	:	Kilogram per Capita per Day
l/day	:	Liter per Day
mm	:	Millimeter
m	:	Meter
m^3	:	Cubic Meter
ml	:	Milliliter
Mg	:	Mega gram
mg	:	Milligram
mg/l	:	Milligram per liter
nm	:	Nanometer
ppm	:	Parts per million

CHAPTER ONE

INTRODUCTION

1.1 General

The safe and reliable long-term disposal of solid wastes is an important component of integrated waste management. Solid waste materials are most often placed in landfills, which can range from uncontrolled open dumps to engineered sanitary landfills. Landfills are facilities for disposing of solid wastes in a controlled fashion. They began to appear in the early twentieth century as replacements for the open dumps that were being used to dispose of wastes.

The lack of appropriate disposal system of MSW result their accumulation of uncontrolled refuse, which cause the pollution and the environmental damage. Indiscriminate throwing of solid waste have resulted in scattered garbage, offensive odor, polluted water and breeding place for mosquitoes and flies. Municipal Solid Waste Landfill (MSWL) is very important to keep environmental clean and beautiful.

1.2 Problem Statement

Solid waste management has become one of the major concerns in Bangladesh. Rapid population growth and uncontrolled urbanization are severely degrading the urban environment and placing serious strains on natural resources and consequently, undermining equitable and sustainable development. Solid waste generation of urban areas of Bangladesh is increasing proportionately with the growth of its population, which is 5.6 percent per annum (JICA, 2004), while solid waste management capacity in cities and towns is lagging behind and the gap is widening every day. In the urban areas, appropriate measures for waste disposal are urgently needed due to the rapid population growth, which resulting the huge increase of MSW.

It is believed that disease occurs due to a disturbance balance between man and his environment. The sanitary environment in the urban areas has deteriorated causing adverse impacts on the health of the residents. Furthermore, the improper management of disposing partially collected MSW causing adverse environmental impacts, which threat to human and nature.

Various studies have been conducted by the assistance of Asian Development Bank (ADB), Japan International Cooperation Agency (JICA) and United Nations Development Program (UNDP) in only Dhaka city whereas no explicit study in other major cities of Bangladesh has been conducted so far. So it is necessary to assess the existing UDS. This study was performed at four UDS in terms of physical characteristics, geotechnical and environmental parameters; receiving municipal solid wastes (MSW) from the four major cities of Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal.

The outcome of this research will clearly represent the present status of UDS of MSW of these studied cities of Bangladesh. The findings will be beneficial for any responsible authority for the potential landfill site selection, installation of clay liner facility, leachate treatment method, carbon credit system, waste to electricity generation plant, up-gradation the existing sites by local available materials and resources or any other cost effective safe and sustainable landfill design and construction.

1.3 Objectives and Scope of the Study

This study is aimed at to manifest the role of geoenvironmental engineering in city development, environment and municipal solid waste management to control pollution and groundwater contamination. The ultimate goal of the study is to determine the overall impact assessment, characteristics of leachate and rate of methane emission, availability and quality of geologic and compacted clay liner materials beneath the UDS and ground water pollution potential.

The major objectives of this study can be listed by the followings:

i) To evaluate the present status of four UDS of MSW in four major cities of Bangladesh.

ii) To determine the characteristics of leachate and leachate risk factors in the studied UDS.

iii) To estimate the methane and equivalent CO_2 emission from the four UDS of study areas.

iv) To identify the availability and suitability of sub-soil of UDS as natural geologic clay liner (GCL) in four major cities of Bangladesh.

v) To investigate the properties of compacted clay liner (CCL) for the subsoil beneath the studied UDS.

At present no effective MSW management is practiced even in major cities of Bangladesh. The scope of study is to compile and collect the existing information concerning UDS status, physical infrastructures, site geology, clay mineralogy, characteristics of leachate, estimation of methane emission in the four major cities of Bangladesh. The reliable informations are collected and the relevant parameters are determined based on the data of primary and secondary sources. Analyses the available data for GCL and CCL, leachate risk factor and overall impact assessment of the four studied UDS.

1.4 Structure of the Thesis

The thesis presents literature review, data analysis and findings of the study in seven chapters and five annexure, as stated below. In addition, a bibliography of related publications has been presented.

Chapter 1 : This chapter includes problem statement, objectives and scope of the study.

Chapter 2 : Literature review covering details about concept of MSW, landfill site selection criteria, criteria for geological clay liner (GCL) and compacted clay liner (CCL) of MSW disposal site, generation and estimation of landfill gas and its affecting factors. Physiochemical and trace metal composition of MSW disposal site leachate with leachate risk factor and overall impact assessment criteria are also described here.

Chapter 3 : Overview of study areas including general informations and existing MSW management practices are described in this chapter.

Chapter 4 : This chapter includes methodology of data collection, field survey & testing, and various laboratory experiments have been conducted.

Chapter 5 : This chapter presents the physical assessment of the existing UDS.

Chapter 6 : The results obtained in this study including brief discussion on the results are presented in this chapter.

Chapter 7 : This chapter includes the conclusions of the findings as an outcome of this study and provides recommendations for future research.

References : A list of relevant publications and reports, which may be useful for any future study in this context, is included at the end of the main chapters.

Abbreviations : Lists of abbreviations used in this thesis are provided here.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Municipal Solid Waste containment facility has the longest history of success and/or failure application. The physical, geotechnical and environmental assessment are the primary factors that should be considered for the environmental sound containment facility.

The purpose of this chapter is to provide the background of concept of MSW, landfill site selection criteria, criteria for geological clay liner (GCL) and compacted clay liner (CCL) of MSW disposal site, generation and estimation of landfill gas and its affecting factors. Physiochemical and trace metal composition of MSW disposal site leachate with leachate risk factor and overall impact assessment criteria are also described here.

2.2 Municipal Solid Waste

MSW is normally assumed to include all the community wastes with the exception of industrial process wastes, agricultural solid wastes and sewage sludge. According to Environmental Protection Agency (EPA) definition, MSW includes durable goods, non-durable goods, containers and packaging, food wastes, yard wastes and miscellaneous inorganic wastes from residential, commercial and institutional sources. MSW can be categorized as: appliances, newspapers, clothes, food scrapes, boxes, disposable tableware, office and classroom paper, wood pallets, rubber tires and cafeteria wastes.

MSW does not include a wide variety of other non hazardous wastes that often are landfilled along with MSW. Other non hazardous wastes includes municipal sludge, combustion ash, hazardous and non-hazardous industrial process wastes, agricultural solid wastes, construction and demolition wastes and automobile bodies (Tchobanoglous et al., 2002).

2.3 Concept of Solid Waste Management

Solid waste management concept is defined differently in developed countries and developing countries. Tchobanoglous, et al, (1993) addressed that the technology aspect of solid waste management was in order to achieve the best principle, efficiency, aesthetically aspect and environmental consideration in according to the level of economy. But Furedy, (1992) stated that in developing countries, in order to understand solid waste management, one had to examine the complexity of interaction among life styles, consumption pattern, form of energy, degrees of poverty and need, social diversity, financial and human resources, system of transportation, types of industrial organization and agriculture and other systematic factor. Typical hierarchy of integrated solid waste management is shown in Fig. 2.1.

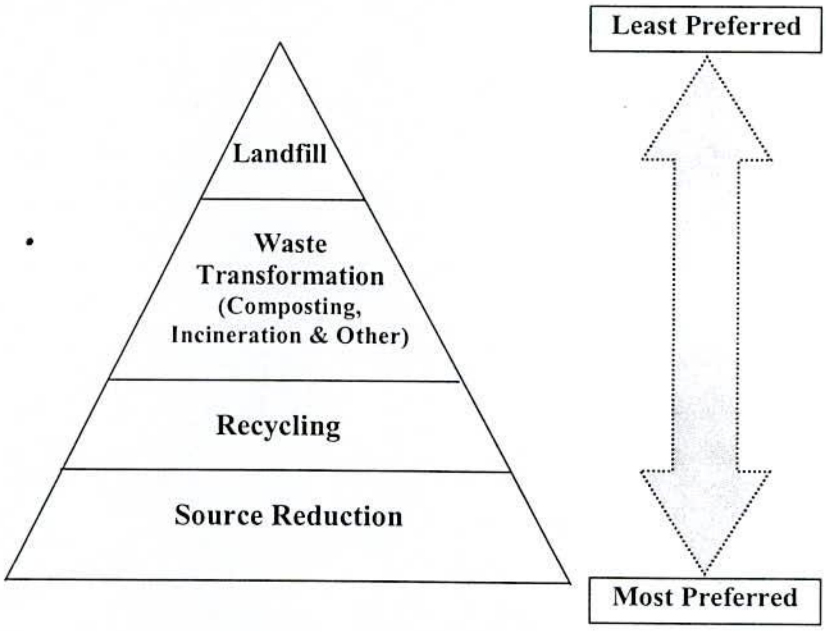

Figure 2.1: Typical hierarchy of integrated solid waste management.

2.4 Solid Waste Disposal

The safe and reliable long-term disposal of solid wastes is an important component of integrated waste management. Although source reduction, reuse, recycling, and composting can divert significant portions of MSW, large amount of wastes still needs to be placed in landfills. Landfills can be classified by three general categories:

i) Open dumps, ii) Controlled dumps and iii) Sanitary landfills

Obviously, these three types of landfills are points on a continuum, with facilities in developing countries most often falling somewhere between open dumps and controlled dumps. The main distinguishing characteristics of each of the three types are summarizes in Table 2.1.

Table 2.1: Key characteristics of MSW landfill

Type	Characteristics
Open dump	poorly sited unknown capacity no cell planning little or no site preparation no leachate management no gas management only occasional cover no compaction of waste no fence no record keeping uncontrolled waste picking and trading
Controlled dump	sited with respect to hydro-geology planned capacity no cell planning grading, drainage in site preparation partial leachate management partial or no gas management regular (not usually daily) cover compaction in some cases fence basic record keeping controlled waste picking and trading
Sanitary landfill	site based on Environmental Risk Assessment planned capacity designed cell development extensive site preparation full leachate management full gas management daily and final cover compaction fence and gate record volume, type and source no waste picking

(Source: Tchobanoglous et al., 2002)

2.5 Open dump approach

Open dump is a traditional and common MSW disposal practice in most Asian countries because of its simplicity such as no need investment for engineering designs, facilities of construction and technical operation. It needs only land area for dumping MSW and then allow solid wastes degradation under natural condition. Table 2.2 illustrates the disposal methods in some selected countries of the Asia. Environmental impacts from open dump are contamination to surface and ground water from leachate, landfill gas emission (e.g. CH_4 and CO_2) and breeding of disease vectors. Furthermore, some open dump sites burning is prevalent to reduce amount of MSW to save land area, recover valuable materials and sale, reduce odor from MSW decomposition. Open burning causes air pollution problems. Therefore, open burning and scavenging are also common practices at dump sites in this region (Hogland, 2005). Presently, open dumping is being phase out in many countries. The closure or upgrading of existing dump sites to engineering landfill is the important steps.

Table 2.2 Disposal methods of MSW in selected countries of the Asia

Country/territory	Disposal methods (%)				
	Open dumping	Composting	Land filling	Incineration	Others*
Bangladesh	95	0	0	0	5
Japan	0	10	15	75	0
Indonesia	60	15	10	2	13
Malaysia	50	10	30	5	5
Nepal	70	5	10	0	15
Philippine	75	10	10	0	5
Republic of Korea	20	5	60	5	10
Singapore	0	0	30	70	0
Sri Lanka	85	5	0	0	10
Thailand	65	10	5	5	15
Vietnam	70	10	0	0	20

*Animal feeding, dumping in water bodies, ploughing into soil and open burning

Source: Wiyada Wisiterakul (2006)

2.6 Landfill Technology

Wastes those are susceptible to contaminate air, groundwater and surface water are needed to contain in an engineered safe containment system, known as engineered or sanitary landfills. In particular, landfill is the term used to describe the physical facilities used for the disposal of solid wastes and solid wastes residuals in the surface soils of the earth. Once a contaminant has escaped into the ground, it flows from pore to pore through the soil, sometimes travelling several kilometres.

The manner and rate of transport depend on many factors, including:

- Whether the soil is saturated or unsaturated
- The type of soil
- The type of material flowing through the soil, especially its solubility in water and its specific gravity
- The velocity and direction of natural groundwater flow
- The rate of infiltration from the source

The primary functions of waste containment systems are (Reddi and Inyang 2000):

- Minimization of the intrusion of moisture, which can generate and mobilize leachate,
- Minimization of the transport of waste constituents into the surrounding environment and
- Isolation of wastes such that the potential for contact by humans and other animals is minimized.

2.6.1 Evolution of Landfill Technology

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 control municipal waste were 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 of land filling has remained relatively unchanged right up to the present day. The summary of the evolution of municipal landfills is given in Table 2.3.

Table 2.3 Summary of municipal landfill evolution (after Bouzza et al. 2002)

Period	Development	Problems	Improvements
1970s	Sanitary landfills	Health/nuisance i.e. odour, fires, litter	Daily cover, better compaction, engineered approach to containment
Late 1970-early 1980s	Engineered landfills, recycling	Ground and ground water contamination	Engineered liners, covers, leachate and gas collection systems, increasing regulation, financial assurance
Late 1980s-early 1990s	Improved sitting and containment, waste diversion and re-use	Stability, gas migration	Incorporation of technical, socio-political factors into sitting process, development of new lining materials, new cover concepts, increased post-closure use
2000s	Improved waste treatment	?	Increasing emphasis on mechanical and biological waste pretreatment, leachate recirculation and bioreactors, "smart landfills"

2.6.2 An Overview of Sanitary Landfill

A landfill receive following type of wastes: (i) Municipal solid waste (MSW), (ii) Industrial solid waste, (iii) Agricultural solid waste, (iv) Sewage sludge, (v) Combustion by-products and (vi) Mining solid waste, for ultimate disposal in a safe encapsulation. Based on the type of ladfill may be categories into three classes: (a) Class-I: Hazardous wastes, (b) Class-II: Designated and (c) Class-III: MSW. However, in class III landfills, limited amount of nonhazardous industrial wastes and sludge from water and wastewater treatment plants are also accepted. Designated wastes are nonhazardous wastes that may release of constituent in concentration that are in excess of applicable water quality objectives establish by recognized authority. Again, based on the physical infrastructures and other associated facilities landfill also designed as:

(a) Sanitary landfill: denote the facility in which waste placed in the landfill is covered at the end of each day's operation.

Today, it refers to an Engineering facility for the disposal of MSW designated and operated to minimize public health & environmental impacts.

(b) Monofill: contains individual wastes constituents such as combustion ash, asbestos, and other similar wastes.

(c) Secure landfill: denote the facility which is used for the disposal of hzardous wastes, and

(d) Uncontrolled land disposal site: refer to those places where waste is dumped on or into the ground in no organized manner.

Concerns with the landfilling of solid wastes are related to the following (Tchobaoglous 2002):

- The uncontrolled release of landfill gases that might migrate off-site and cause odor and other potentially dangerous conditions,
- The impact of uncontrolled discharge of landfill gases on the greenhouse effect in the atmosphere,
- The uncontrolled release of leachate that might migrate to underlying groundwater or surface streams,
- The breeding and harboring of disease vectors in improperly managed landfills,
- The health and enviornmental impacts associated with the release of the trace gases found in landfills arising from the hazardous materials that were often placed in landfills in thepast.

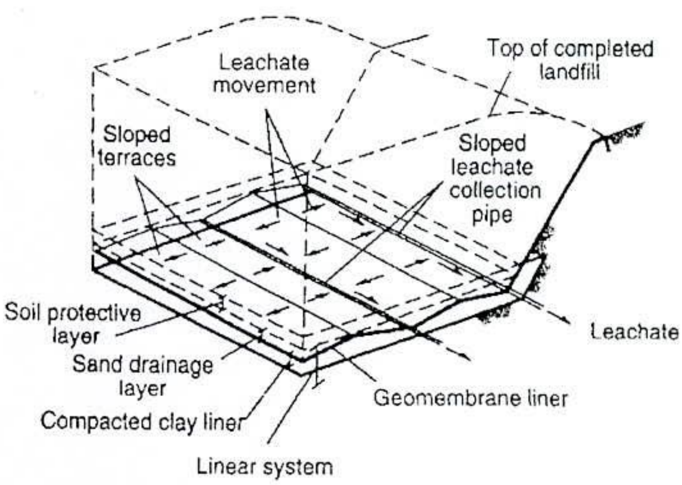

Figure 2.2 (a) A constructed landfill ready for solid waste deposition (after Tchobanoglous et al., 2002)

Therse are two major aspects associated with the instalaltion and functioning of a landfill: these are **Management** which consists of the following key elements of landfill: planning, design, operation, environmental monitoring, closure and postclosure control. **Technical** which consists of following key technical aspects associated mostly with the design: site selection, decomposition, liners, covers, leachate collection and treatment, gas collection and resource recovery or control, closure an postclosure.

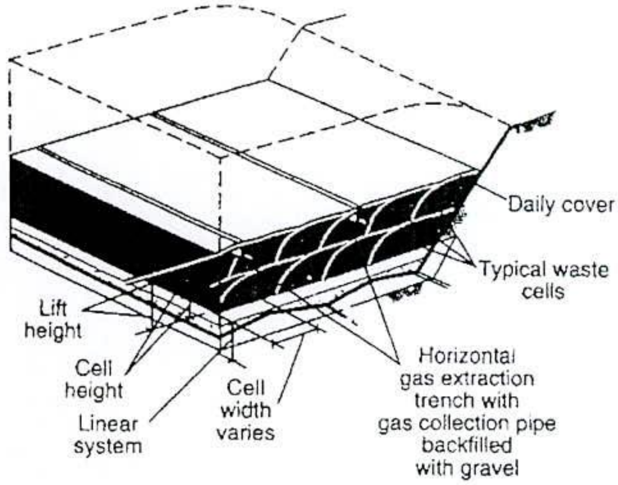

Figure 2.2 (b) Solid wastes deposition is in progress (after Tchobanoglous et al., 2002)

The schematic diagram to illustrate the general features of a sanitary landfill is presented in Figures 2.2 (a), (b) and (c). The figures depict three steps: constructed landfill, deposition of wastes and completed landfill. The following elements are associated with sanitary landfills: Cell, Daily cover, Lift, Bench (terrace), Final lift, Lift height, Cell height & width, Landfill liners (Compacted landfill liner and Geomembrane liner), Landfill cover (Top soil, Drainage layer, Sloped surface, Geomembrane), Leachate collection system (Leachate treatment, Recirculation) and Landfill gas (Gas collection, resource recovery). Details descriptions about the functions of these elements can be obtained in Ludwig et al. (2003), Testa (1993), Tchobaoglous (2002), (Reddi and Inyang 2000) Tchobaoglous et al. (1993), Bradshaw et al. (1992).

Infact a landfill is a biochemical reactor, in which solid wastes and water as the major inputs, while leachate and landfill gas as the major outputs. Landfill gas controll systems are employed to prevent unwanted movement of landfill gas into the

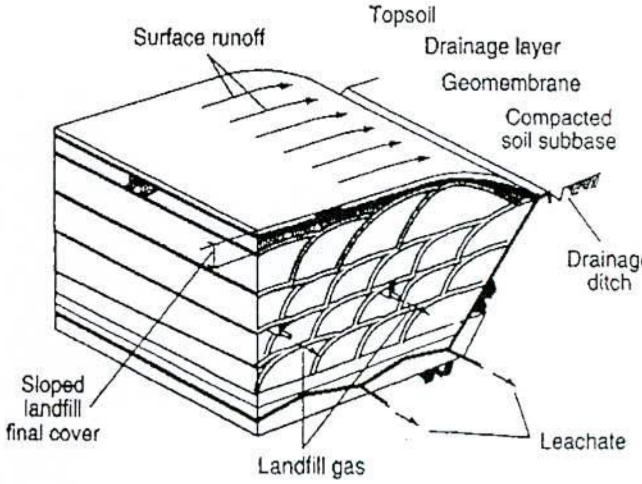

Figure 2.2 (c) Completed landfill with final cover (after Tchobanoglous et al., 2002)

atmosphere. The covered landfill gas can be used to produce energy or flared under controlled conditions to eliminate the discharge of harmful constituents to the atmosphere.

Leachate, the contanimated byproduct of water and solid wastes, is found under the bottom of landfills at normal conditons and moves to the underlying strata. The effects of leacate depend on its chemical and biological constituents and the sub-soil conditions. It is recorded that a number of sanitary landfills contaminated the groundwater through leakage. To save the groundwater from the potential risk, double base liner, detection, collection and removal system are introduced in sanitary landfills.

2.7 Landfill Design Principles

According to the state of technology any waste deposition has to be secured by a multibarrier encapsulation system shown in Figure 2.3. Cap liners and base liners have to be constructed in different ways because they serve different purposes. Cap liners have to prevent precipitation water to infiltrate into the waste and base liners seal the waste from the underground rock resp. groundwater. Standard combined systems consist of mineral barriers and geomembranes. A drainage system at the base for seapage control and a gas collection installation at the surface in case of municipal waste complete the system.

2.7.1 Clay liners and waste disposal

As populations grow and technologies advance, ever-more wastes are produced in ever-growing quantities. Of the many and varied environmental problems, encapsulation of wastes in order to restore sites and protect the environment is the topic of this chapter. Encapsulation means sealing the waste body by geological and engineered liner systems, which in most cases partly consist of clay liners in different modifications. Encapsulation systems are as varied as the environments in which they are built, and the components of an encapsulation system are as multiple and complex as the wastes therein. For all waste types, encapsulation is the only option: permanent isolation from the accessible environment. The requirements for an encapsulation system are basically the same; whether the waste is municipal refuse in a landfill, hospital debris in a low level waste dump, or mixed wastes of diverse industrial productions or construction activities. This leads us to the need to classify wastes because encapsulation systems consist of engineered liner components according to the magnitude of the risks originating from the waste.

From the beginning: sophisticated engineered liners serve two purposes. They have to guarantee practical imperviousness to prevent leachates from infiltrating the environment and secondly have to prove retention or at least retardation properties to prevent contaminant migration by convection and diffusion. In many cases - but not absolutely - the capping barrier might be designed as slightly permeable layer, because further decomposition of sanitary wastes by precipitation moisture could be achieved. Because of the different functions of the surface and the base encapsulation barriers, different systems are state of the art. In any case, for most of the required properties, clay liners are optimal. Practical imperviousness of liner system is shown in Figure 2.4.

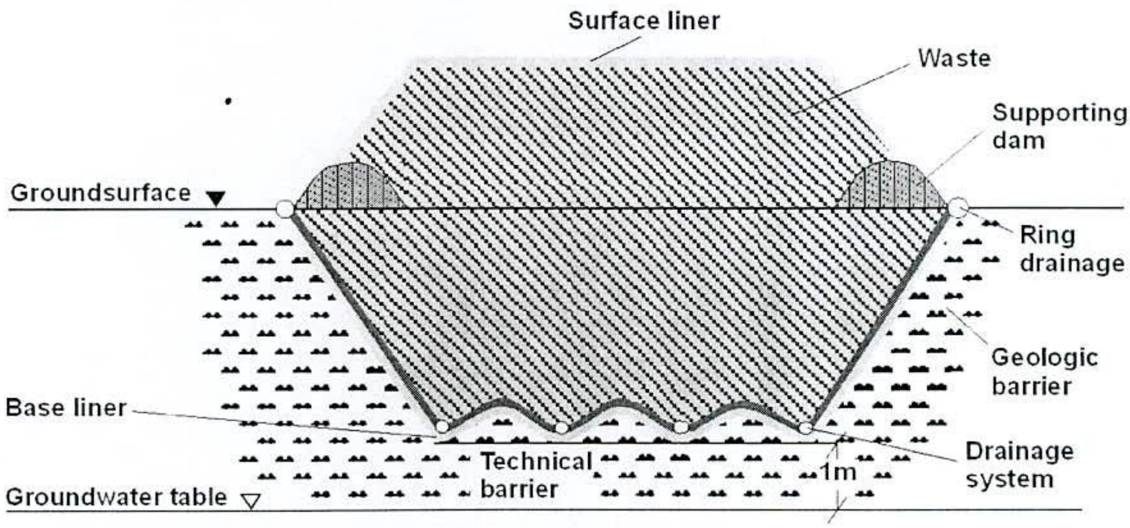

Figure 2.3 Principle of the multibarrier system for waste encapsulation.
Geological in situ barriers and engineered technical barriers (compacted mineral layers and geomembranes) are the main parts of the system.

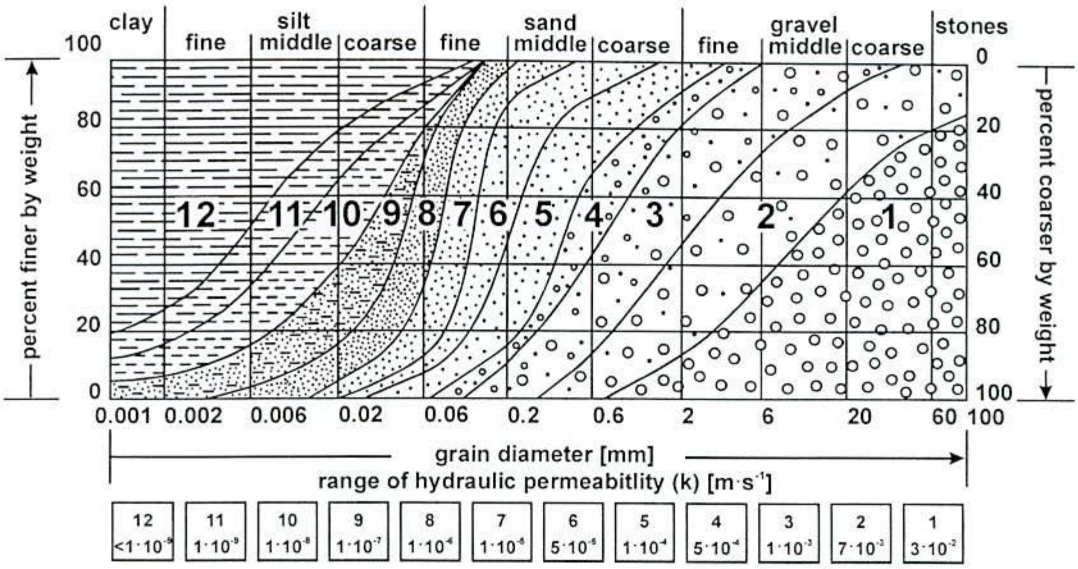

Figure 2.4 Practical imperviousness is the main function of liner systems.

Hydraulic permeabilities are expressed in k-coefficients in ms^{-1}. The range of $k \leq 1.10^{-7}$ m/sec is considered as one of the most important barrier features for mineral sealing units in most of the national regulations. Grain size distribution area 10, 11 and 12 refers to this.

2.7.2 Mineral barriers

As mineral barriers within engineered sealing layers, but as well as constituents of in situ geological barriers - which means the waste deposit location - clay rocks, clay mineral admixtures and zeolite admixtures are the most important and widely used natural materials. Alternative materials like amorphous silica, fly ashes, fly ash zeolites, clay remnants from coal flotation etc. are not treated in the following chapters.

Clay rocks and clay minerals

In using clays and other fine grained material for sealing purposes, two main issues are pursued: leachate retention by low hydraulic conductivities and toxic constituent retention or retardation by retention mechanisms such as adsorption, precipitation, redox processes and others. Soil barriers, containing enough and function-adequate clay minerals to provide low permeability, are used extensively to prevent rapid advective migration of leachate from waste disposal sites. Clayey barriers vary from thin geosynthetic clay liners (GCL) with 1 - 3 cm thickness, to compacted clay liners (CCL) up to 300 cm thickness, to natural undisturbed clayey barriers up to 30 m or more in thickness. The hydraulic conductivity of undisturbed clayey deposits depends on the mineralogy, the environment of deposition and the stress history of the deposits. The same is valid for GCL's and CCL's.

The outstanding properties of clay minerals are to be seen in their extremely small grain size (by definition < 2 ųm), their negatively charged surface properties of the basal planes, the positively charged broken ends of the platelets and the large surface areas. Most clays in natural settings have a phyllosilicate or sheet structure. Clay minerals have a common structure but they are almost always the result of chemical changes or thermal variations in the range of near surface conditions. Clays attract water, other polar liquids and cations. A dried out clay will expand greatly as it adsorbs water between its layers when attached by aqueous solutions. If toxic ions are constituents of the solution an ion exchange on charged surface sites will result. That is to say, they can accept or release ions depending upon the concentration of the ions in solution relative to that of the clays. These ions, e.g. from the leachate, are not finally fixed but are at disposal for further exchange process depending on the chemical environment. Table 2.4 gives an overview of cation exchange capacities (CEC) and specific surface areas of various clay and soil compounds.

Table 2.4 Cation exchange capacity (CEC) and specific surface areas for different clay mineral species and other materials

Mineral	CEC (millimol equv./100g)	Specific surface (m^2/g)
Allophane	50 - 100	500 - 700
Kaolinite	3 - 15	10 - 20
Illite	20 - 50	90 - 100
Smectite	70 - 130	750 - 800
Bentonite	95 - 100	800
Vermiculite	150 - 200	750 - 800
Fe- + Al-hydroxide (pH 8.0)	3 - 25	25 - 42
Humic material	150 - 250	800

Of decisive influence on sorption potentials are the primarily fixed cations, e.g. from the marine environment, on the crystallographic basal surfaces. According to the diameter of hydrated cations and their valency they are differently sorbed to the clay surface and are therefore to different quantities exchangeable. For base liner clays for instance Na-Bentonites are especially suitable because of their high swelling potential and sorption capacities and therefore fulfil the high degree of imperviousness and the high contaminant retention potential required.

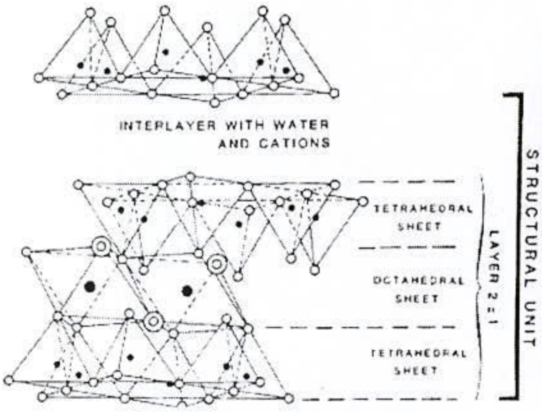

Figure 2.5(a) Three-layer clay mineral illite with tetrahedron/octahedron/tetrahedron arrangement and interlayer space between the O-planes of the tetraeders

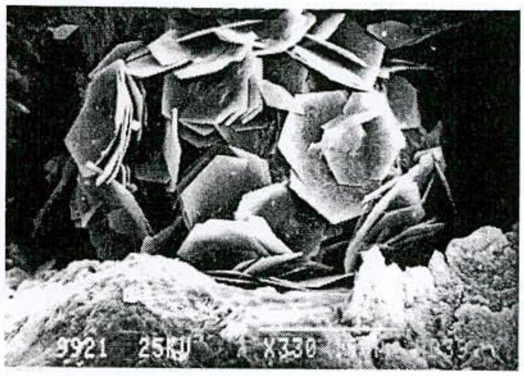

Figure 2.5(b) Illite aggregate with hexagonal clay flakes, scale: 330x

2.8 Waste deposit multi-barrier system

Waste deposits can in principle be constructed as underground storages and at the surface as slope storage, slope dump or depression storage. The common domestic waste, incineration remnants, inert construction wastes etc. are stored at the surface. Underground storage as a special deposition mode is not treated in this chapter.

