Conversion of Municipal Solid Waste (MSW) into Safe Land Filling Material

by

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The thesis titled **"CONVERSION OF MUNICIPAL SOLID WASTE (MSW) INTO SAFE LAND FILLING MATERIAL"** submitted by **Mohammad Rasel Kabir, Roll No.: 1009292009, Session: October 2009,** has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Management of Technology (MOT) on 20th December, 2015.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Mohammad Rasel Kabir

This thesis is dedicated to my parents. Their continuous inspirations made this effort possible.

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I started my Master of Science Program in Management of Technology at the Institute of Appropriate Technology (IAT) of BUET in October, 2009. I feel myself lucky to be enrolled in the first batch of this master's program ever in Bangladesh. I would like to extend my gratitude to all Professors of IAT. Their lectures equipped me with many ideas which were very useful in the development of this thesis, while my skill as a researcher was shaped.

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ABSTRACT

Generation of municipal solid waste is ominously increasing due to the rapid growth of population coupled with the increasing scale of economic activity, i.e. urbanization, industrialization, and improved living standards. Urban local bodies across the world are struggling with the tenacious problems of municipal waste management, particularly in disposal of waste. This research aims to induce an effective and simple technique for treating organic wastes as part of its waste management system with a view to minimizing the negative environmental impacts resulting from land filling. For sampling, fresh municipal solid waste was collected from twenty different sites of Dhaka City and the organic part of collected solid waste was separated and treated with soil, lime, and cement at different proportions. In this manner four samples were developed and separately preserved in open containers. Later, a series of laboratory tests was conducted to study the physical characteristics, prospective chemical reactions and the risks factors of the treated samples at field condition. More than 60 specimens were tested at predetermined intervals at Environmental Microbiology Laboratory of ICDDR'B, Soil Resource Development Institute of Ministry of Agriculture, and Department of Soil, Environment & Water of the University of Dhaka. The experiment results depicted that over time moisture content rates in each samples dropped to almost one third in an average in ambient conditions. The Hydraulic Conductivity rate of four developed samples ranged from 8.44×10^{-3} cm/s to 13.74×10^{-3} cm/s for a density of 0.625 gm/cm^3 to 0.716 gm/cm^3. Moreover, the number of colony forming units of Total Coliforms bacteria in per gram declined dramatically and were found almost zero at the end of the research. Throughout the study all samples were found very mild alkali (average pH value 7.15), which is suitable for land filling. Treatment costs of per m^3 of waste were estimated in Taka for each developed samples. After technical evaluation and analysis of prospective treatment costs, the Sample comprised 77% of organic waste, 4% of lime and 19% of gravellier soil has been evolved as an appropriate technique of converting municipal solid waste into safe land filling material. A waste management system was proposed in context of the Dhaka city for the establishment of the developed technique by the city corporations. At the same time, a layout plan was also designed to accommodate the developed technique with existing landfill process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF MAPS

LIST OF ABBREVIATIONS OF TECHNICAL SYMBOLS AND TERMS

3R	Reduce, Reuse, Recycle
ADB	Asian Development Bank
ADBI	Asian Development Bank Institute
AIT	Asian Institute of Technology
BCC	Barisal City Corporation, Bangladesh
BCSIR	Bangladesh Council of Scientific and Industrial Research
BMDF	Bangladesh Municipal Development Fund
BOO	Build Own Operate
BUET	Bangladesh University of Engineering & Technology
cap	Capita
CASR	Committee for Advanced Studies and Research
CBO	Community Based Organization
CCAC	Climate and Clean Air Coalition
CCAP	Center for Clean Air Policy, Washington, DC
CCC	Chittagong City Corporation
CDM	Clean Development Mechanism
CEO	Chief Executive Officer
CER	Certified Emission Reduction
CFU	Colony Forming Unit
CH_4	Methane
cm	Centimeter
C/N	Carbon Nitrogen Ratio
COD	Chemical Oxygen Demand
CO_2e	Carbon Dioxide Equivalent
DCC	Dhaka City Corporation
DNCC	Dhaka North City Corporation
DOC	Degradable Organic Carbon
DoE	Department of Environment, Bangladesh
DSCC	Dhaka South City Corporation
DU	University of Dhaka
EGAP	Environmental Grant Aid Program
GDP	Gross Domestic Product
GHG	Green House Gases