2.8.1 Base liners

Base liner systems have to prevent leakage from the waste to infiltrate into the subsoil and in addition to guarantee a high potential in toxicant retention by sorption, precipitation and/or redox processes. Sorption on mineral surfaces means ion exchange according to chemical environment changes and surface charge properties. In many cases toxicants can be retarded during their migration through the sealing layers.

As an example Figs. 2.6(a) and (b) show the base liner construction according to German regulations for inert wastes and domestic wastes. Essential are compacted clay layers and in case of domestic wastes a geomembrane in addition to the mineral layers and of course the geological barrier. The basal system contains a leakage-collecting layer, connected with a leakage purification plant. There are different leakage detection systems on the mar

I. Inert waste

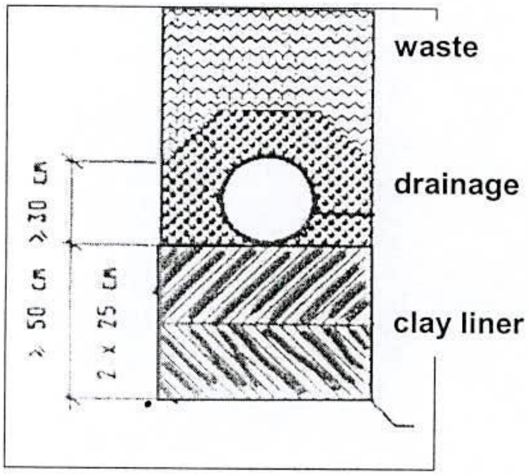

Figure 2.6(a) Base liner system for inert waste. Two compacted clay liners without geomembrane

II. Domestic waste

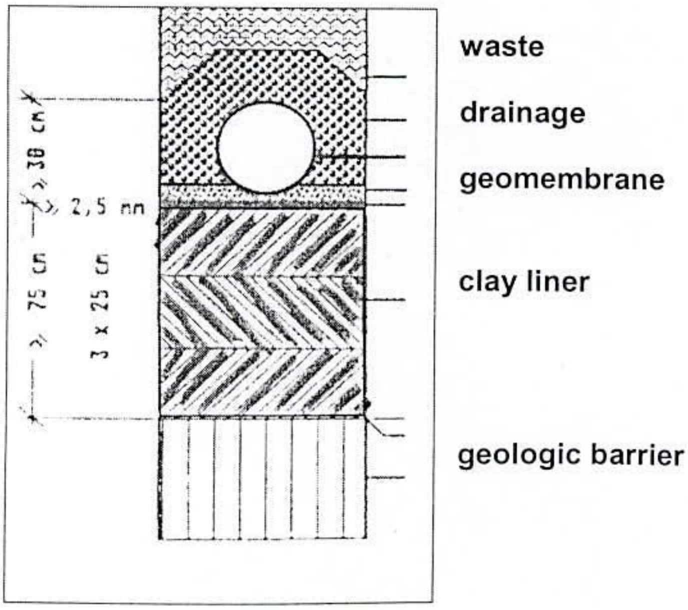

Figure 2.6(b) Base liner system for domestic waste. Three compacted clay liners combined with a geomembrane

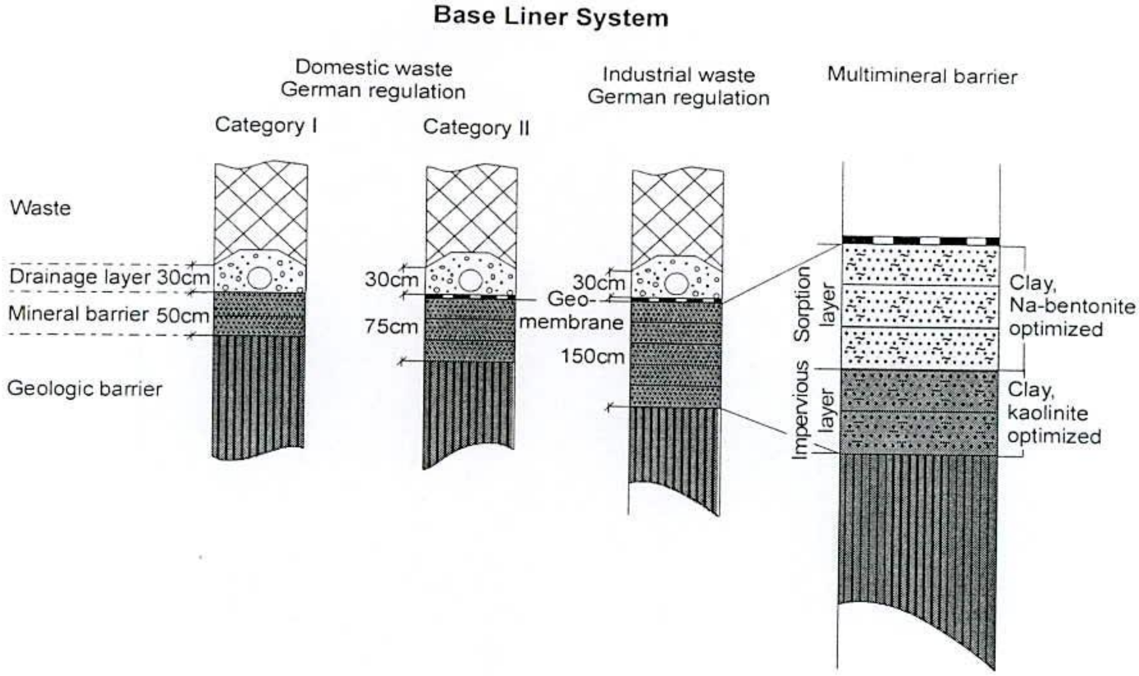

Figure 2.7 Base liner systems in comparison. The multibarrier system consists of two clay units: an adsorbing Bentonite unit and a sealing Kaolinite unit

2.8.2 Cap liners

The functions of the cap liner systems have exclusively to be seen in preventing the precipitation water from infiltrating into the waste. In case of household wastes the capping system in addition has to have a gas drainage system. Capping layers for all types of waste of course are constructions with a drainage layer (usually gravel 16/32 mm) in case of leaks in the system.

Like in the case of basal systems, compacted clay liners (CCL), and geomembranes are the prevailing sealing elements. But there is an important difference in the clay mineral composition of the CCL's. Whereas the base CCL-clay should contain 3-layer-minerals as index minerals, e.g. montmorillonite, vermiculite etc., the surface CCL-clay should contain 2-layer-minerals as index minerals, e.g. kaolinite, etc. The 3-layer-clays enable retardation by adsorption and guarantee a high degree of impermeability and the 2-layer-clays of the surface-sealing unit combined with sand/silt-matrix are practically impermeable as well but are weak in their adsorption potential. The latter is not required for the surface.

Fig. 2.8 shows the crystal lattice scheme of kaolinites, a two layer mineral, which combines an aluminum octahedron layers and silica tetrahedron layers. The center, and by their valency electrically balancing ion, is Al^{3+} respectively Si^{4+}. Because of the lack of negative surface charges the ion adsorption potential is extremely low. Because the particle is - like all other clay mineral particles - extremely small (< 2 μm), a sand-silt-kaolinite admixture for the mineral layer of a cap sealing can result in very low permeability values (k_f 10^{-8} to 10^{-12} m/sec).

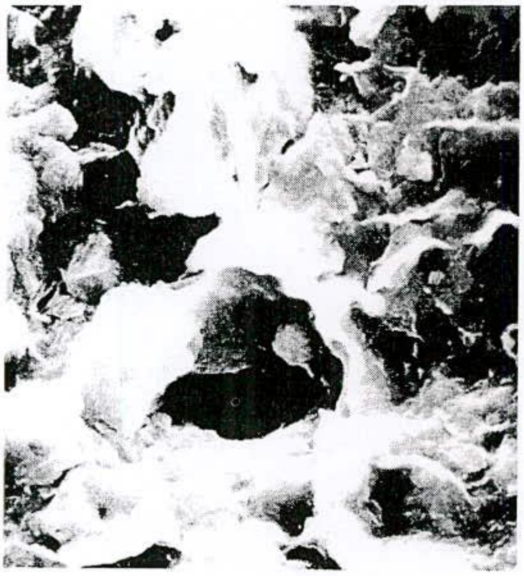

Figure 2.8(a) REM image of kaolinitic clay, scale 5000x. High non-communicating microporosity, electrically neutral two-layer mineral without swelling potential. Preferable mineral phase for cap liners.

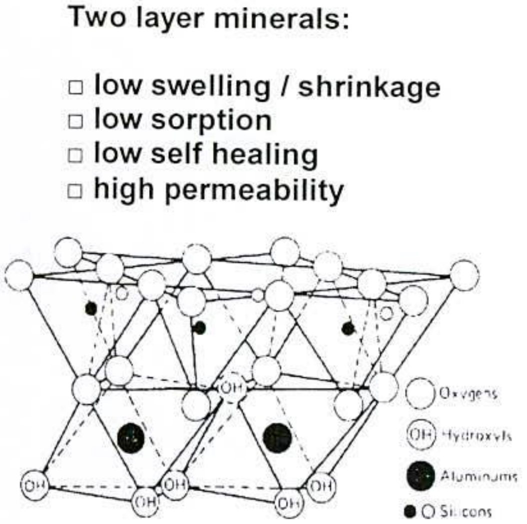

Figure 2.8(b) Crystal structure of two-layer clay minerals (e.g. kaolinite)

2.9 Landfill Site Selection Criteria

The selection and evaluation of any disposal site is dependent upon through understanding of the geologic material in which the waste is placed and the movement of water into and out of the site (Cartwright, 1978).

Generally, sites in less permeable formation can safely contain the wastes if leachate springs and the resulting surface water contamination are controlled. Location sites in formations with moderate to high permeability is more difficult and much more dependent on the nature of groundwater flow systems.

Sanitary landfill is a method of disposing of refuse on the land, without creating nuisance or hazards to public health or safety by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume to cover it with a layer of earth at the conclusion of the earth day operation or at more frequent intervals as may be necessary (Fleming, 1974).

Generally, requirements of any waste disposal sites are as follow (Cartwright, 1978).

(1) It is socially acceptable.

(2) It is accessible.

(3) It does not pollute environment.

(4) It does not pollute surface and groundwater.

(5) Cover material is available, and

(6) Wind direction is away from community.

Criteria used to determine the most suitable site for landfills have been identified based on the guideline produced by the Ministry of Environment, Malaysia in 1995. Malaysia started change from open dump to sanitary landfill step by step which can be followed by us. The criteria were both constraints and factors for an ideal siting of landfills. The constraints were related to roads, open water, protected areas, urban, rural residential areas, soil permeability and soil type, land use/land cover and distance to transportation routes.

1) Proximity to surface water

A landfill must not be located near any surface streams, lakes, rivers or wetlands. For this reason, a 100-meter buffer would be placed.

2) Distance from transportation routes

Aesthetic considerations would be of good practice for good planning and based on this principle, landfills shall not be located within 100 meters of any major highways, city streets or other transportation routes.

3) Distance from environmentally sensitive or protected areas

The location of a landfill in close proximity to sensitive areas such as mangrove areas and areas gazetted for special protection would be excluded. Apart from the area being excluded, a 3,000 meters buffer would also be created surrounding the environmentally sensitive area.

4) Distance from urban areas

Landfills should not be placed too close to high-density urban areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This guards against health problems, noise complaints, odour complaints, decreased property values and mischief due to scavenging animals.

5) Distance from rural settlements areas

Due to the same conflicts relating to the NIMBY syndrome, development of landfills shall be prohibited within 3000 meters from village settlements. There is no pre-qualification of the use of 3,000-metre buffer but such a distance should be sufficient to guard the interests of the rural settlement area

6) Landform and Soil Type

The permeability of the underlying soils and bedrock will greatly influence how much leachate is escaping a landfill site; therefore, preference is given to a landform that is somewhat located in flat or undulating land.

7) Land use/land cover

The Land use and Land cover must be known in order to determine which areas are more suitable for a landfill. Land use types such as grassland, forests and cultivated land would be considered and assigned an appropriate index of land use suitability.

8) Haul distance

Whilst a landfill should not be located within 100 meters of a road it would be more cost efficient for landfills to be located not too far away in order to avoid high transportation costs.

2.10 Natural clay liners

Natural soil liners are relatively impervious geologic formations such as aquitards or aquicludes. An aquitard is a geologic formation that transmits water at a very slow rate relative to an aquifer (eg. Interbedded sand and clay lenses), whereas an aquiclude is a geologic formation so impervious that it completely obstructs the flow of groundwater (eg., clay shale). Waste can be buried above or within a natural occurring formation of low hydraulic conductivity, clay rich soil. Natural liners normally contain significant amounts of clay minerals and have hydraulic conductivity $k < 10^{-8}$ to 10^{-9} m/s. Natural liners more typically serve as a back up to engineered liners, but occasionally a natural liner may represent the only liner at a waste disposal site facility. It is worth noting that the use of a massive uniform natural soil liner as the only means for protecting ground water from contamination is the usual practice in France. The continuity and hydraulic conductivity of natural liner materials are critical issues. To function effectively, the natural liner must be continuous and be free from major hydraulic imperfections such as fractures, joints, and holes. An evaluation of liner continuity is linked directly to the site siting, hydro-geological situations, scale and quality of investigation.

2.11 Compacted clay liners

Since a suitably low hydraulic conductivity precludes the use of any naturally occurring soil other than a clay soil, compacted soil liners often are referred to simply as compacted clay liners, or CCLs.

A primary consideration in using naturally occurring soils as compacted clay liners is finding a borrow soil located near the disposal site that will be able to achieve a sufficiently low hydraulic conductivity after compaction. In this regard, compositional factors for the soil, such as the Atterberg limits and grain size characteristics, are important (Benson et al., 1994). For example, clay soils with a liquid limit (LL) too high are more susceptible to dessication cracking, whereas clay soils with a plastic limit too low are less workable resulting in a higher probability of poor inter-lift bonding and existence of macro-pores. One should also be cautious about using highly plastic soils (soils with plasticity indices > 30-40 %). These types of clay are difficult to break and compact in the field at the optimum moisture content.

Furthermore, these materials form hard clods when the soil is below optimum and are very sticky when the soil is above optimum. Note, that the term clods refers to chunks of cohesive soil.

The hydraulic conductivity of soil generally decreases with:

- An increasing amount of fine grained material, in general, and clay material, in particular.
- A decreasing amount of coarse grained (gravel and/or sand) material.

Benson et al. (1994) evaluated soils used in several landfills to determine minimum values for the Atterberg limits as well as the amount of fines and clay in a soil required to achieve a hydraulic conductivity of 10^{-9} m/s. The results of their analyses are shown in table 2.5.

Table 2.5 Recommended properties of natural soils used for compacted *clay liners (from Benson et al., 1994).*

Soil property	Value
Liquid limit, LL (%)	≥ 20
Plasticity index, PI (%)	≥ 7
Fines (%<0.075 mm)	≥ 30
% Clay (% < 2 μm)	≥ 15

In terms of gravel content, both Daniel (1990) and Mitchell and Jaber (1990) recommend gravel contents of soils used for compacted clay liners to be limited to ≤ 20%.

As specified earlier, soil liner materials are selected based on their ability to meet specific performance standard. The minimum requirements commonly recommended to achieve a low hydraulic conductivity (< 10^{-9} m/s) for most soil liners can be summarized as follows:

Percentage fines (<0.075 mm)	≥ 30%
Plasticity index (PI):	20% ≤ PI ≤ 30%
Percentage very coarse sand/gravel (5 mm to 50 mm):	≤ 20%

Our experience may however dictate more stringent requirements, and, for some soils, more restrictive criteria may be appropriate. According to Daniel (1993), if the criteria tabulated above are not met, it is unlikely that a natural soil liner material will be suitable without additives such as bentonite. A relatively small amount of bentonite can lower hydraulic conductivity as much as several orders of magnitude.

2.12 Hydraulic Conductivity of Clay Liner

Clay liners are widely used in waste containment facilities. It serves as a barrier to reduce or restrict the discharge of leachate to the underlying environment. In order to function effectively, clay liners should have a hydraulic conductivity of $\leq 1 \times 10^{-9}$ m/s and a minimum thickness of about 0.9-1 meter (Schevon & Damas 1986; Peyton & Schroeder 1990; Daniel 1993a; Benson & Daniel 1994; Rowe et al. 1995; Arch 1998; Mohamed & Antia 1998). The hydraulic conductivity is greatly influenced by several factors: soil composition, void ratio, soil structure, degree of saturation during permeation, properties of the permeating fluid, etc. (Lambe 1954). Numerous researchers have studied these factors systematically (Lambe 1954; Mitchell et al. 1965; Acar & Oliveri 1989; Benson & Daniel 1990; Benson et al. 1994). In the following subsections, the factors that affect the hydraulic conductivity of compacted soils are discussed briefly.

2.12.1 Soil Composition

The performance of the compacted soil liner is highly dependent upon the compositional factors of the soil; such as type of clay minerals, soil consistency limits, grain size characteristics, etc. The influences of soil composition on hydraulic conductivity are discussed in details in the following subsections.

2.12.2 Clay minerals

Clays play a primary role in reducing hydraulic conductivity of soils used in the construction of liners for waste containment facilities. In general, the higher the percentage of fine-grained particles (especially clay content) in a soil, the lower the hydraulic conductivity. In fine-grained soil the mineralogical composition is an additional factor because different types of minerals hold on to different thickness of adsorbed water and consequently the effective pore size varies. Thus, the mineral type influences the hydraulic conductivity of soils.

Lambe (1954) showed the sensitivity of hydraulic conductivity to clay minerals by presenting hydraulic conductivities for several different clays. The hydraulic conductivity measurements were conducted in consolidometers on normally consolidated sedimented specimens. The data showed that for a given void ratio monovalent montmorillonite (e.g., sodium) had the lowest hydraulic conductivity, followed by divalent montmorillonite (e.g., calcium), attapulgite, and kaolinite.

The influence of clay types (clay minerals) on hydraulic conductivity was also presented by Mesri and Olson (1971). They investigated how the hydraulic conductivity of three clays was related to clay type, void ratio and permeant chemistry. They back-calculated hydraulic conductivities from consolidation tests on normally consolidated specimens using Terzaghi's consolidation theory. The specimens were kaolinite, illite, or smectite. The specimens were consolidated from homoionic slurries that were prepared by repeated washing with concentrated solutions of sodium chloride or calcium chloride. They found that the order of decreasing hydraulic conductivities (when permeated with water) is kaolinite > illite > montmorillonite.

The influence of clay mineralogy on hydraulic conductivity was also observed by Yong and Warkentin (1975). Their test result was similar to the other researchers. The reasons of the decrease in hydraulic conductivity (kaolinite > illite > Ca-montmorillonite > Na-montmorillonite) were higher swell/expansion index, smaller particles and thicker double layers. The order of increasing expansion index was Na-montmorillonite > Ca-montmorillonite > illite > kaolinite (Lambe & Whitman 1979). Therefore, water is easily absorbed between the layers of montmorillonite, causing swelling of the clay, exert pressure lightly against the surrounding particles, consequently the effective pore size reduces resulting in an apparent low hydraulic conductivity. However, soils with high percentages of swelling clays should be avoided because of their potential for shrinkage in response to cation substitution (Gray 1989; Madsen & Mitchell 1989). High swelling clay amended with coarse-grained soils could be used in liner system to reduce hydraulic conductivity. Soils with much amount of non-swelling clay mineral (kaolinite and illite) content are most suitable for compacted soil liners (McBean et al. 1995).

2.12.3 Soil consistency limits

Soil consistency limits or the Atterberg limits are indices of the quantity of clay size particles and their mineralogical composition. Typically, higher liquid limit and plasticity index are associated with soils having a greater quantity of clay particles or clay particles having higher surface activity (Mitchell 1976). In particular, all other factors being equal, more plastic clays (i.e., having higher liquid limit or plasticity index) should have lower hydraulic conductivity.

Lambe (1954) found that for a given void ratio monovalent montmorillonite (e.g., sodium) possesses the lowest hydraulic conductivity, followed by divalent montmorillonite (e.g., calcium), attapulgite, and kaolinite. Although the consistency limits for the clays were not presented by Lambe (1954), their plasticity typically decreases in the following order: monovalent montmorillonite > divalent montmorillonite > attapulgite > kaolinite (Mitchell 1976). Thus, the hydraulic conductivity of soil is sensitive to its plasticity.

A distinct trend of decreasing hydraulic conductivity with increasing plasticity was also presented by Mesri and Olson (1971). They explained that the clays with a higher plasticity index had smaller particles, less aggregation and thicker double layers. These factors combined to yield lower hydraulic conductivity.

A similar relationship between hydraulic conductivity and plasticity should exist for clays compacted wet of optimum water content, where flow is affected primarily by the size and shape of micro pores. Nevertheless, a trend of decreasing hydraulic conductivity with increasing plasticity cannot be assumed a priori, because sedimented clays and compacted clays are formed by vastly different processes. Benson et al. (1994) collected data (index properties, water content, dry unit weight, initial saturation, hydraulic conductivity etc.) from 67 landfills at various locations in North America. Their graphical presentation of the data (hydraulic conductivity as a function of liquid limit and plasticity index) showed that the hydraulic conductivity decreases as the liquid limit (LL) and plasticity index (PI) increase. Which were consistent with the results of the studies on sedimented clays.

Although clays with higher plasticity index posses low hydraulic conductivity, high plasticity clays are more difficult to break and compact in the field. Low plastic soil is preferable over highly plastic soil, as soils with low plasticity are often easier to mix, hydrate, and homogenise in the field and tend to be less susceptible to desiccation cracking. In addition, high plastic soil has a greater tendency to form clods (Foreman 1984). The presence of clods can significantly increase the hydraulic conductivity of compacted soils (Daniel 1984). However, the plasticity index should be less than 30%, otherwise the soil becomes sticky when wet and may form large clods. It then becomes difficult to construct, as experienced by Elsbury et al. (1988) both in the laboratory and in the field.

However, the low hydraulic conductivity characteristics of soil liners can be adversely affected by environmental changes include desiccation in the summer season and freezing during the winter. Desiccation substantially increases the hydraulic conductivity of compacted soil by inducing shrinkage and cracking (Albrecht 1996; Drumm et al. 1997). Albrecht (1996) showed that shrinkage, cracking, and increases in hydraulic conductivity caused by desiccation are larger in more plastic soils. Freezing and thawing also cause significant structural changes in fine-grained soils, which in turn cause large increases in hydraulic conductivity. The increase is largest for the soil with the highest plasticity index (Chamberlain & Gow 1979). Thus, to minimise the effects of desiccation and frost action, less plastic clays should be selected for constructing clay liners. Silty clays, sandy clays, clayey silts, and clayey sands with low plasticity index are the least likely soils to be damaged by desiccation.

2.12.4 Grain size characteristics

The grain size distribution of compacted soil affects hydraulic conductivity because the relative proportions of large and small particle sizes affect the size of voids conducting flow. The smaller the particles, the smaller the voids between them, and therefore the resistance to flow of water increases (i.e. the hydraulic conductivity decreases) with decreasing particle size. Low hydraulic conductivity is achievable when the soil is well graded and the clay fraction governs the hydraulic behaviour of the matrix.

(a) Percentage of clay content

Sima and Harsulescu (1979) compacted some granular materials mixing with different percentages of bentonite (1 – 20%) to estimate the most suitable proportion of bentonite to be used for achieving the necessary impermeability of these materials. They observed that the addition of 1 – 6% of bentonite leads to a decrease in hydraulic conductivity of these materials of 10 – 100 times. Furthermore, in some materials the hydraulic conductivity was reduced by 10,000 times when they were mixed with bentonite of 8 – 18%. Alther (1987) also presented that the addition of small amount of bentonite reduces the hydraulic conductivity substantially.

Daniel (1987) presented a graph of hydraulic conductivity as a function of percent bentonite for a sand-bentonite mixture. He found that hydraulic conductivity decreased significantly (10^{-4} to 10^{-8} cm/s) as the percentage of bentonite was increased from 0% to 8%. At higher bentonite contents, however, little further reduction in hydraulic conductivity occurred. Similar results have been observed by Kenney et. al. (1992), who compacted and permeated sand-bentonite mixtures at various moulding water contents. For water content wet of optimum, hydraulic conductivity was very sensitive to bentonite content when the bentonite content was less than 12% and insensitive for bentonite contents exceeding 12%.

The low hydraulic conductivities achieved at bentonite contents exceeding 8-12% occurred because clay size particles filled voids between the sand particles and controlled the hydraulic behaviour of the soil. Effectively, the soil was behaving hydraulically as clay even though it was principally composed of sand size particles. This behaviour is consistent with findings of Seed et al. (1964), who found that mixtures of sand and bentonite changed from nonplastic to plastic at bentonite contents near 10%.

(b) Percentage of fines

D'Appolonia (1980) evaluated how the percentage of fines (particles smaller than the No. 200 sieve) affected the hydraulic conductivity of soil-bentonite slurries. His test results showed that hydraulic conductivity decreased as the percentage of fines increased even when the percentage of fines was more than 30%; and the amount of plastic fines (clay fractions) should be at least 15% to lower the hydraulic conductivity of less than 1×10^{-7} cm/s. He also found that slurries containing plastic fines typically had hydraulic conductivity one order of magnitude lower than slurries containing primarily nonplastic or low plasticity fines. Similar results have been presented by Ryan (1987). Moreover, their test results showed that the hydraulic conductivity of the samples contained non-plastic fines (contained no clayey fines) of $\geq$ 35% was in the range of $5x10^{-7}$ to $1x10^{-8}$ cm/s.

D'Appolonia's results are consistent with change in hydraulic conductivity occurring by adding bentonite (Sima & Harsulescu 1979; Daniel 1987; Kenney et al. 1992) or increasing plasticity. Additional fines will fill pores between coarser particles, reduce the size of pores controlling flow, and consequently decrease hydraulic conductivity. Furthermore, as the percentage of fines consisting of clay-size particles increases, the pore spaces conducting the flow decrease further in size and thus the hydraulic conductivity decreases. However, it will not result in low hydraulic conductivity unless the clay particles are well distributed throughout the mix.

(c) Percentage of coarse fraction

Jones (1954) mixed various percentages (0, 20, 35, 50, 65, and 80) of gravel with sand. The hydraulic conductivity of sand-gravel mixtures was significantly less than sand alone for gravel contents less than approximately 65%. For mixtures with gravel contents greater than 65%, coarse particles caused significant interference during compaction, and the voids between gravel particles were not completely filled with finer material. Thus, the hydraulic conductivity significantly increased.

Shakoor and Cook (1990) performed hydraulic conductivity tests on a low plasticity glacial till mixed with various percentages of gravel. The specimens were compacted at slightly dry of optimum water content. They found little change in hydraulic conductivity for gravel contents up to 50%, but a dramatic increase in hydraulic conductivity occurred when the gravel content was increased beyond 50-60%. This result is consistent with the results reported by Jones (1954) for sand-gravel mixtures.

Similar results have been presented by Shelley and Daniel (1993). They compacted varying quantities of sub-round concrete gravel mixing separately with kaolinite and clayey mine spoil at several water contents. Hydraulic conductivity of the compacted gravel/soil mixtures was less than $1x10^{-7}$ cm/s for gravel contents as high as 60%. At higher gravel contents, however, the hydraulic conductivity increased significantly.

The results of Jones (1954), Shakoor and Cook (1990) and Shelley and Daniel (1993) suggest that the primary matrix governing flow change when gravel contents exceed 50-65%. At gravel contents less than 50%, sufficient fines and clay particles are available to fill pores between gravel particles with low hydraulic conductivity materials. The lower hydraulic conductivities measured on the mixtures of gravel and mine spoil also suggest that lower hydraulic conductivity will occur if the finer-size particles are well-graded and the clay particles are more active. Both of these factors will result in smaller pores and greater resistance to flow.

The above studies were conducted under carefully controlled laboratory conditions (i.e., not field conditions). The laboratory experiments did not allow an opportunity for gravel particles to segregate. But in the field during construction isolated pockets of segregated gravel particles can occur, whose voids are not filled with fine fractions, would tend to increase the overall hydraulic conductivity of a soil liner. Thus, even though it is theoretically possible to achieve a hydraulic conductivity of less than $1x10^{-7}$ cm/s using soil with up to 50% gravel, the possibility of gravel segregation during construction must be considered carefully. But Holtz and Lowitz (1957) found that when gravel contents exceeded 40 to 50%, the void ratio of the fine fractions increased; even though the gravel/soil mixture was compacted at optimum water content. The hydraulic conductivity of fines is generally quite sensitive to void ratio. The void ratio of the fine fractions can influence the hydraulic conductivity of compacted soil liner. Furthermore, Shakoor and Cook (1990) showed that when the gravel content in the compacted soil-gravel mixtures exceeded 30%, the void ratio of soil in soil-gravel mixtures increased, maximum dry density of soil in soil-gravel mixtures decreased due to the change of the shape and size of the gravels. However, Daniel (1993b) recommends that gravel contents of soils used for compacted soil liners to be limited to $\leq$ 30%, but this value could be increased or decreased as appropriate for a given soil material and construction process. The potential for gravel segregation to occur depends on the soil material and construction procedures.

2.12.5 Soil Structure

Structure of clayey soils has a great influence on hydraulic conductivity of compacted soil mass. The two elementary structures of clay particles are the dispersed structure and the flocculated or non-dispersed structure. Clays that have flocculent structures (edge-to-face orientations of the particles) are light in weight and possess high void ratios (Das 1998); which may yield higher hydraulic conductivity. On the other hand, clays those form dispersed structures (face-to-face or parallel orientations of the particles) exhibit greater swelling and lower hydraulic conductivity (Oweis & Khera 1998). The parallel orientation of the soil particles result in fewer void spaces available for fluid flow. In addition, the voids in a dispersed structure are typically much smaller than voids in a non-dispersed structure. By decreasing the average pore size, head loss values increase and the energy required to transmit flow through the layer also increases. These changes result in a significantly reduced value of hydraulic conductivity. Thus, hydraulic conductivity of compacted soils changes due to the alteration of the particles orientation or change of structures. Moulding water content, compactive effort and compaction methods alter the structures of the soils as well as hydraulic conductivity (Lambe 1958; Mitchell et al. 1965). The influences of these three factors on hydraulic conductivity are discussed in the following subsections.

2.12.6 Water content and compactive effort

The water content of the soil and compactive effort at the time of its compaction are important factors controlling the hydraulic conductivity of the compacted soil layer. Mitchell et al. (1965) identified that hydraulic conductivity is sensitive to water content and compactive effort; as the water content is increased beyond optimum or the compactive effort is raised, the hydraulic conductivity decreases. Furthermore, the lowest hydraulic conductivities occur at water contents slightly (2-4%) wet of optimum water content. Similar results have been shown by others (Lambe 1954; Acar & Oliveri 1989; Benson & Daniel 1990).

The change in hydraulic conductivity that occurs when the moulding water content or compactive effort is varied is a direct result of changes in the soil fabric at macro and micro scales. At the macroscale, increasing water content or compactive effort generally results in an increased ability to break down clay "aggregates" or "peds" and to eliminate interaggregate pores (Mitchell et al. 1965; Benson & Daniel 1990; Garcia-Bengochea et al. 1979). In addition, the clay particles are more uniformly dispersed and the macropores become constricted and tortuous (Barden 1974). At the microscale, increasing water content or compactive effort result in reorientation of clay particles and reduction in the size of interparticle pores (Lambe 1954; Acar & Oliveri 1989). Studies have shown that the pore-size distribution of compacted clay is bimodal dry of optimum and unimodal wet of optimum, with the large pore mode being eliminated when the moulding water content is increased above optimum water content (Garcia-Bengochea et al. 1979; Acar & Oliveri 1989). Acar and Oliveri (1989) have also shown that increasing compactive effort decreases the frequency of large pores and can eliminate the large pore mode. These changes in pore size yield lower hydraulic conductivity.

Compaction method

The effect of compaction method on the hydraulic conductivity of compacted soil was observed by Mitchell et al. (1965). They prepared specimens of silty clay at various water contents using static and kneading compaction. The compactive effort was controlled so that both compaction methods resulted in the same dry unit weight for a given water content. Results of hydraulic conductivity tests on the specimens showed that kneading compaction yielded hydraulic conductivities approximately half an order of magnitude lower than static compaction when the clay was compacted wet of optimum water content. However, specimens compacted at dry of optimum water content exhibited similar hydraulic conductivities for both compaction methods.

The lower hydraulic conductivity associated with kneading compaction has been attributed to larger shear strains that occur as the foot of the kneading compactor penetrates the soil (Mitchell et al. 1965). Wet of optimum water content, shear strains induced by kneading compaction are more effective in remoulding aggregates and reorienting the clay particles into a compact and oriented arrangement. Consequently, the size of pores controlling flows is reduced and the hydraulic conductivity decreases. However, static compaction is suggested for laboratory specimens so that the test values, though higher, will be more in line with field values (Dunn & Mitchell 1984).

2.12.7 Degree of Saturation During Permeation

The degree of saturation of a soil has an important influence on its hydraulic conductivity. Hydraulic conductivity varies as third power of the degree of saturation (Mitchell 1993). A decrease in the degree of saturation of soil decreases the hydraulic conductivity. Darcy's Law is valid when the degree of saturation is 85% and higher because much of the air in soil is held in the form of small occluded bubbles (Parker & Thornton 1977). The permeability is significantly decreased when the degree of saturation is less than 85% because the bubbles block some of the pores and much of the air is continuous through the voids.

The above informations are all about the effect of saturation on hydraulic conductivity during permeation. However, the "initial degree of saturation" has significant influence on hydraulic conductivity. Elsbury et al. (1990) plotted the results of hydraulic conductivity test on laboratory-compacted specimens as a function of initial degree of saturation. The general trend was that hydraulic conductivity decreased with increasing initial degree of saturation. Similar results have been presented by Benson et al. (1999).

2.13 Acceptable water content and dry density

A critical step in designing of a compacted soil liner is determination of the range of acceptable water content and a minimum dry density of the soil. Water content and dry density values can greatly affect a soil's ability to restrict the transmission of flow. Mitchell et al. (1965) demonstrated on samples of silty clay that even small variations in water content and dry density may results in change to the hydraulic conductivity by up to two powers of ten.

If the soil is too dry at the time of compaction, suitably low hydraulic conductivity may become unachievable. If the soil is too wet, a variety of problems may ensue, e.g., problems with construction equipment operating on soft, weak soils and potential slope instability caused by low strength of the soil. Once an acceptable range of water content has been selected, the soil must be compacted with adequate compactive energy to compress large voids and to remould clods of soil into a homogeneous, relatively impermeable mass. The dry density of the soil can be a useful indicator of the effectiveness of compaction.

The problem is that both the water content of the soil and the compaction energy delivered to soil during construction of a soil liner itself vary. Furthermore, precise duplication of field compaction in the laboratory is impossible. However, several approaches for establishing water content and dry density requirement during the design stage exist and are summarised as follow:

The traditional (prior to 1990) method is developed by first creating a water content-dry density relationship based on a given compaction energy (typically standard Proctor compaction energy). Based on the resulting compaction curve, the soil for the compacted soil liner must be compacted in the field at water content (w) and dry density (γ_d) greater than the optimum water content (w_{opt}) and some specified percentage of the maximum dry density (γ_{dmax}) of the soil respectively, as determined from the laboratory compaction curve (e.g., $w_{field} \geq w_{opt(lab)}$ and $\gamma_{d(field)} \geq \frac{P}{100}\gamma_{dmax(lab)}$). Herrmann and Elsbury (1987) reported that P is usually 95% of $\gamma_{dmax(lab)}$ from standard Proctor compaction or 90% of $\gamma_{dmax(lab)}$ from modified Proctor compaction. The range of acceptable water content varies with the characteristics of the soil, but for soil liners and covers, might typically be about zero to four percentage points wet of standard or modified Proctor optimum water content. For the construction of compacted soil liners, soils are compacted wet of optimum water content because wet-side compaction minimises hydraulic conductivity (Bjerrum & Huder 1957; Lambe 1958; Mitchell et al. 1965; Boynton & Daniel 1985).

Figure 2.9 shows the zone of acceptable water content/dry density combinations based on the backdated traditional method. This approach results in a specification that allows compaction in the field with w-γ_d combinations anywhere within the hatched region (Figure 2.9). The fundamental problem with this method is that the compaction energy in the field rarely is equal to the compaction energy used in the development of the laboratory compaction curve. Therefore, the fundamental problem in this approach is that the construction specification is based on laboratory values of w_{opt}-γ_{dmax} that probably are not relevant to the field construction of the clay liner.

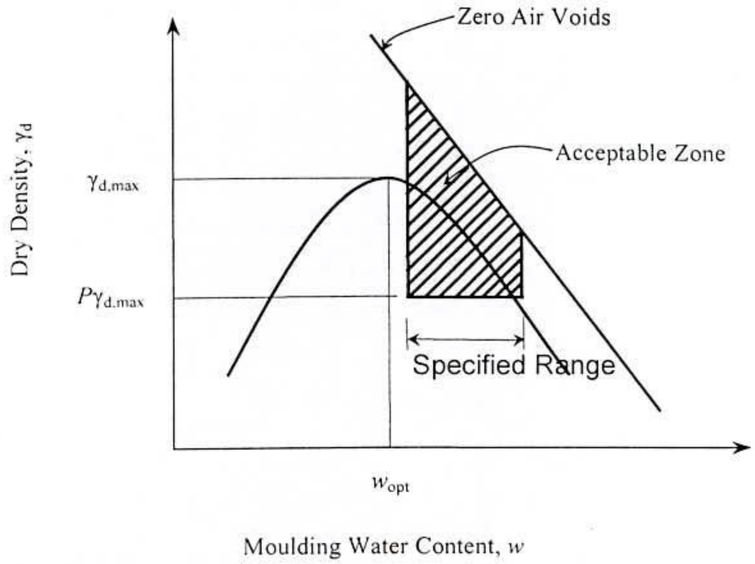

Figure 2.9 Specification of acceptable water contents and dry density for compacted clay liners (Daniel & Benson 1990)

2.14 Landfill Leachate

Landfill leachate arises from the infiltration and passage of water through solid waste (Jasper et al. 1985), followed by a combination of physical, chemical and microbial processes that transfer pollutants from waste material to the water (Kjeldsen et al. 2002). Water percolated through solid waste and has extracted dissolved or suspended materials produce leachate and migrated to the groundwater causes contamination. The composition of leachate is site-specific, varies depending on waste type and composition, amount of water infiltrating the landfill, pH of water, depth of fill, degree of compaction, and landfill age (Shams-Khorzani et al. 1994).

The knowledge of the quantity and composition of leachate usually gives an insight into appropriate, effective and sustainable treatment approach. The necessary outcome from the leachate characteristics is to decide about any physicochemical and/or biological methods of treatment are required or not to treat the MSW disposal site leachate before they are discharged into the environment at the dumpsite to either eliminate, or drastically reduce, the short term and long term detrimental effects on ecology, public health and the environment. The leachate risk assessment can be carried after the compositional analysis of leachate. Water quality monitor program can also be set up by knowing the contaminants characteristics of leachate.

Municipal solid waste landfill leachate contains a wide variety of hazardous chemicals, conventional contaminants, and non-conventional contaminants. Contamination of groundwater and surface water by such leachate renders it and the associated aquifer unreliable for domestic water supply and other uses; "remediation" treatment does not restore their quality. Focus must be placed on prevention of pollution by MSW landfill leachate. There is a common misconception that since the materials placed in MSW landfills are basically household wastes, they are relatively "safe" and would not likely adversely affect public health and groundwater quality. (Lee et. al. 1993a)

Concentrations of leachate can vary depending on decomposition phase (Kjeldsen et al. 2002) and amount of water infiltrating (Chen 1996). Most new landfills are containment landfills and use engineered liners to prevent seepage of leachate into the soil and groundwater (Radenkova-Yaneva et al. 1995, Westlake 1997). This implies that leachate will be collected and require treatment and disposal (Westlake 1997).

2.14.1 Characteristics of Leachate

There are three broad types of contaminants present in municipal landfill leachate that need to be considered in evaluating the public health and water quality impacts of MSW landfills. These are the group of what are called "hazardous chemicals," "conventional contaminants," and "non-conventional contaminants." Conventional contaminants include parameters such as total dissolved solids, hardness, alkalinity, chloride, sulfate, iron, manganese, and hydrogen sulfide. In addition, this group includes a variety of non-differentiated organics measured as COD (chemical oxygen demand), BOD (biochemical oxygen demand), and TOC (total organic carbon). These are common components of a waste stream, analyzed to provide an overview characterization of the waste stream. They are typically present in elevated concentrations in landfill leachate and can thus often indicate the presence of leachate in unsaturated or saturated groundwaters. However, if present in sufficient amounts, conventional contaminants can cause severe degradation of water quality and preclude its use for domestic water supply purposes. For example, organics measured as BOD, COD, or TOC can cause taste and odor problems and oxygen depletion in the groundwater.

Non-conventional contaminants are largely organic chemicals that have not been defined, and whose potential hazards to public health and groundwater quality are not known. Typically the organic Priority Pollutants, those organics that are identified and quantified, represent a very small fraction of the total organic matter present in leachate as measured by chemical oxygen demand and total organic carbon. It is estimated that from 90 to 95% of the organic materials in municipal landfill leachate are of unknown composition. Those chemicals have not been identified and obviously their potential impacts on public health and groundwater quality are unknown.

As discussed by Lee and Jones (1991a, 1992a), it is prudent public health policy to consider any groundwater contamination by MSW landfill leachate to be a significant public health and environmental threat that should trigger immediate efforts to stop the spread of the pollution and address the groundwaters that are or could be used for domestic water supplies. This action should be taken independent of whether any of the Priority Pollutants and conventional contaminants exceed water quality standards or objectives. Further, it is erroneous to assume, as is done by many who advocate the construction and operation of a municipal landfill at a certain location, that at the end of a few decades after landfill closure the landfill and its leachate will not represent a threat to public health and groundwater quality. Freeze and Cherry (1979) have reported that landfills constructed by the Romans some 2000 years ago are still producing leachate. Belevi and Baccini (1989) estimated that unlined sanitary landfills in a fairly wet climate will leachate hazardous chemicals such as lead at concentrations above drinking water standards for several thousand years. Thus lined landfills would be expected to follow a similar pattern once the liners fail to prevent significant leachate migration.

2.14.2 Influence of Leachate Characteristics

It is estimated that each person contributes about 4 L/yr of hazardous chemicals to their MSW stream (Lee and Jones 1991). Lee and Jones listed a wide variety of household products, which eventually reach an MSW landfill, that contain Priority Pollutants; Brown and Nelson (1990) also discussed sources of hazardous chemicals in MSW leachate. "Hazardous" chemicals such as chlorinated solvents and other cleaning compounds, gasoline, waste oil and other hydrocarbons, lead-based paint residues, soil-lead residues, mercury in fluorescent tubes and batteries, etc. are contributed to MSW landfills from residences and commercial establishments. Waste automobile oil with its elevated heavy metals and hydrocarbons is also routinely thrown into the household trash, as are various types of batteries such as mercury-based and nickel-cadmium batteries. It is estimated that on the order of 47 tons of mercury were used in the US in 1988 in mercury batteries with consumer applications (Waste Not, 1990). It is well-known that street sweepings have greatly elevated concentrations of cadmium, lead, as well as other heavy metals and potentially hazardous organics.

Increasing the concentrations of total dissolved solids (TDS), hardness and many other constituents of this type which are typically found in municipal landfill leachate at very high concentrations can prevent the use of the groundwater for domestic water supply purposes. Even if the concentrations do not reach this level of contamination, they cause homeowners greater costs for their domestic water supply as a result of increased water treatment by the utility. If the contaminants are not removed, homeowners and commercial/industrial establishments will experience a less desirable water from a variety of points of view. Typically, waters with increased TDS and hardness are more corrosive for the plumbing fixtures, tend to form scale-coatings in water heaters, etc., require the use of greater amounts of soaps and detergents for cleaning, and shorten the life of clothes, washing machines, dish washers, etc. If the homeowner or municipality softens the water by ion exchange, the softened water will have increased sodium which can be a problem to some individuals with heart disease.

MSW landfill leachate typically contains significantly elevated concentrations of a variety of other chemicals which also represent a threat to groundwater quality. The iron and manganese are of particular concern since they cause staining of fixtures, clothes and other materials. They have to be removed in the water treatment process which adds to the cost of the domestic water supply contaminated by municipal landfill leachate. Groundwaters contaminated by MSW landfill leachate and depleted of oxygen promote the conversion of sulfate to hydrogen sulfide which is highly obnoxious in water supplies. It causes a "rotten egg" smell at very low concentrations, as well as increases the rate of corrosion of plumbing. While hydrogen sulfide can be removed by individual homeowner or municipal water treatment units, such removal adds to the cost of a domestic water supply. Ammonia and a variety of organic nitrogen compounds are conventional contaminants that are also of great concern in MSW landfill leachate. Oxic groundwaters contaminated by ammonia can have greatly elevated concentrations of nitrate. Nitrate above 10 mg/L as N is a public health hazard in groundwater; it causes methemoglobinemia (blue baby disease).

The presence of non-conventional contaminants is one of the most important reasons for preventing contamination of water by MSW landfill leachate. Some of the non-conventional contaminant organics are transformed to methane as part of fermentation-gas production. The majority, however, are not fermentable and will be present in landfill leachate for hundreds to thousands of years depending on the rate of leaching of the organics from the solid wastes. These organics contribute to the high oxygen demand in MSW landfill leachate as measured by BOD_5 of 1,000 to 30,000 mg/L as shown in Table 1. These organics are also responsible for taste and odors in domestic water supplies. Further, it is now well-established that these organics serve as complexing agents for heavy metals which enable their transport in groundwater systems which would not occur in the absence of the organics.

In addition and most importantly, within the non-conventional contaminant organics category is a host of unidentified, potentially highly hazardous chemicals that are not measured as part of the approximately 100 organic Priority Pollutants. There is little doubt that in time new, yet unidentified, highly hazardous chemicals will be found in this group such as the chlorinated phenoxy herbicides noted above. It is for this reason that it is prudent public health policy to not allow domestic use of any groundwater that has been contaminated by MSW landfill leachate, even if the concentrations of contaminants do not exceed drinking water standards or other water quality standard-objectives.

The source of the organics in municipal solid waste leachate that are represented by the non-conventional contaminants is the bulk of the organics that are disposed of in MSW landfills. It is therefore impractical to implement changes in the solid waste stream characteristics as a means of eliminating the known and potential impacts of the non-conventional contaminants in landfill leachate. The organic and inorganic contaminants present in municipal solid wastes which ultimately contribute to the conventional contaminants of concern are derived from essentially all of the major components of municipal solid wastes and therefore their control in the waste stream is also impractical. It is readily apparent that attempting to selectively remove those waste components that contribute conventional and non-conventional contaminants to MSW landfill leachate is an impossible task.

2.14.3 Leachate Risk Factor (LRF)

To assess the level of risk to the environment from contaminants in landfill leachate, the basic principles used were similar to those used in the assessment of contaminants in drinking water for monitoring & grading of water quality. This methodology is simple and yet effective in comparing the level of contaminant in the leachate to the respective environmental standard or guideline. Hence the measured concentrations of contaminants in the leachate are expressed as a ratio of relevant standard or guideline, to assess the relative risks to the environment from the landfill discharges.

It should be noted that the leachate risk factors derived are only one of the key issues for consideration in deciding whether there is a need for resource consent. Other factors, such as relative significance of individual contaminants and sensitivity of the receiving environment may also be a key indicator as to whether resource consent for the specific landfill is required.

2.15 Landfill Gas (LFG)

At solid waste disposal sites (SWDS) the degradable organic carbon in waste is decomposed by bacteria under anaerobic conditions into methane (CH_4) and other compounds. The CH_4 emissions from SWDS are important contributors of global anthropogenic CH_4 emissions. Landfill gas results from the anaerobic decomposition of municipal solid waste (MSW). It is produced immediately after waste deposition, attains a peak at about 10 years but can last for 40 years or more after initial deposition (Qin et al. 2001). Mostly methane and carbon dioxide with trace amounts of volatile organic compounds (VOC) (Qin et al. 2001). Typical gas composition can vary according to type of waste and time since deposition (Environment Agency 2002). The properties of landfill gas are shown below:

* Methane is odourless and colourless, although in landfill gas it is typically associated with numerous highly odoriferous compounds, which gives some warning of its presence. However, the absence of odour should not be taken to mean that there is no methane. Methane levels can only be reliably confirmed by using appropriately calibrated portable methane detectors.

* Methane is a flammable gas and will burn when mixed with air between approximately 5 and 15% (v/v). If a mixture of methane and air with a composition between these two values is ignited in a confined space, the resulting combustion may give rise to an explosion. Methane is also an asphyxiant.

* Carbon dioxide, the other major component of landfill gas is an asphyxiating gas and causes adverse health effects at relatively low concentrations. The long-term Occupational Exposure Limit (OEL) is 0.5% (v/v). Like methane, it is odourless and colourless and its

CHAPTER THREE

OVERVIEW OF THE STUDY AREAS

3.1 General

The ultimate disposal site of MSW is influenced by the characteristics of municipal area as well as MSW. This chapter describes the general information of study areas such as location, city layout, population, annual rainfall and temperature of the study areas, four major cities of Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal. MSW management, generation of MSW, transportation facility, physical composition and characteristics of MSW are also shown here.

3.2 Basic Information

The basic information of study areas like location, population, city area and annual rainfall and temperature is given below.

3.2.1 Location of study areas

The city of Dhaka is located in the southern portion of the district of Dhaka and almost in the middle portion of the country. The city is surrounded by the main river Buriganga in the south; the Balu and the Shitalakhya rivers in the east; Tongi Khal in the north and the Turag river in the west. Khulna city is situated on a natural levee of the Rupsha and Bhairab rivers and characterized by ganges tidal floodplains with low relief, criss-crossed by rivers and water channels and surrounded by tidal marshes and swamps. Rajshahi city is located in the northern region of the country. The city is bounded on the south by the Padma river and on the west by Godagari Thana. Barisal city is situated in southwest region of the country. Table 3.1 shows the location of four city corporations of Bangladesh with latitude and longitude.

The location of four major cities of Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal are shown in Figure 3.1.

Table 3.1 Location of four city corporations of Bangladesh

Name of city	Latitude	Longitude	Location in map
Dhaka[1]	24° 40' N to 24° 54' N	90° 20' E to 90° 30' E	Middle region
Khulna[2]	22° 30' N	89° 20' E	South west region
Rajshahi[3]	24° 21' to 24^0 23' N	88° 28' to 88° 38' E	North west region
Barisal[4]	22° 20' N	90° 15' E	South west region

Source: [1]DCC (2005), [2]KCC (2005), [3]RCC (2005), [4]BCC (2005)

Figure 3.1 Location of study areas in Bangladesh

3.2.2 Population of study areas

The total population in Dhaka city grew from only 3.4 million in 1991 (BCAS, 1991) to 7.0 million in 1999 (DCC, 1999). The rapid rise in population of Dhaka city has been caused mainly by a large number of people migrating from rural areas. Khulna city is also a densely populated area with 18,424 populations per square kilometer (KDA, 2004). According to BBS in 2001 census, total population in Khulna city area is 7,73,000. Khulna city, with a population of about 1.5 million as claimed by city authority in the year of 2005. Rajshahi city covering an area of 9.15 sq. km (3.53 sq. miles) and the population of Rajshahi city is around 0.4 million (BBS 2001) and the total populations are about 0.45 million in the year 2005 as claimed by city authority. In Barisal city, total population is about 0.40 million as claimed by city authority in the year of 2005. Table 3.2 shows total population in four major cities of Bangladesh with city area and number of wards.

Table 3.2 Total population, city area and number of wards in four major cities of Bangladesh

City corporation	City area (sq. km)	Population (million)	No. of wards
Dhaka[1]	360	11.00	90
Khulna[2]	47	1.50	31
Rajshahi[3]	48	0.45	30
Barisal[4]	45	0.40	30

Source: [1]DCC (2005), [2]KCC (2005), [3]RCC (2005), [4]BCC (2005)

3.2.3 Annual rainfall and temperature

The characteristics of MSW and also the decomposition process of MSW in ultimate disposal site depend on rainfall and temperature. Table 3.3 shows the annual average rainfall and temperatures in four major cities of Bangladesh.

Table 3.3 Annual average rainfall and temperatures in four major cities of Bangladesh

City corporation	Annual avg. rainfall (mm)	Temperature (summer)	Temperature (winter)
Dhaka	1824	30 to 37°C	10 to 20°C
Khulna	1714.50	30°C (avg.)	15°C (avg.)
Rajshahi	1624.67	43.3°C (max.)	8.8°C to 25.9°C
Barisal	1526	32°C (avg.)	12°C (avg.)

(Source: DOE 2005)

3.3 Overview of MSW in the Study Areas

The generators of MSW have actually no thinking about the problems associated with solid waste and also illegal dumping in Bangladesh. To reduce the negative impact of MSW from collection to ultimate disposal, it is necessary to adequate knowledge about the characteristics of MSW. Because if the MSW stream can be controlled then the environmental and ecological problems associated with MSW will be drastically reduced. The MSW management, transportation facility, physical composition and characteristics of MSW are shown below.

3.3.1 Organizational Set-up

A typical organizational structure for the MSW in Bangladesh in the major cities is presented in Figure 3.2. Though the conservancy department is entrusted for the management of solid waste, but they rely highly on the engineering section for the transportation and dumping site management. Also in the conservancy section usually non-professional persons are involved which causes less effectiveness. Solid waste management is organized and run by the conservancy section of City Corporation, whose prime responsibility is to provide services to the city dwellers in street lighting, drain cleaning, street sweeping, sanitation, garbage management and other facilities. This section supervises the wastes intensive workers for collection & transports of MSW while the engineering section doing operation & maintenance of vehicles. Engineering section is taken care community bins, SDS and UDS.

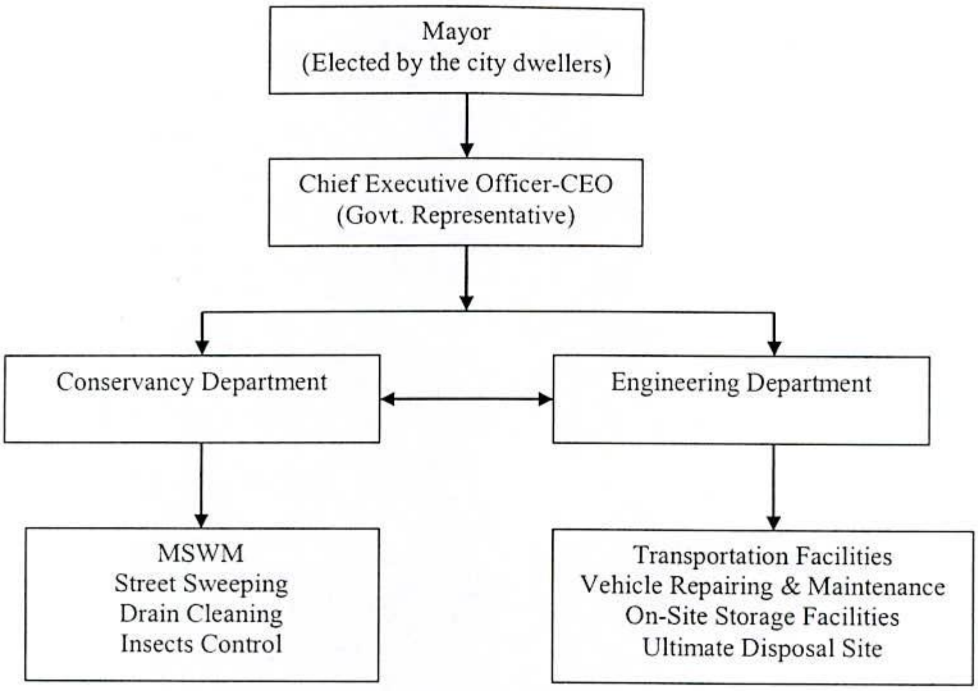

Figure 3.2 Typical organizational set-up for MSWM in the major cities of Bangladesh

The existing organizational layout in terms of administration and function is far beyond the requirements to develop an effective and integrated management for municipal solid wastes. There is no independent body or cell exclusively for MSW management within the administrative set-up of City Corporation. For instance, DCC recently established a 'solid waste management cell' to improve the waste management services in the city. Solid wastes management is generally take care by the Conservancy sections along with other municipality services with the interaction of Engineering Section. Often conservancy section gives preference to other function to proof their credibility since waste management is complex in nature and it is difficult to achieve success from it in the present circumstances.

3.3.2 Existing Management Practices of MSW in Bangladesh

Solid waste management has so far been ignored and least studied environmental issues in Bangladesh, like in most developing countries. Wastes are collected from generation sources by NGOs, CBOs and city authority by door-to-door collection systems. Door-to-door collection systems are introduced recently for wastes collection from generation sources, mainly households, and then dispose major portion of it to the nearest SDS. City authorities collect these wastes and transfer to the (Ultimate Disposal Site) UDS. Recycling, reuse and reduce are not getting support from formal authority, even the composting, a great potential sector of waste treatment and minimization considering the nature of MSW in Bangladesh, fails to reach desired target due to improper planning (Ali et al. 2004, Sinha & Enayetullah 2000 and Enayetullah & Sinha 2003). However, major portions of wastes remain unmanaged - throwing them in the adjacent spaces, roadsides and drains. A portion of medical wastes is managed by NGOs (Alamgir et al. 2003) and the remaining follows in the same path of MSW. A typical waste flow diagram from source to ultimate disposal of Bangladesh is presented in Figure 3.3.

As a result, city authorities are facing very complicated situations for the management of vast quantities of MSW. Due to severe financial constraints, lack of motivation, absence of effective legislation to protect the environment, lack of commitment of authority, the MSW has becoming a threat for city dwellers, planners and other concerned stakeholders.

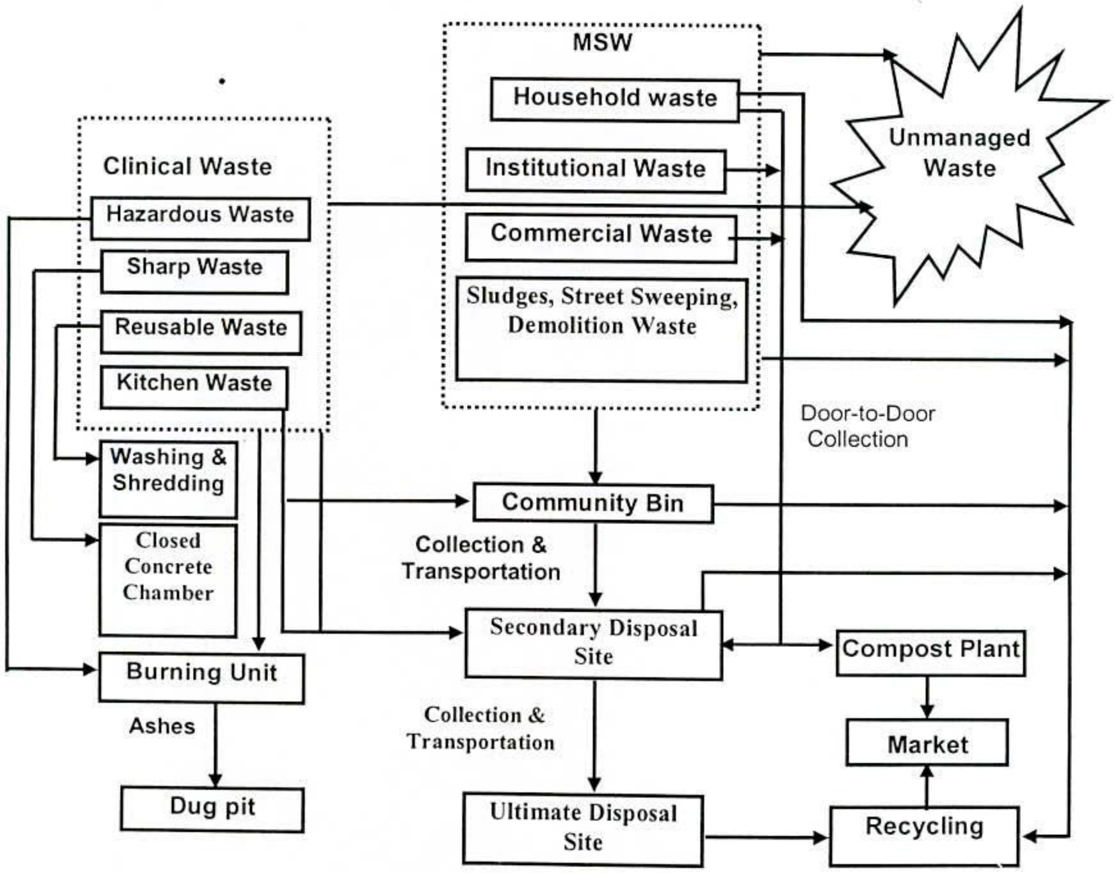

Figure 3.3 Flow path of MSW from source to ultimate disposal in Bangladesh
(Source: WasteSafe 2005)

3.3.3 Generation of MSW in Four Major Cities of Bangladesh

Rapid urbanization of the developing countries has increased the urban population significantly resulting in growth of industrial enterprises for the production of different consumer products. As a result, huge amounts of municipal solid waste are being generated daily from urban areas that create pressure on environmental management. The total generation of MSW with per cipita waste generation in four major cities of Bangladesh, shown in Table 3.4, where 5340 tons are daily generated in Dhaka city, while only 820 tons are daily generated from rest three major cities. Per capita waste generation rate range from 0.325 to 0.485 kg/day where high per capita waste generation rate is 0.485 kg/day in Dhaka city and low generation rate is 0.325 kg/day in Barisal city.