GIZ	German Society for International Cooperation, Ltd.
gm	Gram
GoB	Government of Bangladesh
Hu	Heating Value Unit
HDPE	High Density Polyethylene
IAT	Institute of Appropriate Technology
ICDDR,B	International Centre for Diarrhoeal Disease Research, Bangladesh
IPCC	Inter-governmental Panel on Climate Change
JDCF	Japan Debt Cancellation Fund
JICA	Japan International Cooperation Agency
KCC	Khulna City Corporation
KfW	German Development Bank
LCA	Life Cycle Assessment
LGD	Local Government Division, Bangladesh
LGED	Local Government Engineering Department, Bangladesh
LFG	Landfill Gas
LMU	Landfill Management Unit
Mg	Mega gram
MoEF	Ministry of Environment and Forests, Bangladesh
MoLGRD&C	Ministry of Local Government, Rural Development & Cooperatives
MSW	Municipal Solid Waste
NEMAP	National Environmental Management Action Plan
NGO	Non-Government Organization
ODEQ	Oregon Department of Environmental Quality, UK
O&M	Operation & Maintenance
PCSP	Primary Collection Service Provider
PPP	Public Private Partnership
PRSP	Poverty Reduction Strategic Paper
RAJUK	Rajdhani Unnayan Katripakkha: Capital City Development Authority
RCC	Rajshahi City Corporation
R&D	Research and Development
SAARC	South Asian Association for Regional Cooperation
SCC	Sylhet City Corporation
SEMP	Sustainable Environment Management Program
SRDI	Soil Resource Development Institute

S/S	Stabilization/Solidification
STS	Secondary Transfer Station of MSW
SWM	Solid Waste Management
SWMS	Solid Waste Management System
TCP	Temporary Collection Points of MSW
Tk.	Taka (Bangladeshi Currency)
TWG	Total Waste Generation
UK	United Kingdom
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund
UN-HABITAT	United Nations Human Settlement Programme
ULB	Urban Local Bodies
USA	United States of America
USD	US Dollar (Currency)
USEPA	United States Environmental Protection Agency
VOA	Volatile Organic Acid
VOC	Volatile Organic Compound
WB	World Bank
WMD	Waste Management Department

CONVERSION EQUIVALENT

1 Hectare	: 10000 m^2
1 Acre	: 0.405 Hectare
1 Meter	: 100 Centimeters
1 Tonne	: 1000 Kilograms
1 Kilogram	: 1000 Grams
1 Million	; 1,000,000
1 US Dollar	: Approximately Taka 78.20 (as of January, 2015)

CHAPTER-1: INTRODUCTION

CHAPTER-1: INTRODUCTION

1.1 Background of the Research

Municipal Solid Waste (MSW) has become a menace in large and rapid growing cities in the world. Increasing population, urbanization, industrialization, and changing consumption patterns are resulting in the generation of increasing amounts of solid waste and diversification of the type of the solid waste generated [1]. These increasing rates of MSW create an adverse effect on environment as well as social and professional life of city residents, urban planners, developers, and other concerned stakeholders [2].

Disposal of solid waste poses greater problem because it leads to land pollution if openly dumped, water pollution if dumped in low lands, and air pollution if burnt. It causes serious environmental degradation and public-health risk due to uncollected disposal of waste on streets and other public areas, clogged drainage system by indiscriminately dumped wastes, and by contamination of water resources near uncontrolled dumping sites [3]. According to [4], land filling is the simplest, cheapest, and most cost effective method of disposing of waste in both developed and developing nations of the world. Another study conducted by [5] revealed that land filling is an economical way of disposing of municipal solid waste (MSW) compared to other techniques such as incineration and composting.

Wastes are broadly categorized by DoE into organic or biodegradable wastes (e.g. kitchen rubbish or agricultural wastes) and inorganic or non-biodegradable wastes (e.g. plastic and polythene wastes) [6]. Shearer stated that landfill gas (LFG) is a result of biodegradation of organic matter in the refuse, and since 50-70 percent of MSW is biodegradable, LFG production can be substantial [7]. However, despite the fact that solid waste landfills pose serious threat to environment, the final destination of urban solid wastes in most of the countries in the world is dominated by land filling [8].