Table 3.4 Generation of MSW in four major cities of Bangladesh

MSW Generation	Dhaka	Khulna	Rajshahi	Barisal
Population (Millions)	11	1.5	0.45	0.40
MSW generation (tons/day)	5340	520	170	130
Generation rate (kg/capita/day)	0.485	0.346	0.378	0.325

(Source: Ahsan 2005)

3.3.4 Transportation of MSW

The city authority is responsible for collecting wastes from secondary disposal points and transported it by motorized vehicles/trucks and finally disposed in the designated ultimate disposal site of the city area. Conservancy department setup the time-schedule and types of vehicle for collection and transportation. Generally, collection vehicles such as dump truck, normal truck, open truck, tractor with trolley, tipping truck (container carrier), De-sledging vacuum tanker with tractor, power tiller with trolley stands in the road nearest to the SDS for operation. Staffs are assigned with each vehicle for collection and disposal. Demountable containers are only hauled by tipping truck and no additional workers are required for collection and disposal but its numbers are also limited. Table 3.5 shows the total number of motorized vehicles, number of dumping site and amount of wastes daily collected, transported and dumped in ultimate disposal sites.

Table 3.5 Number of motorized vehicles for transportation of MSW		
City	**Number of motorized vehicles**	**Amount collect, transport and dispose (Tons/day)**
Dhaka	373	2000-2400
Khulna	32	240-260
Rajshahi	15	60-80
Barisal	7	30-40

City authority does not have proper and required number of vehicles and staffs to perform this operation successfully, even; the present management system is not capable to utilize the existing resources properly. As a result, the collection of wastes from SDS is very much disappointing and creating lot of hazards, as wastes remain there for longtime.

3.4 Physical composition of MSW

Since solid waste from different sources is typically dumped into the same container/truck at on-site disposal and secondary disposal points, the waste remains in mixed condition. The composition of MSW, shown in Table 3.6, Figure 3.4 and Figure 3.5, represents the average composition of municipal solid waste from different sources. Food wastes are varied over a wide margin ranging from 58.72 to 88% whereas paper and plastics vary from 1 to 9.59% and 1 to 6.76%, respectively, as reported in the previous studies in Dhaka city. The remaining portions of waste are rubber, cloth, metal, tin, glass, dust and others.

Table 3.6 Physical composition of MSW in four major cities of Bangladesh (in wet weight %)

MSW Composition	Dhaka	Khulna	Rajshahi	Barisal	Average	SDS
Food & Vegetables	68.3	78.9	71.1	81.1	74.9	70.8
Paper & Paper Products	10.7	9.5	8.9	7.2	9.1	6.3
Polythene & Plastics	4.3	3.1	4.0	3.5	3.7	4.3
Textile & Woods	2.2	1.3	1.9	1.9	1.8	6.0
Rubber & Leathers	1.4	0.5	1.1	0.1	0.8	2.0
Metal & Tins	2.0	1.1	1.1	1.2	1.3	1.0
Glass & Ceramics	0.7	0.5	1.1	0.5	0.7	1.5
Brick, Concrete & Stone	1.8	0.1	2.9	0.1	1.2	2.0
Dust, Ash & Mud Products	6.7	3.7	6.5	3.1	5.0	2.3
Others (bone, rope etc.)	1.9	1.2	1.3	1.3	1.4	4.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

SDS -Secondary Disposal Site (average values of four cities)

(Source: Ahsan 2005)

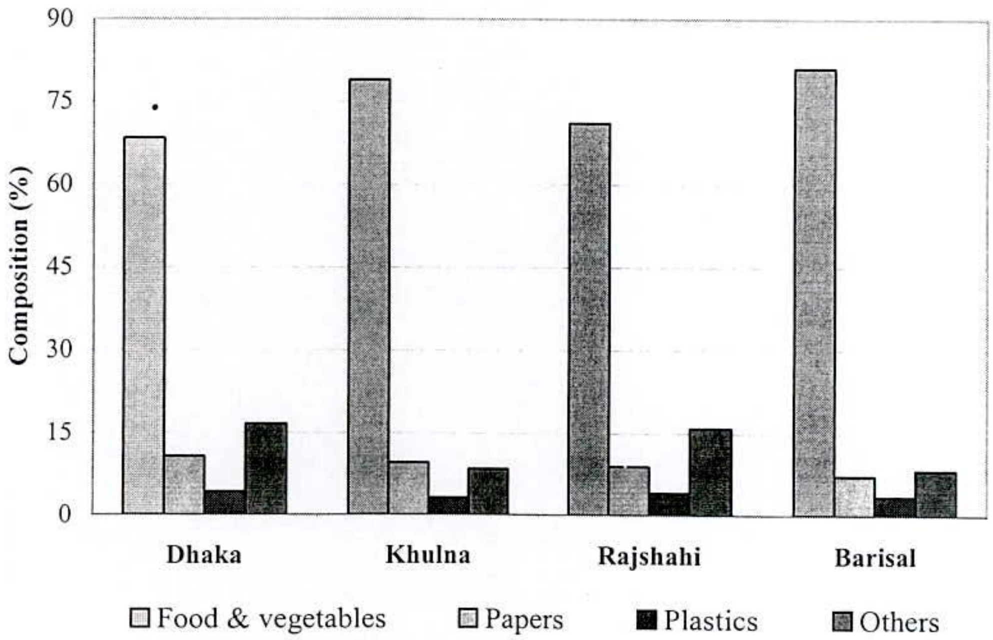

Figure 3.4 Physical composition of MSW in four major cities of Bangladesh

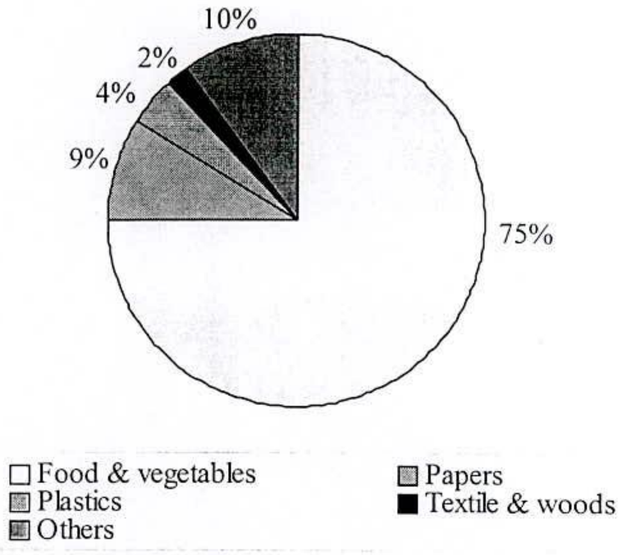

Figure 3.5 Average composition of MSW for four major cities of Bangladesh

3.5 Physical Characteristics of MSW

The physical characteristics of MSW in four major cities of Bangladesh such as pH, percent of moisture content, volatile solid content and ash residue; bulk density and particle size distribution are shown in Table 3.7. The different physical parameters are described in the following sections:

pH

The pH values of MSW are given as 8.69, 7.76, 7.72 and 7.70 for Dhaka, Khulna, Rajshahi and Barisal city, respectively, as presented in Table 5.18. So it can be clearly observed that the MSW of four major cities are in acidic form. Organic materials with a wide range of pH values from 3 to 11 can be composted, but the more desirable pH for composting ranges from 5.5 to 8.5 (Tchobanoglous et al., 1993). Table 3.7 shows that the values of pH in MSW below or near 8.5 for four major cities of Bangladesh.

Moisture content

The moisture contents of MSW are given as 70, 68, 56 and 57% for Dhaka, Khulna, Rajshahi and Barisal city, respectively, as presented in Table 3.7. The highest moisture content is measured as 70%, while the lowest value is 56% for Dhaka and Rajshahi city, respectively. In aerobic composting process, moisture content should be in the range between 50 and 60% during the composting process (Tchobanoglous et al., 1993). The moisture content of above 65% is reducing the interstitial oxygen during composting and causing anaerobic conditions, which produce offensive odors.

Volatile solid content and ash residue

The volatile solid contents are 71, 56, 48 and 43%, while the ash residues are obtained as 29, 44, 52 and 57% for Dhaka, Khulna, Rajshahi and Barisal city, respectively, as presented in Table 3.7. The highest volatile solid content is 71%, while the lowest value is 43% for Dhaka and Barisal city, respectively.

Bulk density

Bulk densities of MSW in four major cities of Bangladesh are shown by both field and laboratory testing as described in the followings. The bulk densities (in field) in loose state are found as 578, 610, 588 and 621 kg/m^3 for Dhaka, Khulna, Rajshahi and Barisal city, respectively, as presented in Table 3.7. The highest bulk density value in field in loose state is 621 kg/m^3, while the lowest value is 578 kg/m^3 for Barisal and Dhaka city, respectively. However these differences can be neglected and an average bulk density of MSW for four major cities of Bangladesh can be considered as 599 kg/m^3 or 600 kg/m^3 as round figure.

The bulk densities (in lab) in loose state as 621, 566, 568 and 577 kg/m^3 where in medium state 951, 764, 921 and 926 kg/m^3 whereas in compacted state 1127, 875, 1052 and 1048 kg/m^3 for Dhaka, Khulna, Rajshahi and Barisal city, respectively, as presented in Table 3.7. The highest bulk density value in loose state is 621 kg/m^3 for Dhaka city, while the lowest value is 566 kg/m^3 for Khulna city.

Table 3.7 Physical characteristics of MSW in four major cities of Bangladesh

Characteristics	Dhaka	Khulna	Rajshahi	Barisal	Average
pH	8.69	7.76	7.72	7.70	8.0
Moisture content (%)	70	68	56	57	63
Volatile solid (%)	71	56	48	43	55
Ash residue (%)	29	44	52	57	46
B. Density[a] (loose)* kg/m^3	578	610	588	621	599
B. Density[b] (loose)* kg/m^3	621	566	568	577	583
B. Density[b] (medium)* kg/m^3	951	764	921	926	891
B. Density[b] (compact)* kg/m^3	1127	875	1052	1048	1026

Note: [a]By field test; [b]By laboratory test; *in wet weight basis; Loose: Just fill up the mold without any compaction or input energy; Medium: Compacted in 3 layers providing 12 blows/layer by a hammer of 5.5 pounds in 12" free fall; Compact: Compacted in 3 layers providing 25 blows/layer by a hammer of 5.5 pounds in 12" free fall.

(Source: Ahsan 2005)

3.6 Particle size distribution

Table 3.8 represents the particle size distribution of MSW in four major cities of Bangladesh. The average percent finer for four major cities is 100% in 200 mm sieve opening whereas 84% in 100 mm, 72% in 76.2 mm, 54% in 38.2 mm and 35% in 19.1 mm and gradually decreases for smaller sieve openings. In 100 mm sieve opening, the average highest value is 92% for Khulna city, while the lowest value is 78% for Dhaka city.

Table 3.8 Particle size distribution of MSW in four major cities of Bangladesh

City	Percent finer								
	Sieve opening (mm)								
	200	**100**	**76.2**	**38.2**	**19.1**	**9.52**	**4.76**	**2.38**	**Pan**
Dhaka	100	78	62	42	23	12	8	3	0
Khulna	100	92	82	64	41	28	24	13	0
Rajshahi	100	85	75	61	46	35	27	19	0
Barisal	100	80	69	50	29	19	14	9	0
Average	**100**	**84**	**72**	**54**	**35**	**24**	**18**	**11**	**0**

(Source: Ahsan 2005)

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 General

This chapter presents the research methodology that has been employed in this study to accomplish the research objectives as reported in section 1.3. The details of the implemented geoenvironmental experiments with necessary modifications are also provided. The research methodology is developed based on literature reviews.

This chapter describes the methodology of physical assessment of the studied UDS conducted in the four major cities in Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal includes the general features and topography, physical infrastructures, site technical facilities. The preparation of contour map, capacity and design life, and overall impact of the studied sites are also described in this chapter. MSW leachate characteristics and leachate risk factor were ascertained in this study through laboratory studied UDS. This chapter describes the working procedure of the various stages of this study, conducted in fields and laboratories. The estimation of Methane emission from UDS of MSW in the studied cities is described here. The hydraulic, compaction and mineralogical properties of soil for the suitability of GCL and CCL are also illustrated here.

4.2 Compilation of Data and Related Information

Regarding to compilation of data and related information, methodology is based on some publication from KUET library, some websites and follows the procedure. Local information on population, topography, geology, soil conditions and municipal solid waste generation of four major cities namely, Dhaka, Khulna, Rajshahi and Barisal are collected from secondary sources such as: Bangladesh Burro of Statistics (BBS), Dhaka City Corporation (DCC), Khulna City Corporation (KCC), Rajshahi City Corporation (RCC), Barisal City Corporation (BCC), Department of Environment (DOE) etc.

4.3 Physical Assessment of the studied UDS

The legal boundary and topography survey of each ultimate disposal site was carried out by GPS instrument and Total station. The actual boundary that is practically dumped the MSW was taken in every site. Contour map was prepared by using Arc view software. The dumping area, capacity and design life of each UDS were calculated which is shown in annexure D. Types of waste disposed in each ultimate disposal site were evaluated by visual identification precisely. It includes the site content either hazardous and/or special waste disposed with and/or without treatment. Different types of animal vectors and the frequency of scavengers are assess by frequent ask questions of nearby local people and also by site visit. The aesthetic view is countered in physical assessment with a fixed ideological reference of mind. The vehicle movement facility was determined for each ultimate disposal site. The length, width, lane and type of road are measured. The distances of the ultimate disposal sites from the different important distance indices such as city center, airport, school, nearest locality, nearest surface water and ground water sources were determined by linear measuring instrument and also by the GPS instrument. The conditions of all the studied sites are evaluated based on the relevant parameters such as fence, surrounding embankment, access road, weighbridge, control room, liner facility, leachate collection facility, leachate pond, gas collection and removal facility, storm water drainage facility, operation road, dumping platform and landfill equipment.

4.4 Overall Impact Assessment

The overall impact assessment was done by Indian Health Service (IHS, 1998) report and Resource Recovery and Conservation Act (RCRA) for classifying the possible threat to health and environment posed by the solid waste site. The detail methodology is described in annexure E. Hazard points shall be derived from Table A (shown in Appendix A) and used in accordance with the point ranges and descriptors listed below thereby resulting in a high, moderate or low (H, M, or L) threat potential designation for the site. This Table is intended to be used as a tool in evaluating the site and based on professional judgment the final determination of hazard potential is calculated.

Low Hazard	: Points total 13 or less
Moderate Hazard	: Points total 14-29
High Hazard	: Points total 30 or more

4.5 Leachate sampling

To collect the leachate sample from the four UDS was a matter of great concern. Six leachate collection points for each MSW disposal sites are selected. A hole of 0.25 meter wide and 0.50 meter deep was dug for this purpose. Soon after digging, a hole was filled with leachate and the leachate sample was collected for laboratory analysis. The sampling procedures followed by EPA standard procedure throughout field testing.

4.6 Leachate Testing

Physical and chemical properties of leachate were analyzed in laboratory that is briefly discussed below. Table 4.1 shows the methodologies used during water laboratory analysis of collected leachate samples for different parameters.

Table 4.1: Testing Method for Leachate Samples

Parameters	**Testing Method**
pH	Electrometric using combination electrodes
Dissolved Oxygen	Membrane electrode Method
BOD_5	5 days incubation, reduction on DO is measured
COD	Colorimetric method
TDS	Gravimetric, dried at 105°C
Lead	Atomic Absorption Spectrophotometer (AAS)
Nickel	AAS
Cadmium	AAS

****Standard Method for the Examination of water and wastewater, 18th Edition, 1992.***

pH

pH is the numerical expression of the concentration of hydrogen ions in a solution. pH was measured by using pH meter. The meter was calibrated at three points against buffer solutions of 4, 7 and 9.2 pH prior to measurement.

Biological Oxygen Demand (BOD)

The Biological Oxygen Demand (BOD) method entails a 5-day incubation of the sample at 20°C. DO was measured before and after incubation and BOD was computed from the difference between the initial and final Dissolved Oxygen.

Chemical Oxygen Demand (COD)

The COD is a measure of the oxygen equivalent of organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The sample was digested at 150°C for two hours in a strong acid solution with a known excess of Potassium dichromate and then measure the value of COD.

Suspended Solids

A well mixed known volume of sample was filtered through a weighed glass fiber filter. The residue was dried to a constant weight at 105°C. The increase in weight of the filter represented the total Suspended Solids.

Heavy Metals Analysis

Requirement for determining metals by Atomic absorption Spectrophotometer (AAS) vary with metal and/or concentration to be determined. The method was used according to the concentration of different metals. Metals by Flame Atomic Absorption Spectrometry were used for the analysis of Lead, Nickel and Cadmium. These methods are taken from the "Standard Method for the Examination of water and wastewater, 18^{th} Edition, 1992".

4.7 Statistical analysis

Statistical data analysis includes minimum, maximum, mean, and standard deviation values were calculated to check the worst condition and to ease of comments on the characteristics of leachate. The analysis is used to estimate the leachate risk factor for studied UDS of four major cities of Bangladesh.

4.8 Leachate Risk Factor (LRF)

In case of Matuail, Rajbandh, Shishu Park and North Kawnia disposal site, eight contaminant parameters were used for calculation of the LRF. These parameters are Chloride, Iron, TDS, BOD_5, COD, Lead, Nickel and Cadmium. The criteria for selection of these parameters are based on the indicators of leachate toxicity to the environment and public health; reliable standards or guidelines are available for these contaminants.

The leachate risk factor (LRF) is estimated by the New Zealand Standard (ANZECC) method. If the level of any contaminant in leachate is below 50% of the guideline value, then the risk of contamination is considered to be not significant and no regular monitoring is required for that contaminant. In this case there would be no requirement for discharge consent.

On the other hand, if the level is measured at 50% to 100% of standard value, then even though the contaminant level is below the guideline, the potential risk of contamination is considered to be significant and the monitoring must be carried out on a regular basis. In such cases, a regulatory consent for discharge of the leachate into the environment may be required, depending on other factors such as the sensitivity of the receiving waters and toxicity characteristics of the contaminant.

Of course if the contaminant level is above the guideline value, then the risk to consumers from the contaminant is considered to be significant. This would require regulatory consent for discharge of the leachate into the environment under specific conditions. Hence the measured concentrations of contaminants in the leachate are expressed as a ratio of relevant standard or guideline, to assess the relative risks to the environment from the landfill discharges.

4.9 Estimation of Methane Emission

The method is simple and emission calculations require only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available. The IPCC Guidelines introduce various specific default values and recommendations, (particularly for use in countries with lack of SW statistics).

The details of each parameter are described in annexure F. The IPCC default method is based on the following equation:

Methane emissions (Gg/yr) $= (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1 - OX)$

Where

MSW_T : total MSW generated (Gg/yr)

MSW_F : fraction of MSW disposed to solid waste disposal sites

MCF : methane correction factor

DOC : degradable organic carbon (fraction) (kg C/ kg SW)

DOC_F : fraction DOC dissimilated

F : fraction of CH_4 in landfill gas

16/12 : conversion of C to CH_4

R : recovered CH_4 (Gg/yr)

OX : oxidation factor

4.10 Soil Sampling

Soil Samples were taken at the vicinity of existing studied four UDS by wash boring method. The disturbed and undisturbed samples were collected upto a depth of 60 ft. The Standard Penetration Test (SPT) value was also taken for every layer of soil sampling. Table 4.10 shows the location and description of soil samples with short name. The soil layers D01, K01, R02 and B01 are selected for the analysis of suitability of compacted clay liner (CCL).

Table 4.10 Location and description of soil samples with short name

No.	Location and description (D = depth in feet, L = Layer)	Short name
1	DHAKA Matuail, D: 10-20, L: 2	D01
2	DHAKA Matuail, D: 20-30, L: 3	D02
3	DHAKA Matuail, D: 30-60, L: 4	D03
4	KHULNA Rajbandh, D: 0-20, L: 1	K01
5	KHULNA Rajbandh, D: 20-30, L: 2	K02
6	KHULNA Rajbandh, D: 30-45, L: 3	K03
7	KHULNA Rajbandh, D: 45-60, L: 4	K04

8	RAJSHAHI Shishu Park, D: 0-5, L: 1	R01
9	RAJSHAHI Shishu Park, D: 5-10, L: 2	R02
10	RAJSHAHI Shishu Park, D: 10-35, L: 3	R03
11	RAJSHAHI Shishu Park, D: 35-50, L: 4	R04
12	RAJSHAHI Shishu Park, D: 50-60, L: 5	R05
13	BARISAL North Kawnia, D: 0-10, L: 1	B01
14	BARISAL North Kawnia, D: 10-30, L: 2	B02
15	BARISAL North Kawnia, D: 30-45, L: 3	B03
16	BARISAL North Kawnia, D: 45-60, L: 4	B04

4.11 Basic properties of Soil

The specific gravity, pH and organic content measurement of the soils were performed according to British Standard (BS1377: 1990) as documented by Head (1992). Particle size determination of the soils were carried out by direct sieving of the sand fraction and by the hydrometer method for silt and clay. The liquid, plastic and shrinkage limits were determined according to British Standard (BS1377: 1990). The data of these index properties were used to classify the soils using the Unified Soil Classification System (USCS).

4.12 Mineral Identification of Soils

The soil samples were transferred to Karlsruhe University for mineralogical analysis and the samples were air-dried in an oven at 60°C, crushed, and manually pulverized in a mortar. X-ray diffraction is the most widely used method for identification of fine-grained soil minerals. The X-ray analyses were performed in a X-ray diffractometer SIEMENS 0-500 with a Cu-Ka tube (wavelength of the X-rays A = 1,5406 A) at 40 KV and 30 mA. For the mineralogical analysis by X-ray diffraction, textured and texture-less powder samples were prepared.

For texture-less samples, air-dried sample powder was filled into sample holders and measured over a diffraction angle width of 2<1> = 1-65° (step size 0.02°, measurement time 2 sec). The results give an overview of the mineralogical composition of the samples and can further be used for semi-quantitative evaluation.

Textured samples were prepared by suspending 3 g of air-dried sample powder in 100 ml of deionised water. To achieve maximum dispersion, tetra-sodium diphosphate was used. The suspension was pipetted on small glass plates (2 cm x 2 cm). During drying, the platy clay mineral particles settle on the glass plate forming a parallel texture, resulting in amplifying the basal diffraction peaks. The textured samples were measured over a diffraction angle width of 2<1> = 1-15° (step size 0.04°, measurement time 4 sec) which is the range of basal peaks of clay minerals. Three different treatment steps were analysed: Untreated ("normal") samples, samples saturated with ethylene glycol ("EG") to identify swelling clay minerals, and samples heated to 550° to differentiate kaolinite/chlorite and other clay minerals.

The contents of non-clay minerals (quartz and feldspar) were estimated from the peak heights of these minerals, on the basis of existing calibration curves. After estimation of the non-clay minerals, the rest to 100% was assumed to consist of clay minerals and other phyllosilicates (micas) and estimated by evaluating the ratios of the areas of their basal peaks. For a more accurate evaluation, which should be performed in cases of concrete landfill sites planning, the internal-standard method should be used for the semi-quantitative mineralogical analysis. The total carbonate content was measured using a calcimeter (method after SCHEIBLER).

4.13 Cation exchange capacity of soil

Methylene blue is cationic organic dye with a high affinity to soil particle surfaces. It is attached to clay minerals by ion exchange reactions. Therefore, the amount of methylene blue adsorbed by a soil can be used as a rough measure to estimate the cation exchange capacity (CEC) of that soil, its specific surface area and its content of swelling clay minerals (after calibrating the method with a clay of known composition). For measuring the Methylene blue adsorption, the "halo method" was used: Methylene blue solution is titrated slowly to a soil suspension until the soil is saturated by the methylene blue dye. To detect saturation, suspension drops are placed on a filter paper during titration. Saturation is reached when the wet halo around the spot of soil particles on the filter paper turns light blue.

4.14 Soil preparation for compaction test

The soils were air dried and broken down into small pieces with a rubber pestle. The crushed soils were then passed through a No. 4 sieve (4.75 mm openings). Soil clods that remained on the sieve were ferther broken down by hand until they passed through the sieve. The sieved soils were wetted with tap water (pH= 6.65) of various percentages using a spray bottle, and stirred with a trowel during hydration to ensure an even distribution of water to achieve the desired water content (e.g. if the desired water content is 10%. Then the moisture content of the air-dried soil was determined, suppose it was 2%. Thus, 10% – 2% = 8% water by weight of soil solids was added to get a sample of 10% water content). Afterward the moistened soils were sealed in plastic bags and stored for at least 3 days to allow moisture equilibration and hydration. These processed soils were used for compaction and hydraulic conductivity tests.

4.15 Hydraulic Conductivity

The hydraulic conductivity was measured in compaction mould with perforated base (rigid wall permeameter) under falling head condition as recommended by Head (1994). Processed soils of different water content were compacted within the mould. Then the moulds were placed in a sink in which water was filled to about 50 mm above the top surface of compacted samples while the top cover plate was opened so that the water could back up through the specimens. This procedure was applied to ensure saturation of the samples and to eliminate entrapped air. The permeameter liquid was deaired tap water. Permeation was conducted on the samples until steady conditions ($h_3=\sqrt{(h_1 x h_2)}$) were achieved. During either saturation or permeation of water no air pressure was applied. The experiment was conducted in triplicate for each particular soil condition to increase the reliability of the test results.

4.16 Acceptable Water Content and Dry Density / Overall Acceptable Zone

Hydraulic conductivity, strength and shrinkage potential are the main factors controlling the performance of compacted clay liners. However, these factors are directly or indirectly related to compaction (moulding water content and dry density). These factors can significantly be altered due to the small variations in compaction parameters. Thus, it is very important to find a suitable or acceptable range of water content and the minimum dry density that will produce compacted soil with acceptable hydraulic conductivity, strength and shrinkage for the two soils.

The traditional (prior to 1990) method is developed by first creating a water content-dry density relationship based on a given compaction energy (typically standard Proctor compaction energy). Based on the resulting compaction curve, the soil for the compacted soil liner must be compacted in the field at water content (w) and dry density (γ_d) greater than the optimum water content (w_{opt}) and some specified percentage of the maximum dry density (γ_{dmax}) of the soil respectively, as determined from the laboratory compaction curve (e.g., $w_{field} \geq w_{opt(lab)}$ and $\gamma_{d(field)} \geq \frac{P}{100}\gamma_{dmax(lab)}$). Herrmann and Elsbury (1987) reported that P is usually 95% of $\gamma_{dmax(lab)}$ from standard Proctor compaction. The range of acceptable water content varies with the characteristics of the soil, but for soil liners and covers, might typically be about zero to four percentage points wet of standard or modified Proctor optimum water content.

CHAPTER FIVE

PHYSICAL ASSESSMENT OF THE STUDIED UDS

5.1 General

The ultimate disposal site should be analyzed critically by the different physical parameters to observed and minimize the environmental pollutions origin from the UDS. The UDS should be sound against all concerned physical factors to avoid the spreading of problems. The disposal site selection criteria are the most important task to control the geo-environmental problems associated with UDS. For the site selection process, the available land area is a key consideration to minimize the transaction costs associated with design, permitting, siting, closure and post-closure requirements.

This chapter describes the physical assessment of the studied UDS includes the Legal boundary, general features and topography, physical infrastructures, different distance indices, types of waste disposed, animal vectors and other technical facilities. The overall impact assessment, contour map, capacity and design life of the studied sites are also described in this chapter.

5.2 General Information and Topography of the UDS

Location of UDS is one of the key factors to reduce the negative environmental impacts and to increase the capacity. But there was no such analytical site selection technique adopted by city authority for the selection of existing UDS. The sites have been using for such purposes just from the availability of unused government land and/or acquired land by consideration of visual and physical factors. The general information and topography of the studied four UDS are given below:

5.2.1 Matuail Disposal Site

Matuail disposal site (MDS) is located about 7 km of southeast of city center of Dhaka city. The location of MDS is shown in Figure 5.1 in DCC map. Matuail is the official ultimate disposal site owed by DCC. The greater part of the Matuail site is flat, surrounded by a concrete pavement along its enclosing embankments. It is free from flood. An elevated tract of land formed by the dumped wastes is seen in the left side of the entrance road. The land to the right side has yet to be ripped.

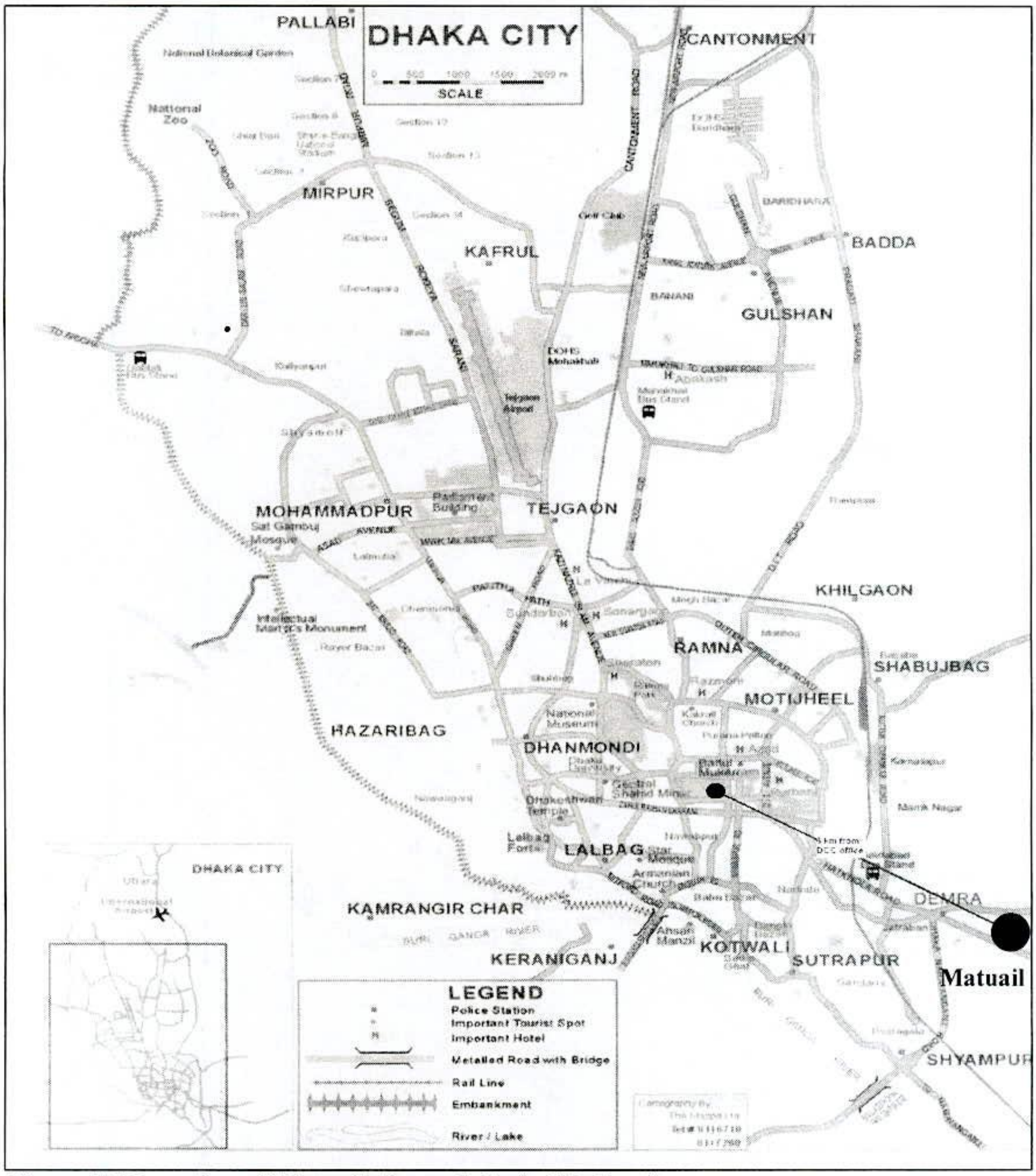

Figure 5.1 Location of Matuail disposal site in Dhaka city

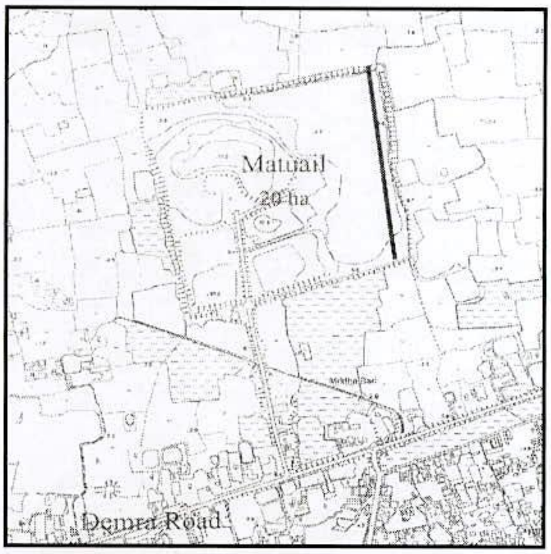

Figure 5.2 Layout of Matuail disposal site of MSW of DCC: Matuail (after DCC 2004)

5.2.2 Rajbandh Disposal Site

The Rajbandh Disposal Site as shown in the Figure 5.3 is situated at a distance of 7 km west of Khulna city center along the right side of Khulna-Satkhira Highway. The topography of the existing disposal site is almost plain and lowland. Three ponds having maximum water depth of 1.5 m are located in the site and other places are relatively high due to scattered deposition of solid wastes.

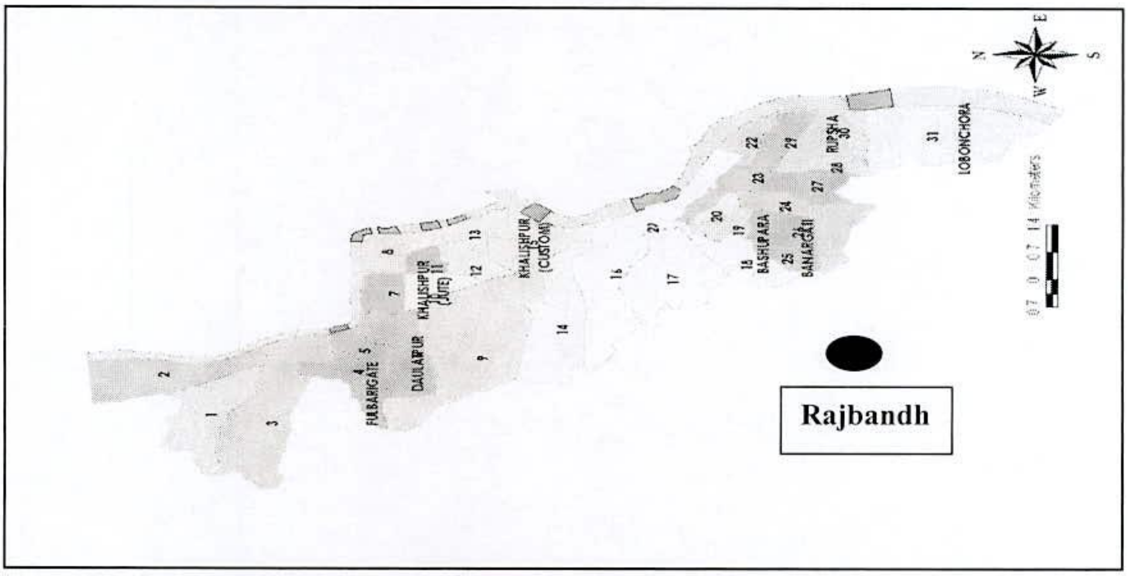

Figure 5.3 The location of Rajbandh disposal site in Khulna city

The ponds are using for unauthorized aquculture which will reduce the total capacity and design life of the site. Leachate produced in the site is directly passes to the ponds. There are four compost plants available near the dump site. Two plants are almost closed due to their product quality, technical and economical constraints. One burning unit of clinical waste is running by NGO named Prodipan, Bangladesh. Total area of present UDS is 20 acre (80,980 m^2). In its present form, it is possible to deposit the wastes for the next few years. But KCC authority has started to dump the MSW in the new Rajbandh DS from January 2006 due to the public objection of that site situated 700 m far from the present site. Now some portion of organic waste deposited in Rajbandh site due to the proper operation of compost plants. KCC have plan to start dumping again at Rajbandh after completion the new 5 acre Rajbandh site closure.

5.2.3 Shishu Park Disposal Site

Rajshahi City Corporation (RCC), operates an ultimate wastes disposal site known as Shishu Park dumping site, is located about 8 km north corner of the city center as shown in the Figure 5.4. The site is located at Tikor Bill near the Rajshahi by-pass Road and Truck Terminal in ward No.17 in the RCC area. Some infrastructures around the center of the site to

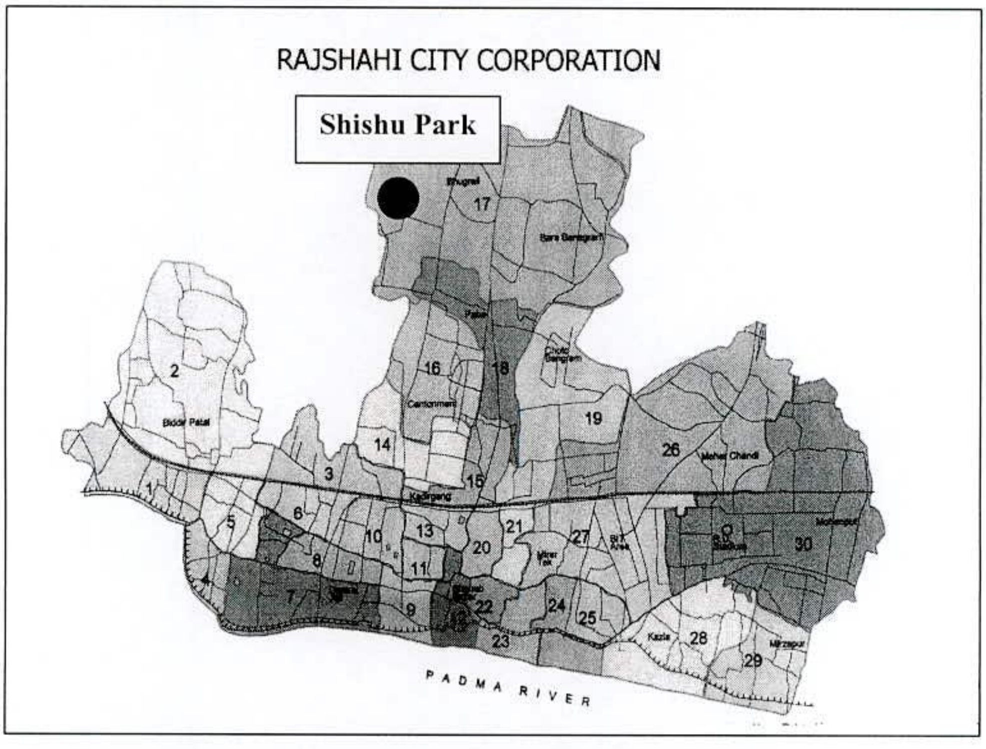

Figure 5.4 The location of Shishu Park Disposal Site in Rajshahi city

locate the position of the disposal area are presented in the Table 6.3. City authority is the owner of this UDS. The authority purchased the site in the year of 2001.

Naturally the disposal site is a low-lying land area. The surface of the disposal site is situated at about 4 and 1.5 m below from the road level of bypass and the connecting road, respectively. The surrounding area is almost the cultivated land. The nearest locality exists about a distance of 300 m in the west-north direction and a college named 'Rajshahi Residential College' is located within a distance of 200 m in the west-south direction from the edge of the site. The population density of the surrounding area is approximately 1833 persons/sq km. The Rajshahi-Chapai Nawabgonj by-pass road passes through the south side of the dumping site. It is a pavement type road and its width is about 8 m. The distance between the bypass road and the edge of the disposal site is about 200 m. The Rajshahi-Naogoan road also passes through the west side of the dumping site at a distance of about 1.78 km. During rainy season the water level rises up to 1.25 m from the existing surface of the disposal site.

Since all types of wastes are dumped here, after a few days the local people sometimes take decomposed wastes to use it as fertilizer. Some people also take wastes to fill up the lowland. The above-mentioned two practices were happened in the previous disposal site. Moreover, open burning and recycling of solid waste are also practiced in the site. On the other hand with the increasing of population the amount of wastes has also been increased. Therefore these factors may be minimized each other.

5.2.4 North Kawnia Disposal Site

Barisal City Corporation (BCC) operates an UDS of MSW, known as North Kawnia dumping site. This UDS is a new one and owned by the city authority and started to dump wastes since January 2004. It is located at Kawnia under ward number 3 as shown in Figure 5.5.

The North Kawnia disposal site is a waterlogged and low-lying land. The ground surface of the disposal site is situated at a depth of about 1.5 to 2m below from the road level. The surrounding area is agricultural land and also abandoned because of water logging. The nearest locality is situated at a distance of about 100m away from the site. A college named as 'Serniabat College' is also located at a distance 400m far from the boundary of the site.

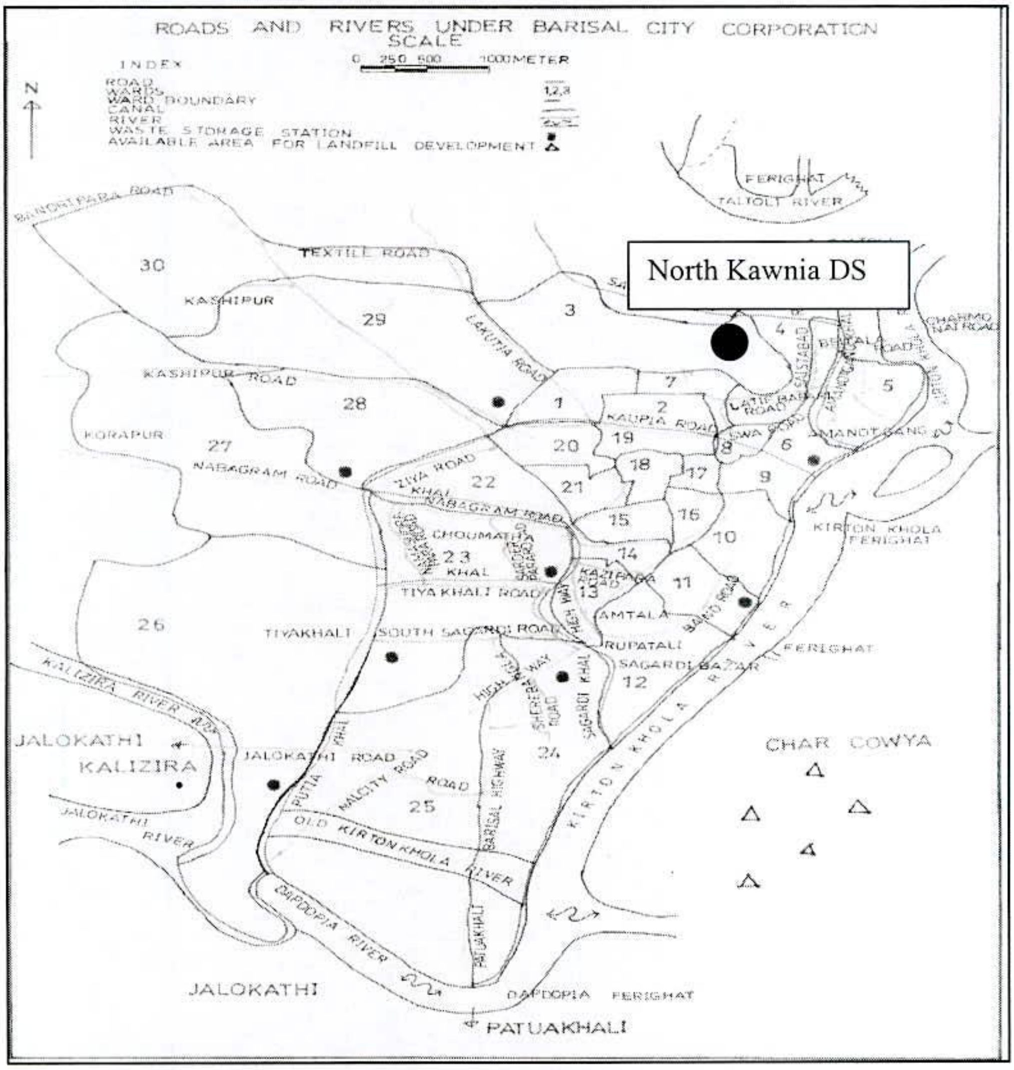

Figure 5.5 The location of North Kawnia Disposal Site in Barisal city

5.3 General Features

Disposal site record books, history and other related general features have to be recorded, monitored and updated by responsible officials for the efficient and appropriate management of any ultimate disposal site. But study shows that in the studied disposal site of Bangladesh no such monitoring and record keeping have been conducted so far at any level of authorities. Table 6.4 represents the general facts of every disposal sites. Figure 5.6 shows the general view of the studied ultimate disposal sites at (a) Dhaka, (b) Khulna, (c) Rajshahi and (d) Barisal run by the respective city corporation.

Figure 5.6 General view of ultimate disposal site run by the four City Corporation of Bangladesh located at: (a) Matuail, Dhaka, (b) Rajbandh, Khulna, (c) Shishu Park, Rajshahi, and (d) North Kawnia, Barisal

5.4 Site contents

Characteristics of waste deposited in the UDS and the management system to handle such varieties of solid wastes must be addressed to reduce the negative environmental impacts and to set-up the criteria for monitoring and future use of the disposal site. Perhaps the largest single factor in determining whether or not a disposal site poses significant threats to public health and the environment is the amount of hazardous materials disposed at the site. The site poses a detrimental effect by containing special and hazardous wastes without any prior treatment and declaration. The effective way to prevent this threat is to control the disposal of toxic and hazardous wastes at the site. Site content evaluations are conducted based on standard descriptions by Resource Recovery and Conservation Act (RCRA 1995). In the studied four disposal sites, there is no regulation about the types of wastes to be deposited.

Any types of wastes deposited in the secondary disposal site are directly transferred and hence deposited. Hazardous and specials wastes including hospital wastes are deposited altogether in all studied UDS of four major cities of Bangladesh.

5.5 Animal vectors

Diseases spread by free access of animal vectors, which should be protected by ensuring safe disposal of wastes. Domestic animals have to be strictly handled by not allowing them at disposal sites. But unfortunately no such provisions against free access of animal vectors are provided in the existing UDS as presented in Table 5.1. Even the pet animals are also found in the sites for feeding with the readily available partly decomposed wastes.

Table 5.1 Animal vectors at disposal sites of MSW

Site name	Cows	Dogs	Crows	Insects	Scavengers
Matuail	N	Y	Y	Y	Y
Rajbandh	Y	Y	Y	Y	Y
Shishu Park	Y	Y	Y	Y	Y
North Kawnia	Y	Y	Y	Y	Y

Note: Y stands for Yes, N stands for No

5.6 Aesthetic aspects

Open dumping site is always incompatible with the surroundings. Wastes exposed all over the site are unsightly. As no proper system is practiced for filling the area, some places are considerably elevated from ground and some areas are the below than the normal surface level due to the haphazard filling of solid wastes. Wind blown litters and in discriminates dumped waste outside the site, the surroundings and on the free water surfaces, are common situation. The aesthetic view of existing site is unpleasant, undesirable, unaccepted and not recommendable, which causes bad impression on human mind and posed threat to human and nature.

In Rajbandh and North Kawnia disposal site, during the dry season the wastes are generally disposed at the opposite end from the roadside of the UDS. At that portion small distance had been filled by the city corporation labors and in the mean time the rainy season usually starts.

As a result the land became swampy. So the trucks became unable to carry the waste to the end portion. Also the UDS are not developed with a good road network in between the site. So the truck drivers are forced to dispose the waste at the roadside of the site. As a result aesthetic view has deteriorated further and creates environmental nuisance.

5.7 Types of disposed wastes

All types of MSW are disposed in this site. As clinical/hospital wastes are not managed properly and the service are available only in the limited areas, so major portions of such wastes are also disposed in the UDS with the main stream of MSW. The composition of solid wastes deposited in the UDS can be listed as:

- Food & Vegetable
- Paper & Paper product
- Plastic/Polythene
- Glass/Broken glass/Glass bottle
- Cardboard/textiles
- Leather
- Metal/tin/aluminum
- Yard waste/wood
- Dust/ashes/street leaves
- Special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires),
- Clinical/Hospital (some portion) etc.

5.8 Collection vehicle movement facility

The situation of approach road and inner road network at the ultimate disposal site is not good. Proper movement facilities for collection vehicles are provided at the Matuail dumping site. A concrete pavement is provided around the site to facilitate deposition of wastes from the trucks. Electric light is installed to facilitate deposition of waste at night.

In KCC, collection vehicles transfer and deposit their collected wastes into Rajbandh disposal site. No enough spaces are available for the movement of vehicle in the disposal point. There is only one partial brick-soling road for waste disposal operation. So all vehicles are entering in the site with rare facing and after dumping go ahead for exit. This situation arises due to improper and haphazard dumping of waste at the disposal area. As a result left, right and back side of the site are not filled properly with the required compaction.

No proper systems are also being practiced for MSW disposal at ultimate disposal sites owned and operated by RCC and BCC. So vehicle movement at UDS is a big problem and headache for the vehicle operators. At Shishu park, Rajshahi, the connecting road between the highway and the site is Brick-soling type and its width and length are 4m and 200m respectively. There was no road to go the inner part of the site. At present a road is being constructed next to the brick-soling road of width 4m and length 247m to go to the inner area of the site. North Kawnia disposal site of BCC is almost a waterlogged area having no concrete or paved road. Two brick-soling roads are available on both sides of the disposal site. As a result the trucks can only dispose the waste besides the road. The roadsides are full by dumping wastes, as trucks are disposed wastes beside the road. But the middle portion of the site is totally free and there is no facility to dump wastes in the middle portion, as no road network exists within the site.

5.9 Distances of important indices

Location of important indices with respect to the distance of UDS is an important factor in determining whether or not a disposal site poses significant threat to public health and environment. Siting in wetlands or other sensitive areas can cause significant damage to local plants and animal species. Surface water contamination is less likely at safe distances from lakes, rivers and fisheries. Table 5.2 shows the distances of the disposal sites from the important distance indices such as city center, airport, school, public gathering place, surface water and ground water sources etc.

It is revealed from the Table 5.2 that all the UDS except North Kawnia DS are located at reasonable safe distance from the city center. The sites are also located far from the Airport of the respective city. However, nearest locality and public gathering are very close to all the sites. It is also observed that the water sources both the surface and ground water are very near, even located in the close vicinity of all the UDS.

Table 5.2 Distances of important indices from ultimate disposal site

UDS	MTL	RJB	SSP	NKW
City center	7.0	7.0	8.0	2.5
Airport	30	38	6.0	7.0
Nearest locality	1.0	0.20	0.50	0.10
Nearest tube well/ground water source	0.20	0.05	0.20	0.20
Nearest river	5.0	0.50	10	3.0
Nearest pond/surface water source	0.005	0.005	0.20	0.10
Nearest public gathering or School/college	1.5	0.10	0.20	0.40

Note: All figures in this table are in km; MTL: Matuail, RJB: Rajbandh, SSP: Shishu park, and NKW: North Kawnia

5.10 Technical considerations

Technical aspects at the site includes gate controls, cell operations and administrations including site permition and regulatory compliance, worker training and safety, public relations, permitting franchisees, record keeping, accounting, and all other clerical duties associated with the operation of an industrial facility. The success of the landfill depends on a strong administration that is committed to provide adequate financing of the facility, transparency in its operations, and accessibility of information to the public. The present status of these technical aspects in the studied disposal sites is shown in Table 5.3. The conditions of all the sites are evaluated based on the relevant parameters such as (i) fence, (ii) surrounding embankment, (iii) access road, (iv) weighbridge, (v) control room, (vi) liner facility, (vii) leachate collection facility, (viii) leachate pond, (ix) gas collection and removal facility, (x) storm water drainage facility, (xi) operation road, (xii) dumping platform and (xiii) landfill equipments.

From this table, it can be seen that most of the necessary technical facilities are absent in all the studied UDS except Matuail DS. There is no existence of fence at any site. No weighing bridge and control room are present at Rajbandh, Shishu Park and North Kawnia DS. There is no embankment so far constructed around the site except Matuail dumping site. However, excess roads are available in all the sites although not adequate and proper. Internal road network is very poor. Since Rajbandh, Shishu Park and North Kawnia disposal sites are belong to open dumping category, no facilities of engineering landfill such as liner facility, leachate collection system, leachate circulation pond, gas removal facility and storm water drainage system etc. Even the required type and number of vehicles for spreading, compacting and surfacing of wastes are not available in every site.

Table 5.3 Technical facilities at the ultimate disposal sites

Facilities	Matuail	Rajbandh	Shishu Park	North Kawnia
Fence	N	N	N	N
Lighting	I	NI	NI	NI
Surrounding embankment	C	NC	NC	C
Access road	C	C	C	C
Weighbridge	C	NC	NC	NC
Control room	C	NA	NA	NA
Liner facility	NI	NI	NI	NI
Leachate collection facility	C	NI	NI	NI
Leachate pond	C	NI	NI	NI
Gas removal facility	NI	NI	NI	NI
Strom water drainage	C	NI	NI	NI
Operation road	C	C	C	NC
Dumping platform	C	NC	NC	NC
Landfill equipment	BLZ (3) EXV (2) WHD (1)	BLZ (1) EXV (0) WHD (0)	BLZ (0) EXV (0) WHD (0)	BLZ (0) EXV (0) WHD (0)

Note: N=None, C=Constructed, NC=Not constructed, UC=Under construction, NA=Not available, I = Installed, NI=Not installed, BLZ=Bulldozer, EXV=Excavator, WHD=Wheel dozer. Figures in the parenthesis indicate the no of equipments available.

5.11 Overall Impact Assessment

The environmental problem causes by a disposal site depends upon a number of factors including: the composition of the waste, the rate of decomposition, the hydrogeology of the site, rainfall, distance to aquifers, types of liners and covers, runoff controls, the ability to collect leachate and gas. MSW disposal can pose significant public health hazards and environmental degradation. The most effective way to prevent this degradation is to limit where landfills can be located and to control the disposal of toxic and hazardous wastes at the site. If prevention techniques are not effective, control technologies must be utilized to address three environmental problems: groundwater contamination, surface water contamination, and air pollution. Regional adjustments based on professional judgment were made in hazard scoring assessments which are detailed shown in Appendix A. The relative threat to health and the environment was evaluated by Indian Health Service (IHS, 1998) report and Resource Recovery and Conservation Act (RCRA) based on the consideration of factors that may contribute to the likelihood that a site might pose a hazard. The surveyed every disposal site poses high threat to health and environment based on the above criteria. The assessments for four UDS are given in Table 5.4 based on the rating criteria detail shown in Appendix A. Assessment is done considering hazard rate factors. From the table it is observed that hazardous nature of all UDS active in four city corporations of Bangladesh is almost same.

Table 5.4 Evaluation of potential hazard caused by the UDS of MSW in Bangladesh

Hazard Point Factors	MTL	RJB	SSP	NKW
Waste contents	0	15	10	30
Rainfall	4	4	4	4
Distance to drinking water aquifer	8	10	10	10
Site Drainage	0	8	8	8
Potential to create leachate at site	2	4	4	4
Distance to domestic water source	2	4	4	4
Site accessibility	2	4	4	4
Frequency of burning	2	2	2	2
Site materials exposure to public & vector	2	2	2	2

Degree of public concern over site esthetics	2	4	4	4
Total Points	**24**	**57**	**52**	**72**
Hazard Potential	**M**	**H**	**H**	**H**

5.12 Site capacity and design life

The total permitted capacity and design life of a UDS is very important parameter for the effective management of any UDS. The site capacity and design life of four studied UDS is calculated. Levelling survey and contouring map was done to evaluate the existing topography of waste dumping to calculate the remaining capacity as well as the design life of the studied UDS. The total permitted capacity was established based on the discussion with the concern authority and professional judgment. Only DCC has prepared the design life of Matuail DS with the help of JICA. If the studied UDS is converted into controlled dump then the capacity can be increased more than existing practice of dumping in case of Rajbandh, Shishu park and North Kawnia DS. Table 5.5 shows the total capacity and extended design life of existing studied UDS. The details of landfill capacity calculation for the existing four studied UDS were shown in annexure F. Figure 5.7 (a, b, c, d) shows the legal boundary, peripheral situation and contour map of existing four studied UDS.

Table 5.5 The site capacity and design life of the existing studied UDS

Name of the site	Waste in place (Gg)	Total permitted site capacity (Gg)	Design life (Year)
MATUAIL	2340	5700	**10.0**
RAJBANDH	374	740	**5.5**
SHISHU PARK	94	415	**13.0**
NORTH KAWNIA	47	190	**12.5**