Hasan, et al., considered that along with other waste disposal option such as, recycling, combustion (incineration) and composting, landfill is the most preferred option, because of its easy operation, low cost, less technological involvement, and comfort of implementation [9]. JICA study on *Solid Waste Management in Dhaka City* under the Clean Dhaka Master Plan Project suggested that it would be a practical approach to establish a base system at first consisting of landfill and once the base system is established, other systems can be introduced with less difficulty [10]. The same study fixed that four alternatives would be considered on treatment and disposal as well [10]:

- Baseline scenario (continuation of present system)
- Landfill with improved operation
- Sanitary landfill with leachate treatment
- Introduction of pre-treatment and sanitary landfill

Alternative forms of disposal are likely to encourage by the authority in different countries to as: Stabilization/Solidification (S/S) is considered to be an effective technology for the commercial treatment of a number of waste streams, including hazardous inorganic waste and contaminated soil, in a number of countries including the USA and France [11]. Likewise, lime stabilization has been used for years to reduce odor and pathogens before land application. The advantages include low cost of lime, easy disposal of treated waste, and reduction in soil acidification [12].

According to Haque, et at., stabilization of solid waste is practiced in many countries because this process reduces not only the volume of solid waste at landfill site but also reduce the risk of environmental pollution [13]. The stabilization of waste is suggested to proceed in five sequential or distinct phases [14] and the rate of progress through these stages is dependent on the physical (availability of free oxygen), chemical and microbiological conditions developed within the landfill with time [15]. Haque, et al., believed that to reduce the volume at landfill site it is essential to take the initiatives for stabilization of solid waste via solidification that convert the waste into re-usable products such as construction material, filler material etc. [13]. Waste composition, moisture content, waste particle size, waste density, temperature and pH are important as these affect the extent and rate of degradation of waste as opined by [16].

1.2 Present State of the Problem

Bangladesh is the eighth most populous [17], [18] country with the population of 158.36 million as of 20 April, 2015 [19] and the fifth most densely [18], [20] populated country having 1015 person/sq. km [21] in the world. The National Report (Volume-3) of Population and Housing Census-2011 of the Government of Bangladesh reveals that 28% of the total country population are living in the urban areas [22] which equals to about 44.34 million of people according to [19]. Urban population in Bangladesh are increasing at a very sharp rate of about 6% and are concentrated mostly in six major cities (namely, Dhaka, Chittagong, Khulna, Rajshahi, Sylhet, and Barisal as shown in **Map-1.1**) which consist nearly 13% of total country population and 55-60% of total urban population [23], [24].