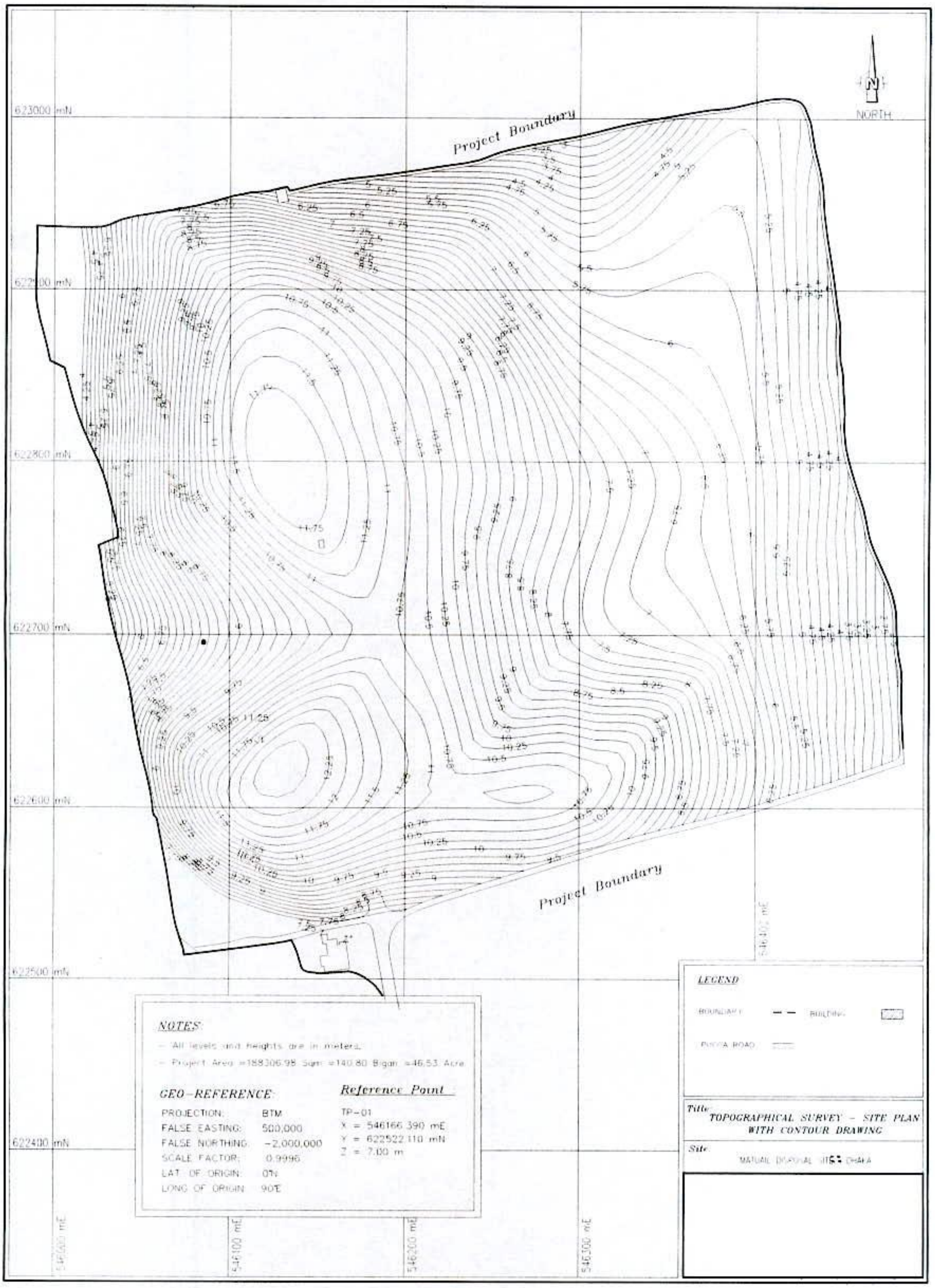

Figure 5.7 (a) Contour map of Matuail Disposal Site in Dhaka city

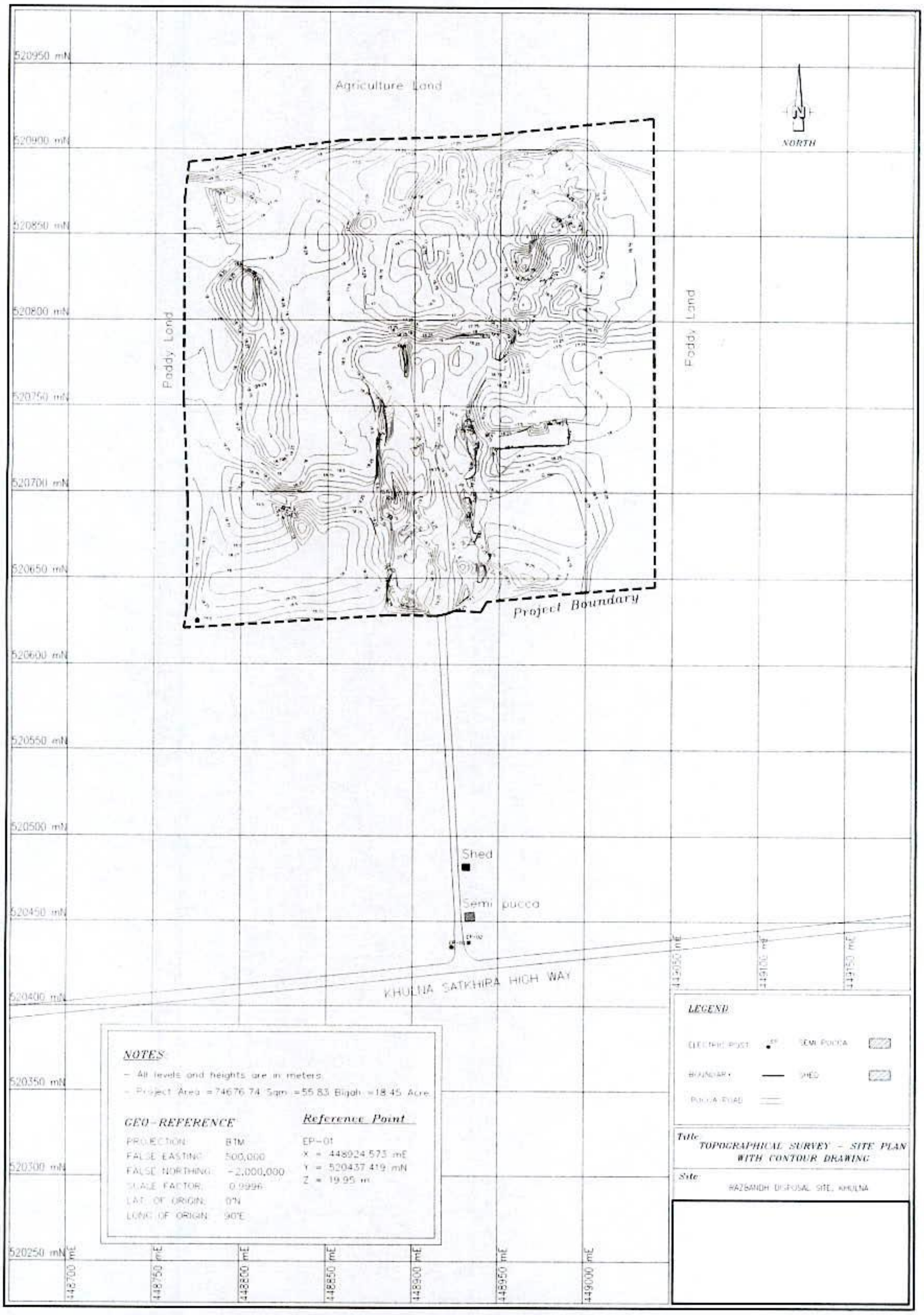

Figure 5.7 (b) Contour map of Rajbandh Disposal Site in Khulna city

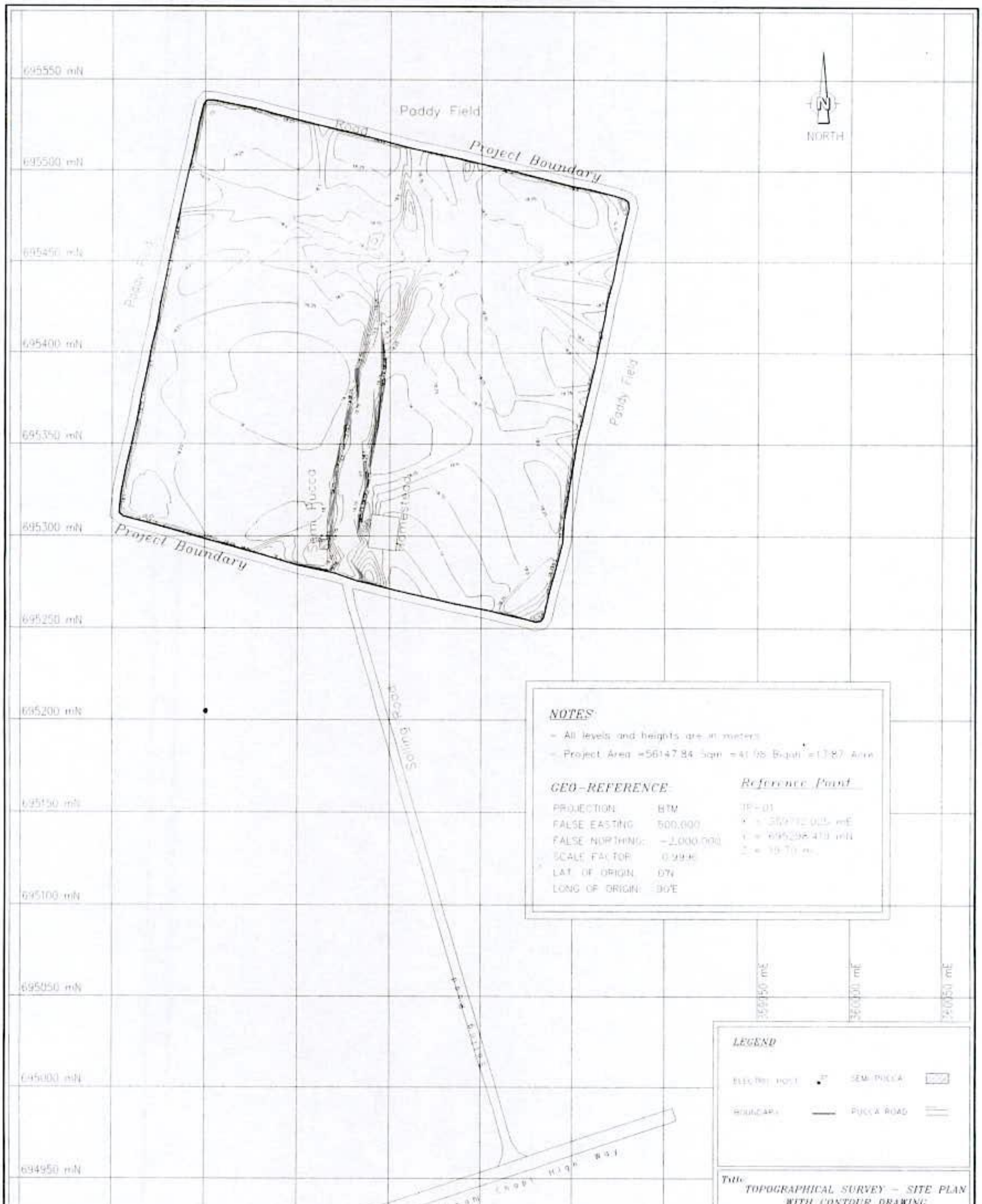

Figure 5.7 (c) Contour map of Shishu Park Disposal Site in Rajshahi city

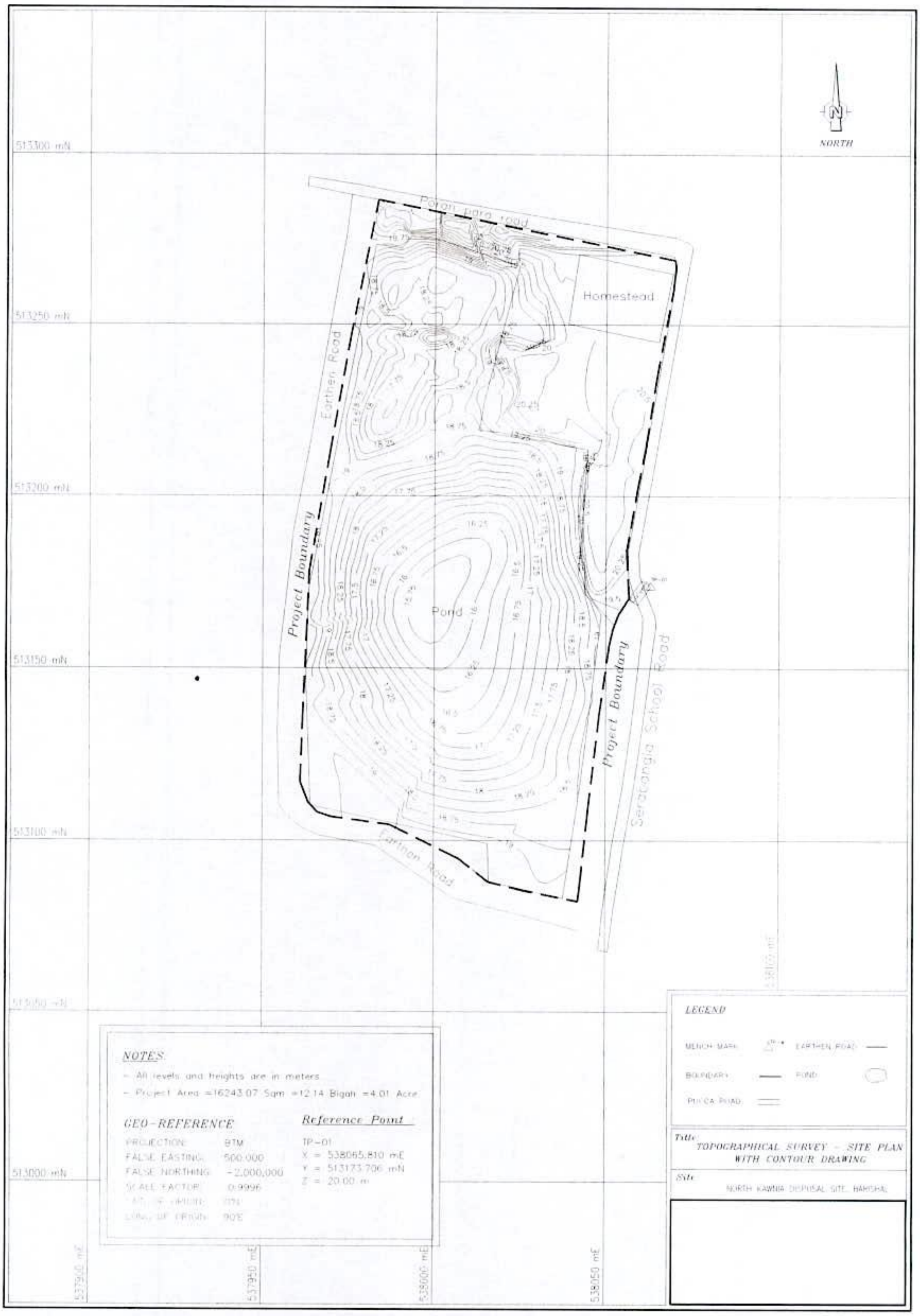

Figure 5.7 (d) Contour map of North Kawnia Disposal Site in Barisal city

CHAPTER SIX

GEOENVIRONMENTAL ASSESSEMENT OF THE STUDIED UDS

6.1 Introduction

This chapter presents the analysis results of the data obtained from laboratory experiments. In addition, detail discussions of the experimental results are reported in this chapter.

This chapter represents the geoenvironmental assessment of the studied UDS. Assessment of Landfill leachate includes the leachate characteristics, leachate risk factors of four UDS in the four major cities of Bangladesh, namely, Dhaka, Khulna, Rajshahi and Barisal are evaluated and describe here. Assessment of Landfill Gas especially the percent of degradable organic carbon and the amount of Methane emissions from all studied UDS are determined and presented in this chapter. Geotechnical assessment includes sub-soil strata, basic properties, strength and hydraulic properties, compaction properties and mineralogical compositions for the availability and suitability of GCL and CCL are illustrated in the following sections.

6.2 Assessment of Landfill Leachate

In a landfill the leachate generation is not constant flow depending on the initial moisture content, decomposition of solid waste, and the influence of climate: rainfall, evaporation, in which the landfill is situated. The characteristic of leachate depends on the variation as well as the type and rate of decomposition of waste. Also the intensity of rainfall affects the characteristics of leachate due to the dilution of concentrated leachate.

The characteristics of Leachate is not consistent with the time and the water enter the waste is widely varying so that the rate of decomposition changes. The maximum, minimum and mean values for the physical properties (pH, TDS), Chemical properties (Iron, Chloride), organic contents (BOD_5 and COD), and heavy metals (Pb, Ni and Cd) of leachate samples are shown in Table 6.1.

Table 6.1 Leachate characteristics of four UDS in Bangladesh

Parameters	Matuail	Rajbandh	Shishu Park	North Kawina
	Test Value, Min – Max (Mean)	Test Value, Min – Max (Mean)	Test Value, Min – Max (Mean)	Test Value, Min – Max (Mean)
pH	7.6 – 8.2 (7.8)	7.1 – 7.9 (7.6)	6.9 – 7.3 (7.1)	6.2 – 7.9 (7.1)
Chloride, mg/L	372 – 1825 (1096.7)	625 – 3000 (1672.2)	7.5 – 65 (41.8)	45 – 1300 (509.2)
Iron, mg/L	1.2 – 50 (17.0)	3.5 – 55 (29.5)	0.8 – 4.3 (2.5)	0.4 – 8.8 (3.5)
TDS, mg/L	2150 – 6110 (4150)	5568 – 8652 (7409)	1200 – 4700 (2825)	260 – 2750 (987.5)
BOD_5, mg/L	40 – 580 (280.8)	450 – 2550 (926.2)	80 – 600 (298.3)	78 – 1200 (417.2)
COD, mg/L	110 – 1760 (1020.8)	1834 – 5400 (3044.3)	820 – 5550 (3450)	280 – 3116 (1093.8)
Lead , mg/L	0 – 0.08 (0.04)	0.257 – 0.425 (0.33)	0 – 0.003 (0.001)	0 – 0.205 (0.04)
Nickel , mg/L	0.001 – 0.042 (0.02)	0.047 – 0.085 (0.06)	0.001 – 0.004 (0.003)	0.004 – 0.46 (0.13)
Cadmium, mg/L	0 – 0.012 (0.01)	0 – 0.04 (0.01)	0 – 0.003 (0.001)	0 – 0.105 (0.03)

pH:

pH basically the buffering capacity of the CO_3-HCO_3 system in water. pH of leachate influences chemical and biological processes of precipitation, sorption and methanogenesis. Figure 6.1 illustrated the variation of pH with time during the study period at the studied four UDS in Bangladesh. The pH rises when the microorganisms utilize the carbonates in the water, while the decomposition of organic pollutants causes pH to drop to the acidic range. pH as measured in this study ranges from 6.2 to 8.2. Maximum pH in sampling sites was noted at Matuail DS at Dhaka.

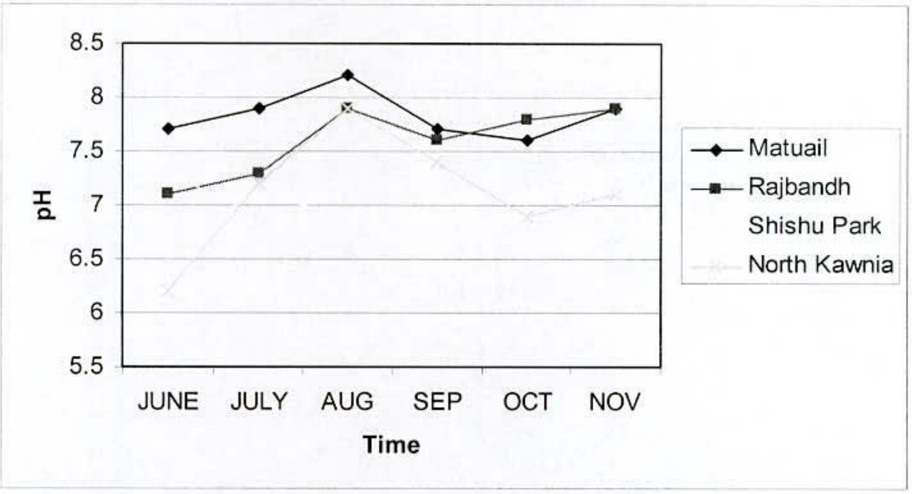

Figure 6.1 Concentration variations of pH with Time in leachate samples

TDS:

In general, the TDS values presents in the water less than 500 mg/L are the most pleasing for domestic use. The maximum allowable concentration of TDS for water supply is 1500 mg/L according to the WHO standard. The TDS values in all UDS are the range between 260 to 8652 mg/L. The TDS values are affected by the natural seasons especially during rainy season due to the dilution.

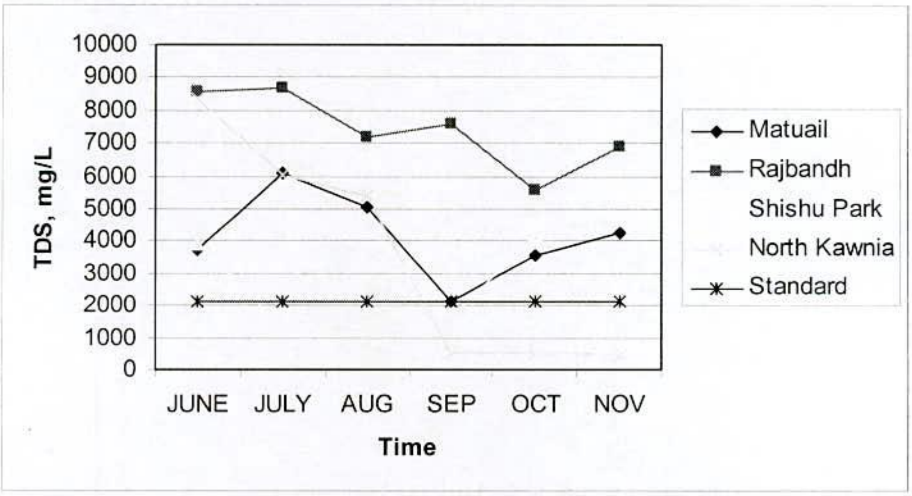

Figure 6.2 Concentration variations of TDS with Time in leachate samples

Chloride:

Chlorides in reasonable concentrations are not harmful to human. In many areas of the world where water supplies are scarce, source containing as much as 2,000 mg/L are used for domestic purposes without the development of adverse effects. Before the development of bacteriological testing procedures, chemical test of chloride and its various forms served as the basis or detecting contamination of groundwater through wastewater. Chlorides are used to some extent as tracers in sanitary engineering practice; however, they have been replaced to a great extent by organic dyes. The concentration of Chloride in leachate samples varies from 7.5 to 3000 mg/L which is shown in Figure 6.3. The maximum concentration of Chloride was shown in Rajbandh DS at Khulna.

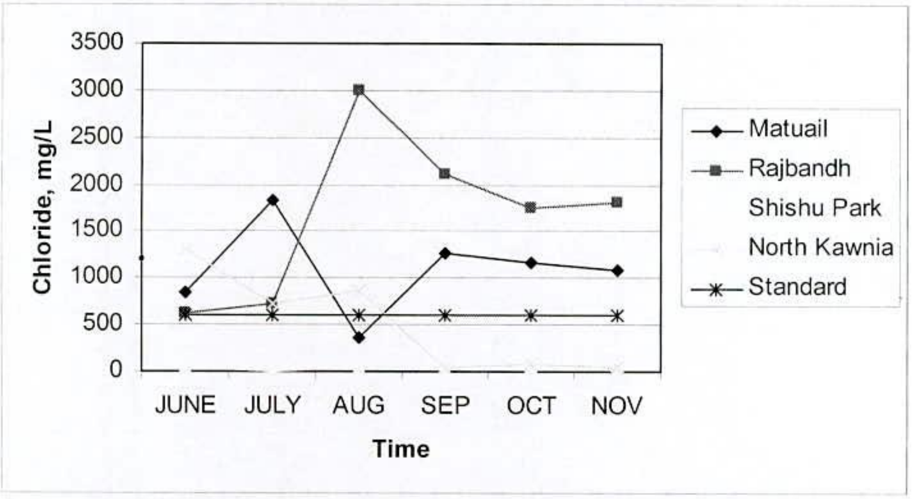

Figure 6.3 Concentration variations of Chloride with Time in leachate samples

Iron:

The rates of Iron oxidation at the pH level below 6 increased by the presence of certain inorganic catalysts of through the action of micro-organisms. Iron interfere with laundering operations, impart objectionable stains to plumbing fixtures and cause difficulties in distribution systems by supporting growths of iron bacteria. Iron also imparts a test to water, which is detectable at very low concentrations. The concentration of Iron in leachate samples varies from 0.40 to 55 mg/L which is shown in Figure 6.4. The maximum concentration of Iron was shown in Rajbandh DS at Khulna.

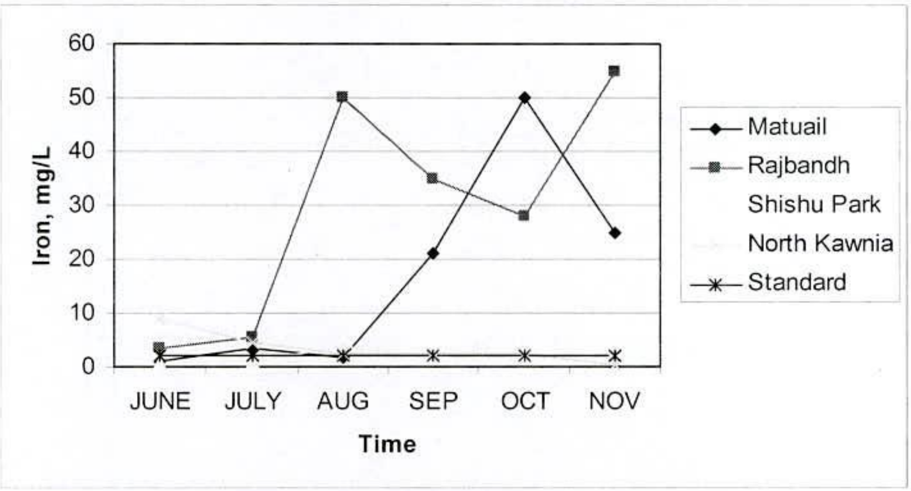

Figure 6.4 Concentration variations of Iron with Time in leachate samples

Organic content of Landfill Leachate:

The organic content of landfill leachate was measured as COD and BOD. The high organic content inside UDS in the beginning stage of decomposition cause the high COD and BOD values. The COD values are lower concentrations during rainy season owing to dilution of the pollutant due to heavy rainfall.

BOD represents the quantity of oxygen required by bacteria and other microorganisms during biochemical degradation and transformation of organic matter present in wastewater or leachate under aerobic condition. The BOD test is important in the analysis of leachate generated in the solid waste-dumping site. It is best available method for accessing organic pollution and the most important parameter used in stream pollution control.

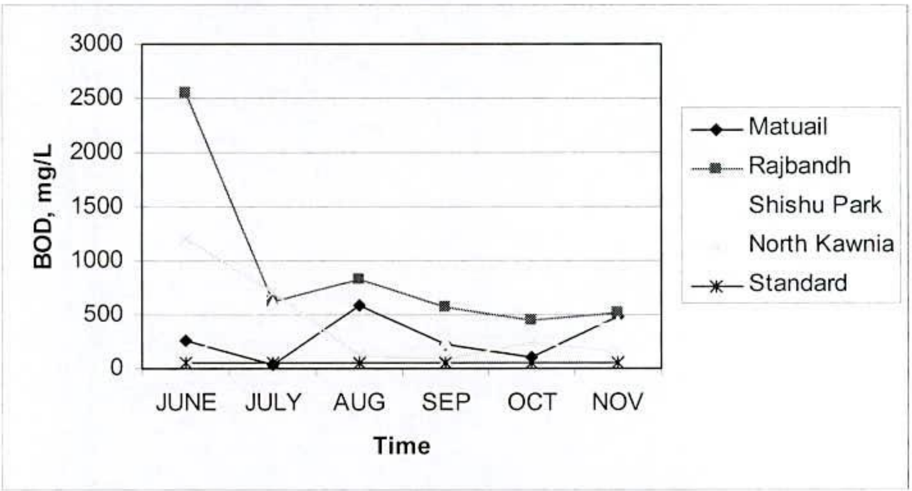

Figure 6.5 Concentration variations of BOD with Time in leachate samples

BOD and BOD/COD ratios give valuable input regarding the difficulty to degrade the organic substances, the supply of carbon source in identification, or the maturity phase dominating the dumping site or landfill site. Test results of BOD at different sampling locations varied from 0.40 to 8340mg/l. The highest concentration of BOD in water sample was noted at Rajbandh disposal site, Khulna that has the highest concentration. This is due to the kitchen waste dumped directly to the landfill site and may contain industrial waste. This high BOD of leachate sample deteriorates the environment.

Chemical Oxygen Demand (COD) is the measure of oxygen equivalent to the portion of organic matter that is susceptible to oxidation by Potassium Dichromate. COD is an important test and gives a quick measurement of pollution load of the leachate samples varied between 72.0 to 28320.0mg/l. Here also like BOD the highest concentration of COD was measured at Rajbandh disposal site, Khulna. Table 6.2 represents the relative biodegradability of leachate.

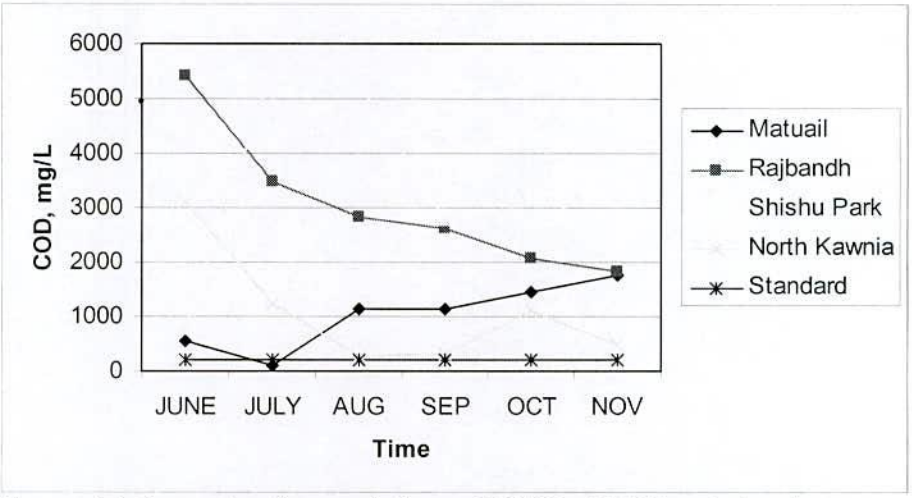

Figure 6.6 Concentration variations of COD with Time in leachate samples

BOD/COD ratio of the leachate sample collected from the MSW disposal site ranges from 0.01 to 0.46, which shows that the biodegradability of leachate sample is very low.

Table 6.2 Relative Biodegradability of Leachate

Biodegradability	BOD/COD
Low	< 0.5
Medium	0.5 – 0.75
High	> 0.75

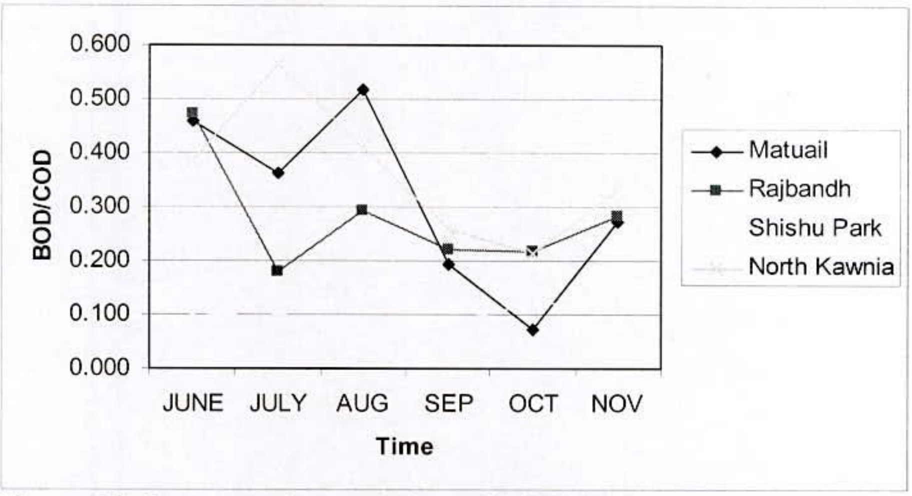

Figure 6.7 Concentration variations of BOD/COD with Time in leachate samples

Heavy metals:

Heavy metals are found in industrial wastes in a variety of forms. Lead, Nickel and Cadmium were determined in leachate samples. Maximum concentration of Nickel was found at North Kawnia disposal site, Barisal as 0.46 mg/l. Rajbandh DS contains the higher concentration of Lead ranges from 0.257 to 0.425 mg/L.

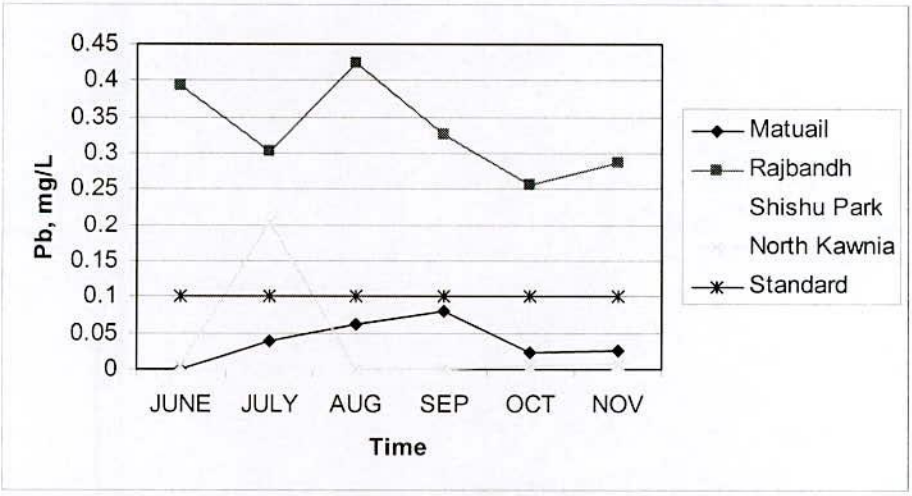

Figure 6.8 Concentration variations of Lead with Time in leachate samples

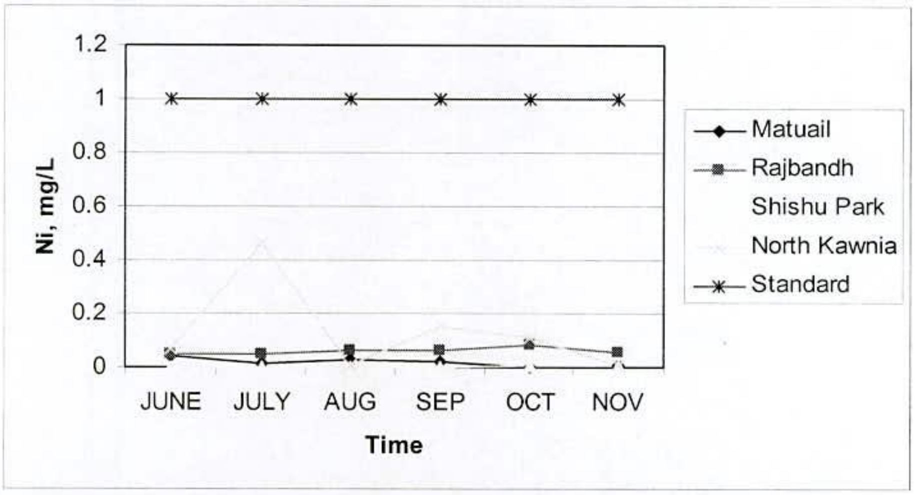

Figure 6.9 Concentration variations of Nickel with Time in leachate samples

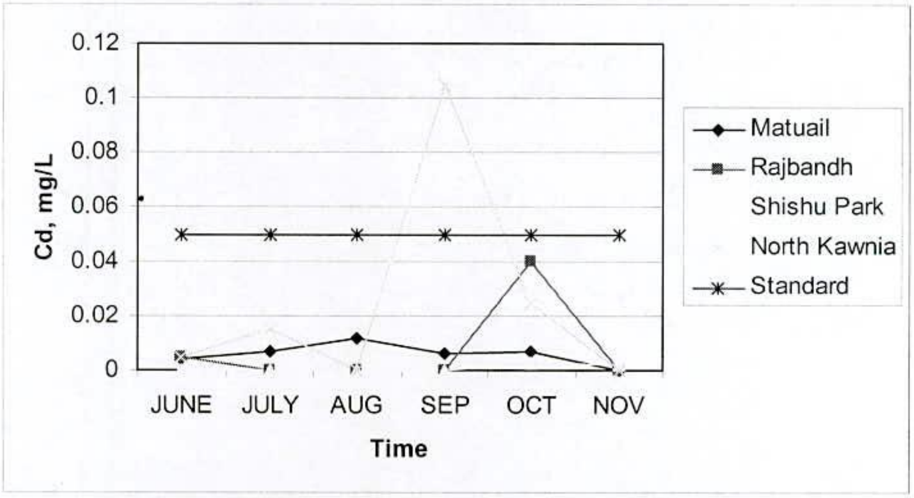

Figure 6.10 Concentration variations of Cadmium with Time in leachate samples

6.3 Leachate Risk Factors (LRF)

The environmental risk assessment based on leachate toxicity risk factors are derived from measurements of contaminants in the landfill leachate and the respective environmental discharge standard or guideline values. In case of Matuail, Rajbandh, Shishu Park and North Kawnia disposal site, eight contaminant parameters were used for calculation of the LRF. These parameters are Chloride, Iron, TDS, BOD_5, COD, Lead, Nickel and Cadmium. The criteria for selection of these parameters are based on the indicators of leachate toxicity to the environment and public health; reliable standards or guidelines are available for these contaminants. Table 6.3 shows the maximum concentration of leachate collected from four UDS of Bangladesh. Most of the cases the maximum concentration exceeded the standard value of discharge in land water according to ECR 1997.