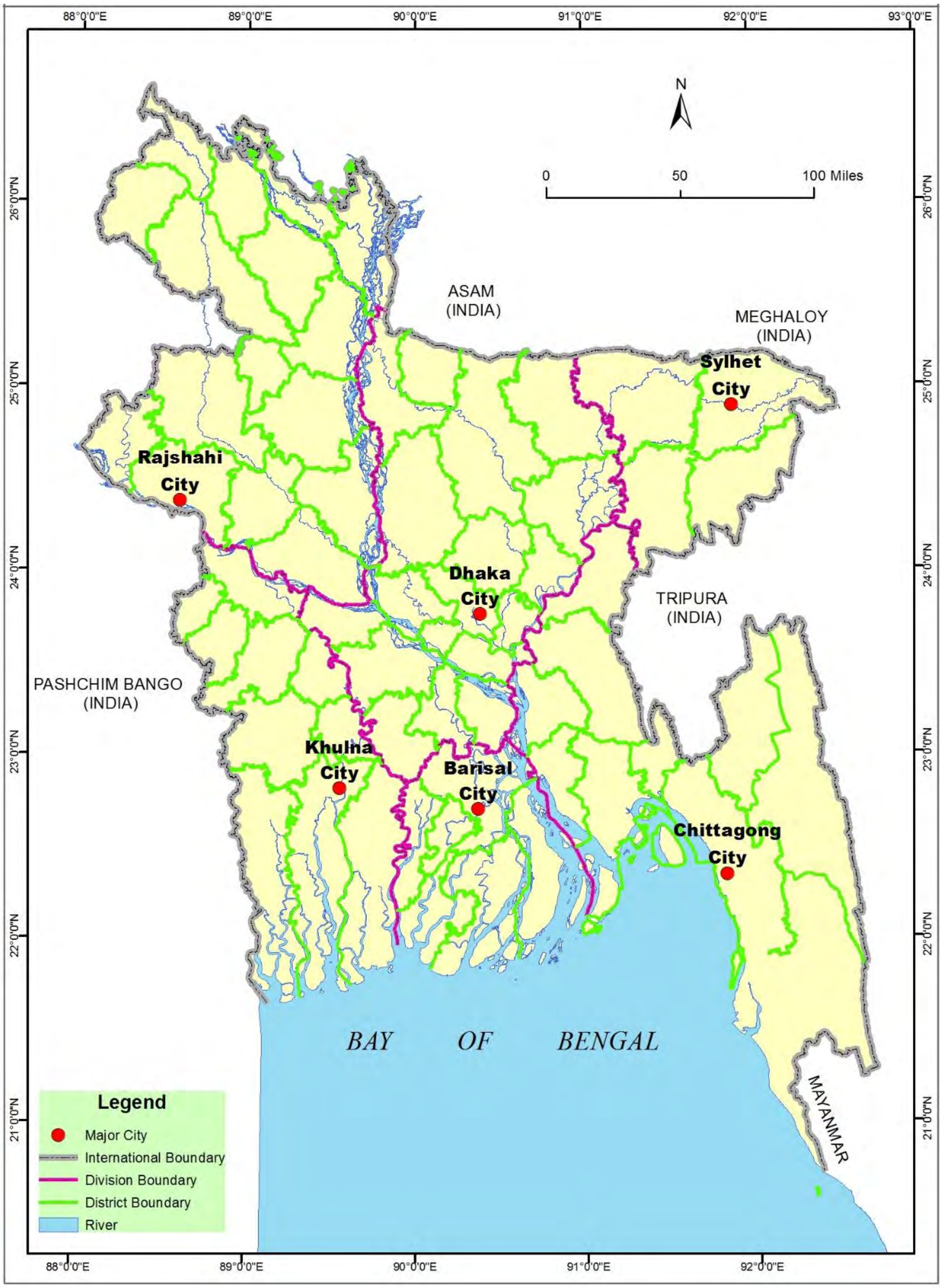
Since urbanization magnifies the risk of environmental hazards including the disposal of solid waste, Bangladesh is very vulnerable to contend with the growing amount of municipal solid waste. Like other countries, Bangladesh is also facing same adversity as the amount of waste generated from domestic and commercial activities is increasing day-after-day in the large cities including the mega-city Dhaka [6]. Considering the rapid growth of the country's population and per capita waste generation, [25] projected that by the year 2025 the generated amount of urban waste will be approximately 47,000 tonnes/day. **Table-1.1** shows the growth of municipal solid waste generation in Bangladesh over last 25 years and the trend of growth till the year of 2025.

Table-1.1: Municipal Solid Waste Generation in Bangladesh

Year	Total Urban Population	Urban Population (% of total)	Waste Generation Rate (kg/cap/day)	Total Waste Generation (tonne/day)
1991	20,872,204	20.15	0.49*	9,873.5
2001	28,808,477	23.39	0.50**	11,695
2004	32,765,152	25.08	0.50**	16,382
2015	44,341,456	28.00	0.55***	24,388
2025	78,440,000	40.00	0.60*	47,064

Source: * ADBI and ADB, 2000, ** Zurburg, 2002 cited by [26]; ***Estimated by author using trend extrapolation method

Map-1.1: Location of Six Major Cities in Bangladesh



Source: Developed by Author, 2015

As reported by [24], organic matters are usually the predominant component in the waste stream in six major cities of Bangladesh, which ranged from 68% to 81% due to the common habit of fresh food consumption, while paper and plastic are about 7% to 11% and 3% to 4%, respectively. According to the observation of [6], ultimate disposal of all types of waste is done crudely in open dumps, lowlands or water bodies in an unsanitary manner resulting the environment, surrounding the dumpsites, is barely hygienic. For the greenhouse gas (GHG) calculation, it is assumed that municipal solid waste at land filled site in a year would be converted completely into methane (CH_4) which would be emitted from the landfill site in the same year [27].