Table 6.3 Maximum Concentration of contaminants of leachate in four studied UDS

Site Name	Maximum Concentration in mg/L							
	Chloride	Iron	TDS	BOD_5	COD	Pb	Ni	Cd
Matuail	1825	50	6110	580	1760	0.08	0.042	0.01
Rajbandh	3000	55	8652	2550	5400	0.425	0.085	0.04
Shishu Park	65	4.3	4700	600	5550	0.003	0.004	0.003
North Kawnia	1300	8.8	2750	1200	3116	0.205	0.46	0.105
Standard Value*	**600**	**2**	**2100**	**50**	**200**	**0.1**	**1.0**	**0.05**

* discharge in land water (according to ECR 1997)

The concentration values used for calculation of LRF for each of the chosen parameters are based on worst-case scenario. That is, using the highest measured concentration of the contaminant in any of the leachate sample obtained from the respective landfill. The LRF values obtained for the eight individual contaminants are combined and expressed as a sum in Table 6.4 below.

Table 6.4 Leachate Risk Factor (LRF) Values for Individual Contaminants

Site Name	Leachate Risk Factor (LRF) Values							
	Chloride	Iron	TDS	BOD_5	COD	Pb	Ni	Cd
Matuail	3	25	2.91	11.6	8.8	0.8	0.042	0.20
Rajbandh	5	27.5	4.12	51	27	4.25	0.085	0.80
Shishu Park	0.11	2.15	2.24	12	27.75	0.03	0.004	0.06
North Kawnia	2.17	4.4	1.31	24	15.58	2.05	0.46	2.10
Acceptable Value	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

The concentrations of contaminants, volume of leachate produced and the sensitivity of the receiving environment are some of the critical factors in assessing the environmental risk level from a landfill. In this context the aggregate Leachate Risk Factors (LRF) derived in Table 6.5, are used as one of the key indicators for identifying sites that may pose significant risk to the environment and may require resource consent for discharge of leachate.

Table 6.5 Aggregated leachate risk factors

Site Name	**Aggregated LRF Values**
Matuail	52.35
Rajbandh	119.75
Shishu Park	44.34
North Kawnia	52.07
Maximum Acceptable Value (MAV)	**8.0**

On the above basis, the studied four UDS listed above were identified that may pose a significant risk to the environment and hence require resource consents for discharge of leachate to the receiving environment.

6.4 Landfill Gas (LFG) Assessment – Methane Emission

The IPCC guidelines were followed to calculate the methane emissions for each disposal site. These guidelines suggest an equation related to MSW fractions to estimate the degradable organic fraction (DOC) of the total MSW landfilled. The detail estimation methods with essential parameters are discussed in Appendix D. The calculated value for the DOC fraction was varies from 0.15 to 0.16. The total methane emissions in the year of 2006 from four studied UDS were estimated as 31.18 Gg shown in Table 6.6, which is equivalent of CO_2 of total 673.20 Gg released. In this estimated emissions of CH_4 and CO_2, it is observed that the MLS lonely contributed 86.8% of the total emission from studied UDS.

Table 6.6 Net CH_4 emissions from MSW sites in Bangladesh in 2006

Site Name	MSW Dumped (Gg)	DOC Dumped (Gg)	CH_4 Emission (Gg)	Equivalent CO_2 Emission (Gg)
Matuail	402.96	59.96	27.09	586.89
Rajbandh	80.6	12.56	2.84	59.64
Shishu Park	25.21	3.86	0.87	18.27
North Kawnia	11.78	1.77	0.40	8.4

The ratio of CH_4 emitted to the amount of waste generated in different countries of the world varies from 0.014 to 0.060 (Thorneoloe, 1996), whereas this ratio varies from 0.008 to 0.015 in the four major cities of Bangladesh as presented in Table 6.7. In Bangladesh, this ration of CH_4 emitted is on the lower side compared to other developing countries. This can be attributed from differences of waste composition and estimation methodology.

Table 6.7 City specific CH_4 emissions from MSW sites in 2006

City	MSW Generated (Gg/yr)	Net CH_4 Emissions (Gg/yr)	Ratio $\left(\frac{g-CH_4}{g-waste}\right)$
Dhaka	1950	27.09	0.014
Khulna	190.5	2.84	0.015
Rajshahi	62.0	0.87	0.014
Barisal	47.5	0.40	0.008

6.5 Geotechnical Assessment of UDS

All the ultimate disposal sites of MSW i.e. landfill should be safe concerning all relevant aspects. The propagation of leachate through the underlying sub-soils is one most concern factors while designing or constructing a landfill for safe encapsulation of disposed solid wastes. It is desirable to take advantage of the geology of a site. In particular, the types of soil and rock underlying the disposal site and the thickness of each soil layer can restrict the migration of the leachate towards groundwater and reduce the concentration of contaminants. The sub-soil investigation was carried out near four ultimate disposal sites located in the study cities i.e. four major cities of Bangladesh to identify the soil strata and properties of sub-soil concerning with its strength, natural geologic barrier and technical barrier. In all sites, drillings up to the depth of 60ft were executed by wash boring method. Disturbed and undisturbed soil samples were collected at 5 ft. regular intervals for required field and laboratory investigations. Standard penetration tests were conducted during drilling to identify the subsoil strength.

6.5.1 Sub-soil strata

Table 6.8 shows the sub-soil stratification of UDS of MSW in the study areas of Bangladesh. The Figure reveals that the sub-soil mainly consists of sedimentary deposits, however, the soil types vary from each other. A thick fine-grained soil i.e. clay layer is encountered in all the UDS in which sub-soil mainly consist of fine sand till the final depth of boring i.e. 60 feet. In the UDS at DCC, clay deposit extends till the final depth of boring at Matuail; after that sand is encountered. In Rajbandh of KCC, cohesive soil i.e. mainly clay with silt and organic exists throughout the depth. In Shishu park of RCC, clay exists till the depth of 40 feet and organic soil also encountered in some depth, after that sand exists. In North Kawnia UDS of BCC, sub-soil strata consists of cohesive soil layer, mainly silty clay and clayey silt and clayey sand till the depth of 35 feet, beyond the sand exists. Though organic matter increases the CEC and decreases the permeability of soil, it may cause high plasticity, high shrinkage, high compressibility and low strength (Mitchell 1976). From the site investigation, it revealed that the existing sites contain a considerable amount of clay percent, which might be a very much suitable material for the natural geologic barrier and the construction of base liner.

Table 6.8 Sub-soil strata of four ultimate disposal sites in Bangladesh

<table>
<tr><th>Depth (ft)</th><th>Matuail</th><th>Rajbandh</th><th>Shishu Park</th><th>North Kawnia</th></tr>
<tr><td>0-5</td><td rowspan="2">Filling Sand</td><td rowspan="4">Clay with Organic</td><td>Clayey Silt</td><td rowspan="2">Silty Clay</td></tr>
<tr><td>5-10</td><td rowspan="2">Clay with Organic</td></tr>
<tr><td>10-15</td><td rowspan="2">Clay</td><td rowspan="4">Clayey Silt</td></tr>
<tr><td>15-20</td><td rowspan="3">Silty Clay</td></tr>
<tr><td>20-25</td><td rowspan="2">Clayey Silt</td><td rowspan="8">Silty Clay</td></tr>
<tr><td>25-30</td></tr>
<tr><td>30-35</td><td rowspan="6">Silty Clay</td><td rowspan="3">Clay</td><td rowspan="2">Clayey Sand</td></tr>
<tr><td>35-40</td></tr>
<tr><td>40-45</td><td rowspan="4">Fine Sand</td></tr>
<tr><td>45-50</td><td rowspan="3">Fine Sand</td></tr>
<tr><td>50-55</td></tr>
<tr><td>55-60</td></tr>
</table>

6.5.2 Basic properties of Sub-soil

The performance of all the Geoenvironmental structures such as landfill liners, covers, impoundments or vertical barrier depends mainly on the basic characteristics of the soils. It is therefore important to know the basic properties of the soils as thoroughly as possible before assessing their physio-chemical or hydro-mechanical behavior. The activity [PI/%clay fraction] of clay layers of sub-soil are about 0.25 to 0.667. Thus, according to Skempton's classification (1953) they are inactive clay. Inactive clayey soils are the most desirable materials for CCL (Rowe et. al. 1995). In order to achieve a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s for soil liners, soils with an activity of 0.3 or greater may be specified (Benson et al. 1994; Rowe et al. 1995). However, soils with high activity are not recommended for use in landfill liners or containment structures as they are more readily affected by pollutant (Oweis & Khera 1998). The basic properties of soils are listed in Table 6.9. The typical grain size distribution curves of each site are presented at Figure 6.11.

Table 6.9 Physical properties of sub-soils in eight UDS at Bangladesh

Depth (feet)	Soil Strata	Liquid limit, w_L (%)	Plasticity index, PI	Clay (%)	Activity
		Matuail			
0 to 10	Filling Sand	-	-	-	-
10 to 20	Clay	47	23	40	0.575
20 to 30	Clayey Silt	33	7	31	0.226
30 to 40	Silty Clay	40	12	22	0.545
40 to 50	Silty Clay	45	9	17	0.530
50 to 60	Silty Clay	38	10	15	0.667
		Rajbandh			
0 to 10	Organic Clay	85	27	28	0.964
10 to 20	Organic Clay	79	20	23	0.870
20 to 30	Silty Clay	38	8	20	0.400
30 to 40	Silty Clay	46	9	26	0.346
40 to 50	Silty Clay	42	10	26	0.384
50 to 60	Silty Clay	49	12	28	0.428

Shishu Park					
0 to 10	Clayey Silt	32	7	27	0.260
10 to 20	Organic Clay	65	18	30	0.600
20 to 30	Silty Clay	42	13	28	0.464
30 to 40	Clay	48	20	33	0.606
40 to 50	Fine Sand	-	-	-	-
50 to 60	Fine Sand	-	-	-	-
North Kawnia					
0 to 10	Silty Clay	33	3	12	0.250
10 to 20	Clayey Silt	35	8	15	0.533
20 to 30	Clayey Silt	28	12	10	1.20
30 to 40	Clayey Sand	-	-	-	-
40 to 50	Fine Sand	-	-	-	-
50 to 60	Fine Sand	-	-	-	-

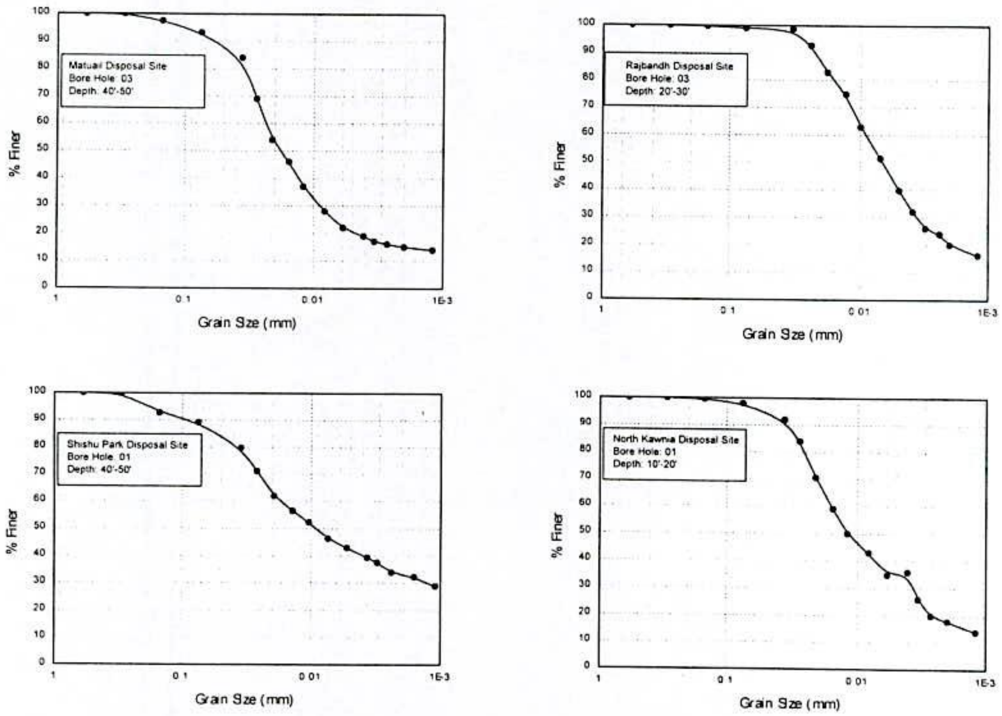

Figure 6.11 Typical grain size distribution curves of sub-soils collected from the sites four studied UDS in the major cities of Bangladesh

6.5.3 Hydraulic Properties

Solid wastes can be buried above or within a natural occurring formation of low hydraulic conductivity, clay rich soil. Natural liners normally contain significant amounts of clay minerals and have hydraulic conductivity, $k<10^{-8}$ to 10^{-9} m/s. Recommended properties of soils to achieve a low hydraulic conductivity ($k<10^{-9}$m/s) for most soil liners by compaction if not exists naturally are: percentage fine (<0.075mm) ≥ 30%, 20≤PI≤30 and percentage of very coarse sand/gravel (5 to 50mm) ≤ 20%. Natural liners more typically serve as a back up to engineering liners, but occasionally a natural liner may represent the only liner at a waste disposal site facility (Daniel 1993 and Rowe et al. 1995). It is worth to note that In LDACs, as most of the existing sites are crude open dumping, a massive uniform natural soil liner as the only means for protecting ground water from contamination due to the percolation of leachate. As all the UDS in Bangladesh is open disposal type and the sites contain the sub-soil rich in clay, the continuity and hydraulic conductivity of natural liner materials i.e. sub-soil are crucial issues. Considering this crucial aspects for future construction of sanitary landfills in Bangladesh or to see the present situation of the existing UDS, the sub-soil in all four sites, active in four city corporations, were collected up to a depth of 60ft. and the hydraulic conductivity were examined in the laboratory. The test results averaged for different designated depth are presented at Table 6.15. The results indicate the sub-soils are suitable for natural clay liner.

Table 6.10 Hydraulic properties of sub-soils in eight UDS at Bangladesh as measured in the laboratory

Depth from ground surface (feet)	Hydraulic conductivity, k (x10^{-9} m/sec)			
	Matuail	Rajbandh	Shishu Park	North Kawnia
0 to 10	-	1.90	1.51	4.75
10 to 20	2.40	2.35	7.50	228.0
20 to 30	22.2	20.40	11.20	324.0
30 to 40	1.35	26.75	11.50	1645
40 to 50	8.50	2.75	7.10	1285
50 to 60	1.05	3.20	2.35	1378

6.5.4 Strength Properties

A waste containment system should retain its structural integrity during its design life. The settlement of foundation soils might damage the top cover, leachate collection system and bottom liner and allow the leachate to exit the system freely. Similarly, the slope failures of the structures, either local or systematic, would lead to catastrophic consequences (Reddi and Inyang, 2000). Therefore, the knowledge about the strength of sub-soils in the existing UDS is very important to apply required counter measures against any possible slope stability failure. The strength of the sub-soil is measured in the field through standard penetration test (SPT) and hence presented in Table 6.11 as penetration resistance i.e. N-value. From the field results as illustrated in the table, it is observed that sub-soil condition of Matuail site is reasonably good. But at other locations, sub-soil conditions are not good. At Rajbandh site of KCC, the sub-soil condition is very poor even till the final depth of boring. However, at North Kawnia site of BCC and Shishu Park site of RCC, the sub-soils conditions up to a depth of 25 ft is not good but beyond this depth, the soil strength has increased significantly, till the final depth of boring. Therefore, the situation of sub-soil conditions must be kept in mind while designing a sanitary landfill in these sites or for the upgrading of the sites. In the sites, where sub-soil conditions are poor, required counter measure such as soil improvement can be an option to be employed for the safe installation of solid waste containment facility.

Table 6.11 Strength of sub-soils in eight UDS at Bangladesh as measured in field

Depth from ground surface (feet)	Matuail	Rajbandh	Shishu Park	North Kawnia
0 to 5	-	2	5	6
5 to 10	-	3	3	4
10 to 15	8	2	6	5
15 to 20	11	4	8	9
20 to 25	18	5	7	7
25 to 30	21	4	12	10
30 to 40	28	5	16	22
40 to 50	35	6	35	27
50 to 60	42	5	56	53

6.5.5 Mineralogical composition

In most of the soil samples taken at four different sites in Bangladesh, clay minerals account for around one-half to two-thirds of the overall mineralogical composition. The results are compiled in Table 6.12, Figure 6.12 and detailed shown in Appendix C. Swelling clay minerals, which are mainly responsible for positive barrier features of soils, are present in varying amounts. Cation exchange capacities in the range from 10-25 meq/100g are estimated for some of the sampled soils as presented in Table 6.13. Especially the soils sampled in Rajshahi, Dhaka (Matuail) and Khulna appear to be of suitable composition for their use as a natural clay barrier material for potential landfill sites. The Barisal samples, although containing an overall high clay mineral content, also exhibit low CEC values due to their low amount of swelling clay minerals. In general, fine-grained sediments in Bangladesh appear to constitute a valuable material for geological and technical barriers for landfills and should be investigated further in this respect.

Table 6.12 Mineralogical compositions of sub-soil at the UDS of Bangladesh

Sampling depth (feet)	Quartz	Feldspars	Carbo-nates	Illite / Musco vite	Kaolinite	Chlorite	Swelling clay minerals	Other
Dhaka - Matuail								
10-20	20-30	5-10	n.d.	25-35	~20	~5	~10	<5
20-30	25-35	5-10	n.d.	30-40	~20	~5	~2	<5
30-60	25-35	5-10	n.d.	30-40	~20	~5	~1	<5
Khulna - Rajbandh								
0-20	10-20	~5	n.d.	~50	10-20	2-4	10-15	-
20-30	20-30	5-10	4.2	~40	~10	~2	~10	-
30-45	20-30	2-5	1.2	40-50	10-15	~2	~10	-
45-60	20-30	2-5	2.4	40-50	10-15	~2	~10	-

Rajshahi – Shishu Park								
0-5	20-30	<5	10.1	~40	5-10	<1	10-15	-
5-10	10-20	~5	n.d.	35-45	~15	traces	~25	-
10-35	20-30	~10	n.d.	30-40	~15	traces	10-15	-
35-50	~30	<2	n.d.	50-60	2-5	n.d.	10-15	-
50-60	~40	5-10	n.d.	~40	5-10	n.d.	~5	-
Barisal – North Kawnia								
0-10	25-35	~5	n.d.	30-40	20-25	1-5	~5	<5
10-30	25-35	~5	n.d.	30-40	20-25	1-5	4-5	<5
30-45	25-35	~5	n.d.	30-40	20-25	1-5	3-4	<5
45-60	25-35	~5	n.d.	30-40	20-25	1-5	1-2	<5
Note: n.d – not detected								

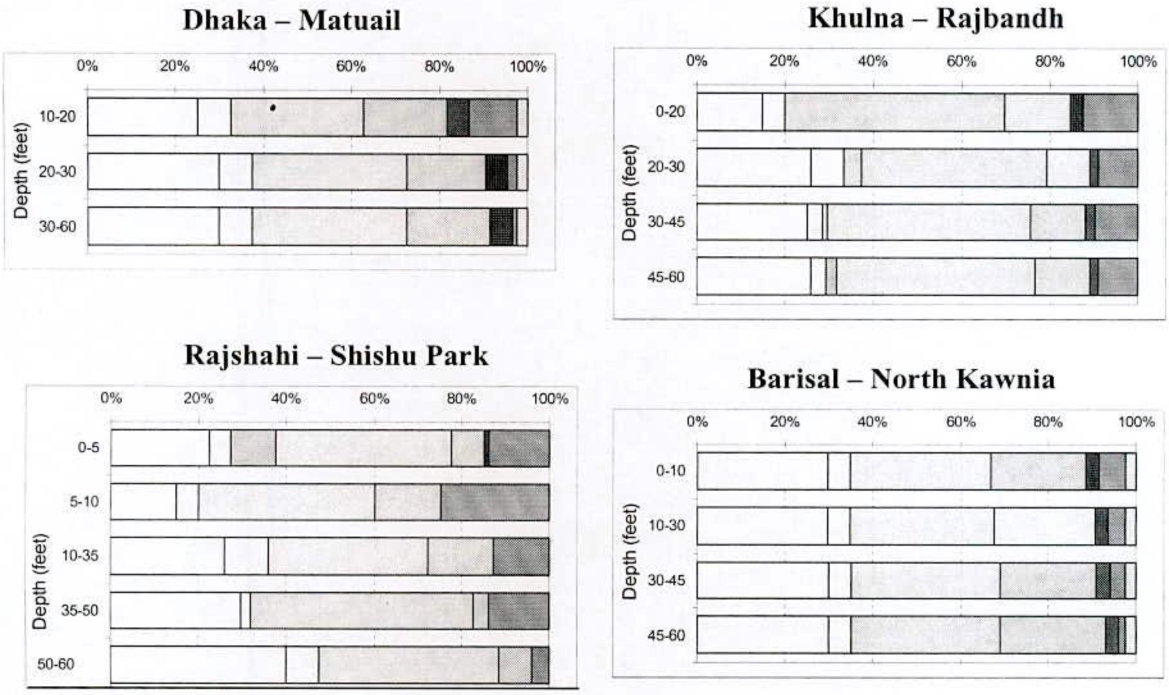

Figure 6.12 Mineralogical compositions of sub-soil at studied ultimate disposal sites of six major cities in Bangladesh

Table 6.13 Methylene blue (MB) adsorption of the soil samples (ml MB/g sample)

[cation exchange capacity (CEC) and content of swelling clay minerals derived from it by means of a Bentonite standard (IBECO S-80)]

Sampling depth (feet)	Methylene Blue adsorption (ml/g)	CEC (meq/100g) from MB adsorption	Swelling clay mineral phases (%) from MB adsorption
Dhaka – Matuail			
10-20	8.0	13	11
20-30	1.5	2	2
30-60	0.8	1	1
Khulna - Rajbandh			
0-20	9.0	15	13
20-30	6.2	10	9
30-45	7.4	12	10
45-60	6.2	10	9
Rajshahi – Shishu Park			
0-5	10.0	16	14
5-10	17.1	28	24
10-35	9.2	15	13
35-50	10.0	16	14
50-60	3.0	5	4
Barisal – North Kawnia			
0-10	4.1	7	6
10-30	3.0	5	4
30-45	2.5	4	3
45-60	1.0	2	1

Matuail (Dhaka): A high clay mineral content of up to two-thirds of the mineralogical composition is present in the samples, consisting mainly of illite/muscovite, kaolinite and a small amount of chlorite. The amount of swelling clay minerals consisting of smectite is high in the upper part of the drilling (~10%) and low in the lower samples (1-2%). As non-clay minerals quartz, feldspar and an unidentified mineral (main peak at 8.5 $\overset{0}{A}$), but no carbonates, were detected.

Rajbandh (Khulna): Clay minerals account for around two-thirds of the mineralogical composition of the samples from Khulna. The clay mineral composition is dominated by illite/muscovite, with some amount of kaolinite and a small amount of chlorite. The amount of swelling clay minerals is high, in the range of 10-15%, dominated by highly-swelling smectites. As non-clay minerals, quartz and small amounts of feldspars and carbonates could be detected.

Shishu Park (Rajshahi): Clay minerals account for around one-half to two-thirds of the mineralogical composition of the samples from Rajshahi. As non-swelling clay minerals, illite/muscovite could be detected in high amounts and some kaolinite, and a little amount of chlorite. The amount of swelling clay minerals is very high in the upper part of the drilling (15-25%) and somewhat lower in the lower parts (~5%), consisting of smectite and various mixed layer minerals. As non-clay minerals, the samples contain quartz and a small amount of feldspars. Carbonates could be detected only in the top sample which showed a quite high carbonate content of ~10%, with calcite dominating and some dolomite.

North Kawnia (Barisal): Clay minerals account for around one-half to two-thirds of the mineralogical composition of the samples from Barisal. The samples of thi..drilling showed a very homogeneous composition. As non-swelling clay minerals, illite/muscovite and kaolinite could be detected in high amounts, with a little amount of chlorite. A small amount of swelling clay minerals in the form of smectites is also present. As non-clay minerals, the samples contain quartz, small amounts of feldspars and a small amount of an unidentified mineral (main peak at 8.5 $\overset{0}{A}$). No carbonates could be detected.

6.5.6 Compaction Properties of Sub-Soil

Naturally occurring soils or borrow soils located near the disposal sites can be used as compacted clay liner in wastes containment facility by achieving a sufficiently low hydraulic conductivity after proper compaction. In this regard compositional factors of soil such as Atterberg limits and grain size characteristics are very important (Benson et al. 1994). The recommended properties are: $w_L \geq 20\%$, $PI \geq 7$, fines (less than 0.075mm)≥30% and clay≥15%. Clay soil with a too high liquid limit is susceptible to desiccation cracking, and with a too low plastic limit is less workable, causes poor inter-lift bonding and existence of macro-pores. Again highly plastic soil (PI≥30-40) is very difficult to break and compact in the field at optimum moisture content. However, to examine the potentiality of available sub-soils near the existing disposal sites for use as a compacted clay liner, the sub-soils were collected from each site and the physical properties were determined. To see the achievement in the increment of dry density and to get the value of optimum moisture contents, compaction tests on the selected sub-soils designated by D01, K01, R02 and B01 were conducted in the laboratory. The information about the optimum moisture contents are important since the soils are required to compact at the wet side of optimum moisture content while using it as a compacted clay liner. The results indicate that the sub-soils in the disposal sites are suitable for using as compacted clay liner. Table 6.13 shows the acceptable range of water content and dry density for the compacted clay liner (CCL). The hydraulic conductivity of compacted soil samples of each ratio of mixing water content were < 1 x 10^{-9} m/s which also satisfied the requirements of liner facility.

Table 6.14 Acceptable Range of Water Content for CCL

Site ID	Optimum Moisture Content, %	Maximum Dry Density, gm/cc	Acceptable Range of Water Content, %
Matuail, D01	18.0	1.68	18.50 – 21.0
Rajbandh, K01	25.50	1.48	26.0 – 29.50
Shishu Park, R02	24.0	1.62	24.50 – 27.0
North Kawnia, B01	19.0	1.66	20.0 – 23.50

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This comprehensive study on the geoenvironmental assessment of ultimate disposal sites (UDS) reveals that:

1. There is no sanitary landfill in the studied four UDS situated in the four major cities in Bangladesh, uncontrolled crude open dumping of MSW have been practiced, which causes severe negative environmental impacts. However, recently some attempts have been accomplished to convert Matuail UDS of Dhaka city into controlled disposal site of MSW.

2. The relative threat to health and the environment was evaluated by Indian Health Service (IHS, 1998) report and Resource Recovery and Conservation Act (RCRA) based on the consideration of factors, shown in article 5.11 and appendix A that the surveyed Rajbandh, Shishu park and North Kawnia disposal site poses high threat to health and environment based on the above criteria and it is expected that after complete implementation to convert Matuail disposal site into controlled landfill, it will pose moderate threat to health and environment.

3. The available clay deposits of all sites satisfied the CCL requirements followed by compaction with acceptable water content shown in Table 6.14.

4. The basic properties of sub-soil, continution of clay deposit and mineralogical investigation indicates that Matuail, Rajbandh and Shishu Park Disposal Site has the potential GCL except North Kawnia Disposal Site.

5. Based on leachate characteristics and sub-soil criteria, the probability of groundwater contamination is high in the North Kawnia Disposal Site.

6. The site capacity and design life of four studied UDS is calculated. The design life of Matuail, Rajbandh, Shishu Park and North Kawnia disposal site can be extended by 10, 5.5, 13.0 and 12.5yrs, respectively.

7. Leachate concentration is widely varies due to directly affecting by the rainfall in around the year. Most of the cases the maximum concentration exceeded the standard value of discharge inland water according to ECR 1997. pH as measured in this study ranges from 6.2 to 8.2. The TDS values in all UDS are in the range between 260 to 8652 mg/L. The concentration of Chloride in leachate samples varies from 7.5 to 3000 mg/L and the maximum concentration of Chloride was shown in Rajbandh site at Khulna. The concentration of Iron in leachate samples varies from 0.40 to 55 mg/L. BOD_5 varies from 0.40 to 8340mg/l. The highest concentration of BOD in water sample was noted at Rajbandh site. BOD/COD ratio of the leachate sample collected from the MSW disposal site ranges from 0.01 to 0.46, which shows that the biodegradability of leachate sample is very low. The maximum concentration of Lead (0.425 mg/l) at Rajbandh site, Nickel (0.46 mg/l) and Cadmium (0.105 mg/l) at North Kawnia site were found in the leachate samples.

8. It is shown that in all sites the individual LRF value of each contaminant exceeded the safe limit of one unit (1.0). It is indicated that the leachate of the studied UDS poses significant risk to the environment and required resource consent and needed treatment before discharge it. The maximum acceptable value (MAV) value is 8.0 for the aggregated leachate risk factors which show the monitoring of leachate is necessary to reduce the negative impact to the human health and environment.

9. Methane emission has been estimated by IPCC methodology for four studied disposal sites. The DOC fraction is found nearly 15% of the MSW in the studied sites of Bangladesh. The total methane and equivalent CO_2 emission from four studied sites was estimated at 27.09 Gg and 623.0 Gg, respectively during the baseline year of 2006. The Matuail site, the largest UDS in Bangladesh, emitted 86.8% of the total surveyed MSW methane emissions in the country. The average CH_4 emission ratio 0.013 in Bangladesh is on the same side compared to other developing countries.

10. The sub-soil investigation reveals that the sub-soil mainly consists of sedimentary deposits. A thick fine-grained soil i.e. clay layer is encountered in all the UDS. The hydraulic conductivity of different soil layers varies from 1.05 x 10^{-9} to 11.50 x 10^{-9} m/s from the four studied sites except some layers which may need to compaction for target value. Based on the basic properties of soil such as liquid limit, plasticity index and clay content, each layer upto 60 ft of Matuail and Rajbandh UDS, 0 to 40 ft of Shishu Park and 10 to 20 ft of North Kawnia UDS satisfied the minimum values to achieve the required hydraulic conductivity for the compacted clay liner (CCL) of potential landfill site.

10. A high clay mineral content of upto two-thirds of the mineralogical composition is present in the samples, consisting mainly of illite/muscovite, kaolinite and a small amount of chlorite. The amount of swelling clay minerals consisting of smectite is high in the upper part of the drilling (~10%) at Matuail site. The amount of swelling clay minerals is high, in the range of 10-15%, dominated by highly-swelling smectites at Rajbandh site. The amount of swelling clay minerals is very high in the upper part of the drilling (15-25%) consisting of smectite and various mixed layer minerals at Shishu Park site. At North Kawnia site the non-swelling clay minerals, illite/muscovite and kaolinite is detected in high amounts, with a little amount of chlorite. A small amount of swelling clay minerals in the form of smectites is also present. The mineralogical analysis shows that the natural formation of soil layer is suitable for geologic clay liner (GCL) for potential landfill sites because of lower hydraulic conductivity and continuation of swelling clay layer except the layers containing fine sand and organic matter.

7.2 Recommendation for Future Studies

From the above given conclusion, the following recommendation could be further implied for future study:

1. Experimenting the Pilot scale landfill lysimeter studies for the tropical climatic influence on leachate generation and characterization, settlement variation and the top cover methane oxidation under the ambient conditions of Bangladesh.

2. Monitoring the ground water and surface water quality near the landfill site throughout the year to evaluate the pollution potential.

3. Considering the seasonal variation of leachate characteristics and water balance of landfill site by using HELP model.

4. Laboratory scale simulations for possible methane oxidation at the site, kinetics of methane production, methane migrating through aerobic soil or waste and methane oxidized by microorganisms based on the ambient conditions of the site.

5. Identifying the soil contaminants, assess toxicity, and characterize risk of the site.

6. Pilot scale study of leachate treatment to get the appropriate, effective and sustainable treatment approach.

7. Determining the health risk assessment of landfill workers, scavengers and nearest inhabitants.

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APPENDIX A: Information on Overall Impact Assessment

A-1 Definition of Terms and Indications

Municipal Solid Waste (A): means any *household, commercial/industrial, or institutional* solid waste that legally can be discarded in a municipal landfill under the provisions of the Resource Recovery and Conservation Act, (RCRA), "subtitle D and 40 CFR Subchapter I - Solid Wastes".

Municipal solid waste includes:

- Garbage and trash derived from households, multiple residences, hotels, motels and campgrounds.
- Commercial and industrial waste from stores offices, restaurants, warehouses, non-manufacturing activities at industrial facilities, and other similar establishments not meeting the definition of regulated hazardous wastes under subtitle C.
- Institutional wastes include material discarded by schools, hospitals, non-manufacturing activities at prisons, government facilities and other similar facilities.

Sites receiving limited quantities of hazardous or special waste from households shall not be excluded from this classification. This would generally include small amounts of paints, oil, non-segregated medical wastes, batteries, pesticides, and household chemicals that would be discarded in quantities typical of an individual household. It is noted that professional judgment was applied to subdivide the hazard point for the partial hazardous/clinical waste mixed with this type.

Special Waste (B) shall include solid or other wastes not specifically regulated as hazardous under subtitle C but which are considered to require special handling either due to regulation under other statutes or for worker safety. Segregated infectious and medical wastes, wood pallets, demolition wastes, asbestos materials, household appliances containing environmentally sensitive materials, sewage sludge, septic tank pumping, motor vehicles/parts, segregated tire piles of 50 or more, and segregated piles of ten or more auto batteries should be included under this classification.

Hazardous Waste (C) shall include those materials listed by EPA under Subtitle C as hazardous. Regulated hazardous wastes are specifically listed in statute and regulations and generally have one or more of the following characteristics; ignitable, corrosive, reactive, or toxic. Small amounts of hazardous wastes as would be generated by households are excluded. This classification would generally be used when large quantities of segregated hazardous materials are encountered.

Combined Wastes A + B in evidence: notate category **(D)**
Combined Wastes A + C in evidence: notate category **(E)**
Combined Wastes A + B + C in evidence: notate category **(F)**
Combined Wastes B + C in evidence: notate category **(G)**

HEALTH/ENV. THREAT: Table A below may be used as a **guideline** for classifying the possible threat to health and environment posed by the solid waste site. Hazard points shall be derived from Table A and used in accordance with the point ranges and descriptors listed below thereby resulting in a high, moderate or low (H, M, or L) threat potential designation for the site. This guideline may be adjusted for Area specific conditions but the H, M, or L designations must be maintained. This Table is intended to be used as a tool in evaluating the site but the final determination of hazard potential should be based on professional judgment. Areas using other criteria are asked to attach a description of the adjustments upon submittal of the data.

Low Hazard	: Points total 13 or less
Moderate Hazard	: Points total 14-29
High Hazard	: Points total 30 or more

Table A-1 Hazard point of different factors for overall impact analysis

Hazard Point Factors	**High Factors**	**Moderate Factors**	**Low Factors**
Contents	Site Waste Content **C, E, F or G** (30 points)	Site Waste Content **All Categories Except A** (hazardous waste < 2% by volume) (15 points)	Site Waste Content **A** only
Rainfall	high rainfall (>25 in/yr) (4 points)	medium rainfall (10-25 in/yr) (2 points)	low rainfall (<10 in/yr)
Distance to drinking water aquifer	less than 50' (30 points)	51' - 100' 10 points 101'-200' 8 points 201'-600' 4 points	> 600'
Site Drainage	Site drainage increases the likelihood of ground or surface water contamination (8 points)	Moderate drainage - limited ponding - drainage effects largely neutral (2 points)	Site drainage contributes to protection of ground or surface water
Potential to Create Leachate at Site	high probability (4 points)	moderate probability (2 points)	low probability
Distance to domestic water source	less than 1000 ft (4 points)	1000 ft - 5000 ft (2 points)	>5000 ft
Site Accessibility	Unrestricted Access - residences nearby (less than 1 mile) (4 points)	Unrestricted access but remote from population (2 points)	Restricted - controlled access
Frequency of Burning	Frequent burning (weekly) (4 points)	Infrequent burning (monthly) (2 points)	Burning never occurs
Site Materials Exposure to Public & Vectors	surface materials, no cover, scavenging by public (4 points)	materials in open trenches, limited scavenging (2 points)	materials are covered, no scavenging
Degree of Public Concern over Site - Esthetics	Frequent expressions of public concern over the site (4 points)	Little public concern - government awareness only (2 points)	No concern expressed by any entity

APPENDIX B: Landfill Capacity Calculation

B-1 Landfill Capacity Calculation Worksheet Information

Note that the results of this worksheet/calculator provide an estimate of remaining landfill capacity. It is not meant to replace a more accurate calculation completed by an engineer, or by the use of a terrain computer model program. Input the best available information that you have to ensure that the result estimate is reasonable.

A) Total landfill area (permitted area) in acres. This represents the area defined as the "top" area of the landfill.

B) Total permitted volume (gross capacity) in cubic yards as permitted. If you do not know this amount, use the following formula to obtain this number: 43,560 square feet per acre multiplied by the number of permitted acres, multiplied by the permitted height in feet. Divide this amount by 27 to convert cubic feet to cubic yards (The permitted height equals both the vertical height above ground and the depth of the cell. Example: 30 acre permitted site, with 20 feet deep cell, that can be filled 30 feet above ground for a total height of 50 feet.

43,560 square feet/acre x 30 acres=1,306,800 square feet

1,306,800 square feet x 50 feet high=65,340,000 cubic feet

65,340,000 cubic feet ÷ 27 cubic feet/cubic yard=2,420,000 cubic yards

Use your final cubic yards for B in the calculator

C) Thickness of liner protective layer in feet. (Amount of soil placed on liner for protection before waste placement) If unknown use 2 feet as default.

D) Thickness of final cover in feet. This value is the amount of cover that will be required when landfill is closed. (If unknown, use 2 feet). A value for this factor must be entered.

E) Estimated percentage of gross capacity taken by the use of daily cover and intermediate covers. Use actual % if it has been calculated/determined. If you use a tarping system your percentage will be less than 25%. If unknown use 25%.

F) Historical tons through 2005. If you weigh wastes on a scale, fill in the amount of tons you received and placed in all cells up to 12/31/2005. Note, if scales were not used for a portion of this time and some of your records are in cubic yards, also include the historical amount of cubic yards in G

G) Provide information for all historical cubic yards of wastes disposed of at your site through 2005, that were not weighed on a scale.

H) 2006 Tons received. (One year only)

I) 2006 cubic yards received (One year only). Enter "0" if you have scales and have a tonnage number.

J) Compaction rate - Use 1 if you believe you have either no compaction or a low compaction rate 350 pounds or less per cubic yard

Use 2 if you believe you have a medium rate of compaction 350-750pounds per cubic yard

Use 3 if you believe that you have a high rate of compaction 750-1,500 pounds per cubic yard

Use 4 if you have calculated a compaction rate higher than >1,500 pounds per cubic yard

> As a general rule of thumb smaller landfills, with less height have a low rate of compaction, while larger landfills with bigger, deeper, and higher cells and larger equipment have a higher rate of compaction.

Answers:

K is the resulting net waste capacity

L is the remaining permitted capacity

M is the estimated remaining site life. If you get a negative value in this line, it means you are at or near your capacity. You should plan for additional cells, closure, or increase your compaction.

Table B-1 Capacity Calculation of Matuail Disposal Site

(A)	Total landfill area	50.0	Acres
(B)	Total permitted volume (gross capacity)	4,961,000	Cubic yards
(C)	Thickness of protective soil layer	2.0	Feet
(D)	Thickness of final cover	2.5	Feet
(E)	Estimated percentage of gross capacity taken by daily and intermediate covers	25.0	%
(F)	Waste received through 2005 based on tonnage	X	Tons
(G)	Waste received through 2005 based on gate-yards	1,529,127	Cubic yards
(H)	Waste received in 2006 based on tonnage	X	Tons
(I)	Waste received in 2006 based on gate-yards (if no gate-yard receipts, enter 0)	470,501	Cubic yards
(J)	Compaction rate of emplaced waste	2.0	
(K)	Net waste capacity K=B - A*(C+D)*4840/3 - B*E/100	3,357,750	Cubic yards
(L)	Remaining permitted waste capacity L=K - (F+H)*6/J - (G+I)/J	2,357,936	Cubic yards
(M)	Estimated remaining site life M=L/(H*6/J + I/J)	10.0	Years

Table B-2 Capacity Calculation of Rajbandh Disposal Site

(A)	Total landfill area	20.0	Acres
(B)	Total permitted volume (gross capacity)	645,333	Cubic yards
(C)	Thickness of protective soil layer	2.0	Feet
(D)	Thickness of final cover	2.5	Feet
(E)	Estimated percentage of gross capacity taken by daily and intermediate covers (if unknown, use default value of 25%)	25.0	%
(F)	Waste received through 2005 based on tonnage (if no tonnage receipts, enter 0)	X	Tons
(G)	Waste received through 2005 based on gate-yards (if no gate-yard receipts, enter 0)	161,333	Cubic yards
(H)	Waste received in 2006 based on tonnage (if no tonnage receipts, enter 0)	X	Tons
(I)	Waste received in 2006 based on gate-yards (if no gate-yard receipts, enter 0)	75,280	Cubic yards
(J)	Compaction rate of emplaced waste	2.0	
(K)	Net waste capacity K=B - A*(C+D)*4840/3 - B*E/100	338,800	Cubic yards
(L)	Remaining permitted waste capacity L=K - (F+H)*6/J - (G+I)/J	220,493	Cubic yards
(M)	Estimated remaining site life M=L/(H*6/J + I/J)	5.9	Years

Table B-3 Capacity Calculation of Shishu Park Disposal Site

(A)	Total landfill area	15.0	Acres
(B)	Total permitted volume (gross capacity)	363,000	Cubic yards
(C)	Thickness of protective soil layer	2.0	Feet
(D)	Thickness of final cover	2.5	Feet
(E)	Estimated percentage of gross capacity taken by daily and intermediate covers	25.0	%
(F)	Waste received through 2005 based on tonnage	X	Tons
(G)	Waste received through 2005 based on gate-yards	61,165	Cubic yards
(H)	Waste received in 2006 based on tonnage	X	Tons
(I)	Waste received in 2006 based on gate-yards	18,820	Cubic yards
(J)	Compaction rate of emplaced waste	2.0	
(K)	Net waste capacity K=B - A*(C+D)*4840/3 - B*E/100	163,350	Cubic yards
(L)	Remaining permitted waste capacity L=K - (F+H)*6/J - (G+I)/J	123,357	Cubic yards
(M)	Estimated remaining site life M=L/(H*6/J + I/J)	13	Years

Table B-4 Capacity Calculation of North Kawnia Disposal Site

(A)	Total landfill area	6.0	Acres
(B)	Total permitted volume (gross capacity)	164,560	Cubic yards
(C)	Thickness of protective soil layer	2.0	Feet
(D)	Thickness of final cover	2.5	Feet
(E)	Estimated percentage of gross capacity taken by daily and intermediate covers	25.0	%
(F)	Waste received through 2005 based on tonnage	X	Tons
(G)	Waste received through 2005 based on gate-yards	30,583	Cubic yards
(H)	Waste received in 2006 based on tonnage	X	Tons
(I)	Waste received in 2006 based on gate-yards	9,410	Cubic yards
(J)	Compaction rate of emplaced waste	2.0	
(K)	Net waste capacity K=B - A*(C+D)*4840/3 - B*E/100	79,860	Cubic yards
(L)	Remaining permitted waste capacity L=K - (F+H)*6/J - (G+I)/J	59,864	Cubic yards
(M)	Estimated remaining site life M=L/(H*6/J + I/J)	12.7	Years

APPENDIX C: Mineralogical Composition

Table C-1 Mineralogical composition of the soil samples

	Sample	Minerals	Amount (in weight-%)
DKAKA Matuail	**D01**	Non-clay Minerals:	
	10-20 feet	Quartz	20 – 30 %
		Feldspars (Na and K)	5 -10 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	25 – 35 %
		Kaolinite	~ 20 %
		Chlorite	~ 5 %
		Swelling clay minerals:	
		Smectite	~ 10 %
	D02	Non-clay Minerals:	
	20-30 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	5 -10 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	30 – 40 %
		Kaolinite	~ 20 %
		Chlorite	~ 5 %
		Swelling clay minerals:	
		Smectite	1 – 2 %
	D03	Non-clay Minerals:	
	30-60 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	5 -10 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	

		Illite/Muscovite	30 – 40 %
		Kaolinite	~ 20 %
		Chlorite	~ 5 %
		Swelling clay minerals:	
		Smectite	1 – 2 %

KHULNA Rajbandh	Sample	Minerals	Amount (in weight-%)
	K01	Non-clay Minerals:	
	0-20 feet	Quartz	10 – 20 %
		Feldspars (Na and K)	~ 5 %
		Carbonates	n.d.
		Non-swelling clay minerals:	
		Illite/Muscovite	~ 50 %
		Kaolinite	10 – 20 %
		Chlorite	2 – 4 %
		Swelling clay minerals:	
		Smectite	10 – 15 %
	K02	Non-clay Minerals:	
	20-30 feet	Quartz	20 – 30 %
		Feldspars (Na and K)	5 – 10 %
		Carbonates	4.2 %
		Non-swelling clay minerals:	
		Illite/Muscovite	~ 40 %
		Kaolinite	~ 10 %
		Chlorite	~ 2 %
		Swelling clay minerals:	
		Smectite	~ 10 %
	K03	Non-clay Minerals:	
	30-45 feet	Quartz	20 – 30 %
		Feldspars (Na and K)	2 – 5 %

		Carbonates	1.2 %
		Non-swelling clay minerals:	
		Illite/Muscovite	40 – 50 %
		Kaolinite	10 – 15 %
		Chlorite	~ 2 %
		Swelling clay minerals:	
		Smectite	~ 10 %
	K04	Non-clay Minerals:	
	45-60 feet	Quartz	20 – 30 %
		Feldspars (Na and K)	2 – 5 %
		Carbonates	2.4 %
		Non-swelling clay minerals:	
		Illite/Muscovite	40 – 50 %
		Kaolinite	10 – 15 %
		Chlorite	~ 2 %
		Swelling clay minerals:	
		Smectite	~ 10 %

	Sample	Minerals	Amount (in weight-%)
RAJSHAHI Shishu Park	**R01**	Non-clay Minerals:	
	0-5 feet	Quartz	20 – 30 %
		Feldspars (Na and K)	< 5 %
		Calcite	7.5 %
		Dolomite	2.6 %
		Non-swelling clay minerals:	
		Illite/Muscovite	~ 40 %
		Kaolinite	5 – 10 %
		Chlorite	< 1 %
		Swelling clay minerals:	
		Smectite	10 – 15 %

		$[10\text{-}14_M]$ mixed layers (Vermiculite?)	< 1 %
	R02 5-10 feet	Non-clay Minerals: Quartz Feldspars (Na and K) Carbonates Non-swelling clay minerals: Illite/Muscovite Kaolinite Chlorite Swelling clay minerals: Smectite	 10 – 20 % ~ 5 % n.d. 35 – 45 % ~ 15 % traces ~ 25 %
	R03 10-35 feet	Non-clay Minerals: Quartz Feldspars (Na and K) Carbonates Non-swelling clay minerals: Illite/Muscovite Kaolinite Chlorite Swelling clay minerals: Smectite Chorite to Chlorite/Smectite mixed layers (C-$[14_C\text{-}14_M]$)	 20 – 30 % ~ 10 % n.d. 30 – 40 % ~ 15 % traces 10 – 15 % < 1 %
	R04 35-50 feet	Non-clay Minerals: Quartz Feldspars (Na and K) Carbonates Non-swelling clay minerals: Illite	 ~ 30 % < 2 % n.d. 50 – 60 %

		Kaolinite	2 – 5 %
		Swelling clay minerals:	
		Smectite	10 – 15 %
	R05	Non-clay Minerals:	
	50-60 feet	Quartz	~ 40 %
		Feldspars (Na and K)	5 – 10 %
		Carbonates	n.d.
		Non-swelling clay minerals:	
		Illite	~ 40 %
		Kaolinite	5 – 10 %
		Swelling clay minerals:	
		Smectite	2 – 4 %
		Various mixed layers	2 – 4 %

BARISAL North Kawnia	Sample	Minerals	Amount (in weight-%)
	B01	Non-clay Minerals:	
	0-10 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	~ 5 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	30 – 40 %
		Kaolinite	20 – 30 %
		Chlorite	1 – 5 %
		Swelling clay minerals:	
		Smectite	1 – 5 %
	B02	Non-clay Minerals:	
	10-30 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	~ 5 %
		Carbonates	n.d.

		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	30 – 40 %
		Kaolinite	20 – 30 %
		Chlorite	1 – 5 %
		Swelling clay minerals:	
		Smectite	1 – 5 %
	B03	Non-clay Minerals:	
	30-45 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	~ 5 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	30 – 40 %
		Kaolinite	20 – 30 %
		Chlorite	1 – 5 %
		Swelling clay minerals:	
		Smectite	1 – 5 %
	B04	Non-clay Minerals:	
	45-60 feet	Quartz	25 – 35 %
		Feldspars (Na and K)	~ 5 %
		Carbonates	n.d.
		Unidentified mineral	< 5 %
		Non-swelling clay minerals:	
		Illite/Muscovite	30 – 40 %
		Kaolinite	20 – 30 %
		Chlorite	1 – 5 %
		Swelling clay minerals:	
		Smectite	1 – 5 %

APPENDIX D: Methane Emission – IPCC Methodology

D-1 Estimation of Methane Emission – IPCC Methodology

The IPCC method assumes that all the potential CH_4 emissions are released during the same year the waste is disposed. The method is simple and emission calculations require only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available. The IPCC Guidelines introduce various specific default values and recommendations, (particularly for use in countries with lack of SW statistics):

The default method is based on the main equation 1:

$$Methane\ emissions\ (Gg/yr) = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1 - OX)$$

Where,

MSW_T : A selection of national specific MSW generation (in kg/capita/day) figures are provided, but information appropriate for many low and medium income countries and regions is missing

MSW_F : A selection of national specific MSW disposal figures (in kg/capita/day) are provided (to be used instead of MSWT)

MCF : Three default values ranging from 1.0 to 0.4 are included, depending on the site management. For Matuail Site the value of MCF 0.80 is use (depth > 5m) and 0.40 is use (depth < 5m) for other UDS.

DOC : A selection of national values for DOC in MSW are provided, although a more limited selection than for MSWT and MSWF. In addition, an equation is provided below with default values related to MSW fractions to estimate country specific figures based on national MSW composition.

DOC_F : Tabasaran's (1981) theoretical equation $DOC_F = 0.014T + 0.28$, where T = temperature is used to determine the value. For this study the value of 0.56 is used for all UDS.

F : Varies from 0.50 to 0.60. The value of 0.55 is used.

OX : 0 is the IPCC default value

DOC - Content (fraction) of degradable organic carbon

The *IPCC Guidelines* provide the following equation:

$DOC = 0.4 \times (A) + 0.17 \times (B) + 0.15 \times (C) + 0.30 \times (D)$

Where default values for DOC related to A, B, C and D are as presented in Table 2:

Table D-1 Default DOC Values for Major Waste Streams

	Waste Stream	**% DOC (by weight) in wet SW**
A	Paper and textiles (% portion in SW)	40
B	Garden and park waste (% portion in SW)	17
C	Food waste (% portion in SW)	15
D	Wood and straw waste (% portion in SW)	30

Table D-2 DOC value for the four UDS
[$DOC = 0.4 \times (A) + 0.17 \times (B) + 0.15 \times (C) + 0.30 \times (D)$]

	A (%)	**B (%)**	**C (%)**	**D (%)**	**DOC (%)**
MATUAIL	7.0	0.50	70.0	5.0	14.88
RAJBANDH	7.0	2.80	68.0	7.0	15.58
SHISHUPARK	7.0	2.10	69.0	6.0	15.31
NORTH KAWNIA	4.0	1.50	76.0	6.0	15.05

APPENDIX: Tabulation and Figure of Leachate Data

Table E-1 Characteristics of Leachate from Matuail Disposal Site

	JUNE	JULY	AUG	SEP	OCT	NOV	Minimum	Maximum	Mean	Median	SD
pH	7.7	7.9	8.2	7.7	7.6	7.9	7.6	8.2	7.83	7.8	0.22
Chloride, mg/L	850	1825	372	1270	1175	1088	372	1825	1096.67	1131.5	480.15
Iron, mg/L	1.2	3.5	1.8	21	50	25	1.2	50	17.08	12.25	19.14
TDS, mg/L	3750	6110	5080	2150	3550	4260	2150	6110	4150.00	4005	1359.31
BOD_{5days} ,, mg/L	260	40	580	220	105	480	40	580	280.83	240	210.82
COD, mg/L	566	110	1125	1132	1432	1760	110	1760	1020.83	1128.5	595.84
Lead , mg/L	0	0.038	0.062	0.08	0.023	0.026	0	0.08	0.04	0.032	0.03
Nickel , mg/L	0.042	0.015	0.031	0.02	0.001	0.006	0.001	0.042	0.02	0.0175	0.02
Cadmium, mg/L	0.004	0.007	0.012	0.006	0.007	0	0	0.012	0.01	0.0065	0.00

Table E-2 Characteristics of Leachate from Rajbandh Disposal Site

	JUNE	JULY	AUG	SEP	OCT	NOV	Minimum	Maximum	Mean	Median	SD
pH	7.1	7.3	7.9	7.6	7.8	7.9	7.1	7.9	7.6	7.7	0.3
Chloride, mg/L	625	728	3000	2110	1750	1820	625.0	3000.0	1672.2	1785.0	891.2
Iron, mg/L	3.5	5.5	50	35	28	55	3.5	55.0	29.5	31.5	21.7
TDS, mg/L	8550	8652	7191	7614	5568	6882	5568.0	8652.0	7409.5	7402.5	1149.2
BOD_{5days} ,, mg/L	2550	628	834	575	450	520	450.0	2550.0	926.2	601.5	806.1
COD, mg/L	5400	3500	2832	2625	2075	1834	1834.0	5400.0	3044.3	2728.5	1294.8
Lead , mg/L	0.394	0.302	0.425	0.325	0.257	0.286	0.257	0.425	0.33	0.3135	0.07
Nickel , mg/L	0.047	0.051	0.064	0.062	0.085	0.058	0.047	0.085	0.06	0.06	0.01
Cadmium, mg/L	0.005	0	0	0	0.04	0	0	0.04	0.01	0	0.02

Table E-3 Characteristics of Leachate from Shishu Park Disposal Site

	JUNE	JULY	AUG	SEP	OCT	NOV	Minimum	Maximum	Mean	Median	SD
pH	7.3	6.9	7.1	7.1	7.2	7.2	6.9	7.3	7.1	7.2	0.1
Chloride, mg/L	47	7.5	33	40	58	65	7.5	65.0	41.8	43.5	20.4
Iron, mg/L	0.8	1.2	3.8	2.2	4.3	2.8	0.8	4.3	2.5	2.5	1.4
TDS, mg/L	3900	1350	1200	1600	4200	4700	1200.0	4700.0	2825.0	2750.0	1604.9
BOD_{5days}, mg/L	80	600	120	240	320	430	80.0	600.0	298.3	280.0	195.8
COD, mg/L	820	5550	5280	2800	2650	3600	820.0	5550.0	3450.0	3200.0	1775.4
Lead , mg/L	0	0	0.001	0.002	0.003	0.002	0	0.003	0.0013	0.0015	0.00
Nickel , mg/L	0.003	0.001	0.001	0.003	0.004	0.004	0.001	0.004	0.0027	0.003	0.00
Cadmium, mg/L	0	0	0	0	0.003	0.002	0	0.003	0.0008	0	0.00

Table E-4 Characteristics of Leachate from North Kawnia Disposal Site

	JUNE	JULY	AUG	SEP	OCT	NOV	Minimum	Maximum	Mean	Median	SD
pH	6.2	7.2	7.9	7.4	6.9	7.1	6.2	7.9	7.12	7.15	0.56
Chloride, mg/L	1300	725	860	50	75	45	45	1300	509.17	400	531.0
Iron, mg/L	8.8	4.4	2.5	2.4	2.5	0.4	0.4	8.8	3.50	2.5	2.9
TDS, mg/L	8330	6030	5400	540	500	480	480	8330	3546.67	2970	3470.1
BOD_{5days}, mg/L	1200	708	115	78	240	162	78	1200	417.17	201	447.3
COD, mg/L	3116	1255	280	302	1120	490	280	3116	1093.83	805	1074.2
Lead , mg/L	0.005	0.205	0	0	0.006	0.008	0	0.205	0.04	0.0055	0.08
Nickel , mg/L	0.072	0.46	0.008	0.15	0.11	0.004	0.004	0.46	0.13	0.091	0.17
Cadmium, mg/L	0.005	0.015	0	0.105	0.025	0	0	0.105	0.03	0.01	0.04

APPENDIX F: Photographs

Photograph F-1(a,b) Scavenging at Matuail Disposal Site in Dhaka city

(a)

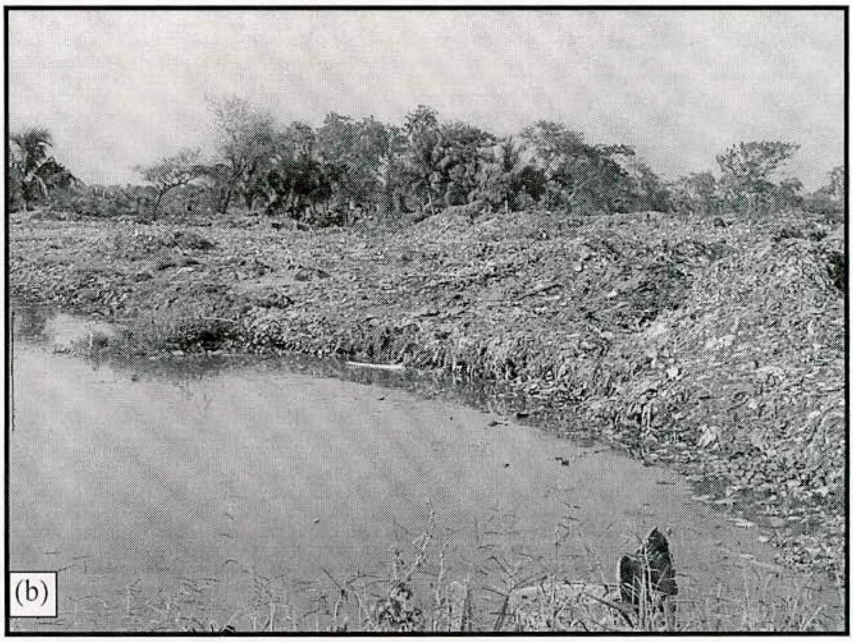
(b)

Photograph F-2(a,b) MSW spreading by Mechanical equipment at Matuail Disposal Site in Dhaka city

Photograph F-3 MSW is dumped at Rajbandh UDS at Khulna city

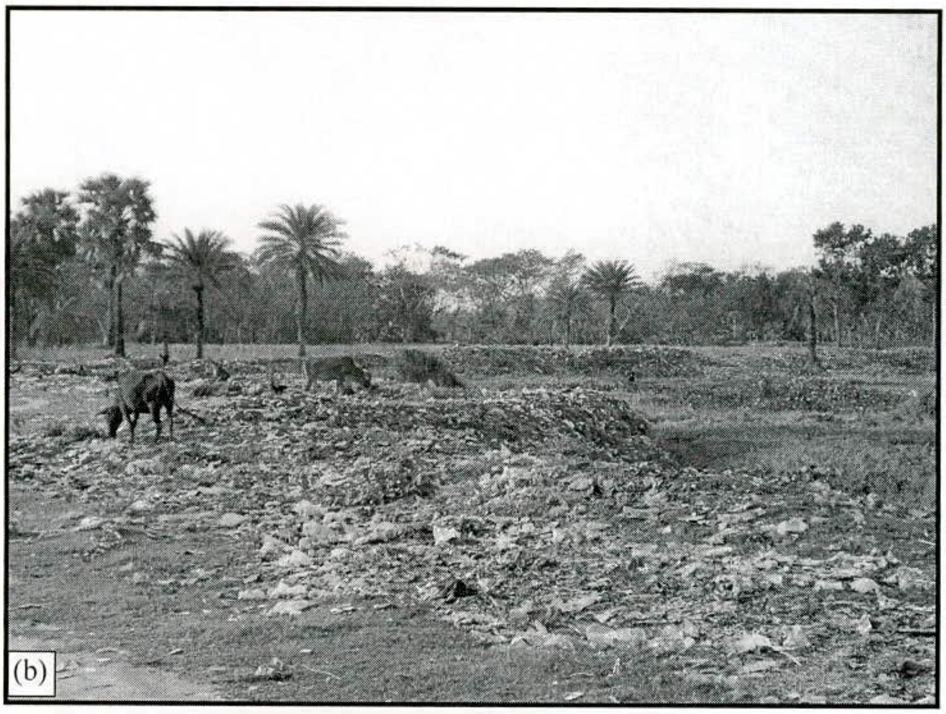
Photograph F-4 Approach road of Rajbandh UDS at Khulna city


(a)


(b)

Photograph F-4(a,b) Nearest surface water source of Rajbandh UDS at Khulna city

Photograph F-5(a,b) Shishu Park Ultimate Disposal Site at Rajshahi city



Photograph F-6(a,b) North Kawnia Ultimate Disposal Site at Barisal city