DoE study revealed that Dhaka's problem regarding solid wastes is worse compared to cities in other developing countries [6]. According to the UNFPA report, Dhaka is one of the most polluted cities in the world and one of the concerning issues is the management of municipal waste [28]. Alamgir & Ahsan estimated a total of 7690 t of MSW generated daily in the six major cities, while the Dhaka city contributed the most (69%, 5340 t) to the total waste stream [24]. The annual rate of increase of solid waste has been estimated by [29] at an average 1.2%, which is less than either the urbanization rate of about 4% [29] or the GDP growth of Bangladesh of about 6.12% [30].

Rahman, et al., claimed that the waste in Dhaka comprises mainly 60% of organic waste which can produce landfill gas (methane) upon decomposition [27]. Chowdhury, et al., assessed Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) collectively generate about 1.6 million tonnes of municipal waste per year which emit approximately 1 million tonnes of GHG annually [31]. From subsequent calculations, it is assumed that in Dhaka, 0.63 tonne of GHG yields annually from per tonne of landfilled waste. In a previous study, Hai and Ali expressed their concern that all the dumping sites in Dhaka City run the risk of explosions due to complete absence of provisions for the escape and/or collection of gases generated continuously, no matter whether it is a filled site or an operating site [3].

Field survey conducted for this study revealed that till January 2015, there was no full sanitary landfill for ultimate disposal of solid waste in Dhaka. Matuail and Amin Bazar landfill, constructed by erstwhile Dhaka City Corporation (now divided into DNCC and DSCC), are basically controlled landfill and are not properly operated to protect the environment and the neighborhood from adverse impacts of landfill gas and leachate. Besides, potential health hazards as well as vegetation damage, unpleasant odors, soil and water pollution are major concerns [32]. JICA Study remarked appropriate solid waste management system in Dhaka would be a combination of several technologies where landfill would be predominant because only landfill could receive and treat the whole amount of waste generated [10]. For the sustainable management of municipal solid waste, it is rational to convert solid waste into safe land filling material through waste stabilization process.

1.3 Objectives with Specific Aim and Possible Outcome

The current study aims to develop an effective and simple (low technology) technique for treating organic wastes as part of its waste management system. The purpose of the research is to minimize the negative impacts of landfilling on environment and public health. To attain this target, the following objectives will be emerged as inevitably outcomes of this research-

1) Assessment of traditional Municipal Solid Waste Management (MSWM) system
    a. composition of municipal solid waste, waste generation trends and rates
    b. waste management system by urban local body
2) Development of the conceptual framework and development of sampling and testing programs
    a. key parameters selection
    b. test schedule and laboratory selection
    c. site sampling
    d. development of samples for laboratory experiments
3) Discussions on experiment results
    a. Physical tests results
    b. Chemical tests results
    c. Biological tests results

4) Selection and establishment of a simple and effective method for conversion of MSW into safe land filling materials
    a. layout plan of a landfill site suitable for the developed technique
    b. schematic model to improve existing waste management system

According to the concept of sustainable waste disposal, a successful treatment of Municipal Solid Waste (MSW) should be safe, effective, environmentally sound, and socially acceptable. The expectations from this study are to determine the optimum mix proportion of solid waste and stabilizing additives for providing desired environmental compatibility, and to develop an advanced waste management system with a layout plan of landfill site compatible in Bangladesh context. The study focuses merely on the treatment of organic or biodegradable waste. Treatment of inorganic wastes are not included in the scope of this research, rather the study comply with the national 3R strategy.

1.4 Outline of Methodology

Based on the study objectives and background information, the entire research has been accomplished in following processes and the detail research methodology has been illustrated with a flow chart in **Figure-1.1**.

1) At first, theoretical aspect of municipal solid waste management system has been discussed briefly. Afterwards, a short descriptions of waste scenario in Bangladesh has been presented based on previous studies. Apart from that, an analytical overview of the organizational, legal, financial, and management aspects regarding solid waste management practices in Dhaka city has been narrated to observe the practical experience of waste management by urban local body. These discussions have been developed based on both primary and secondary information.

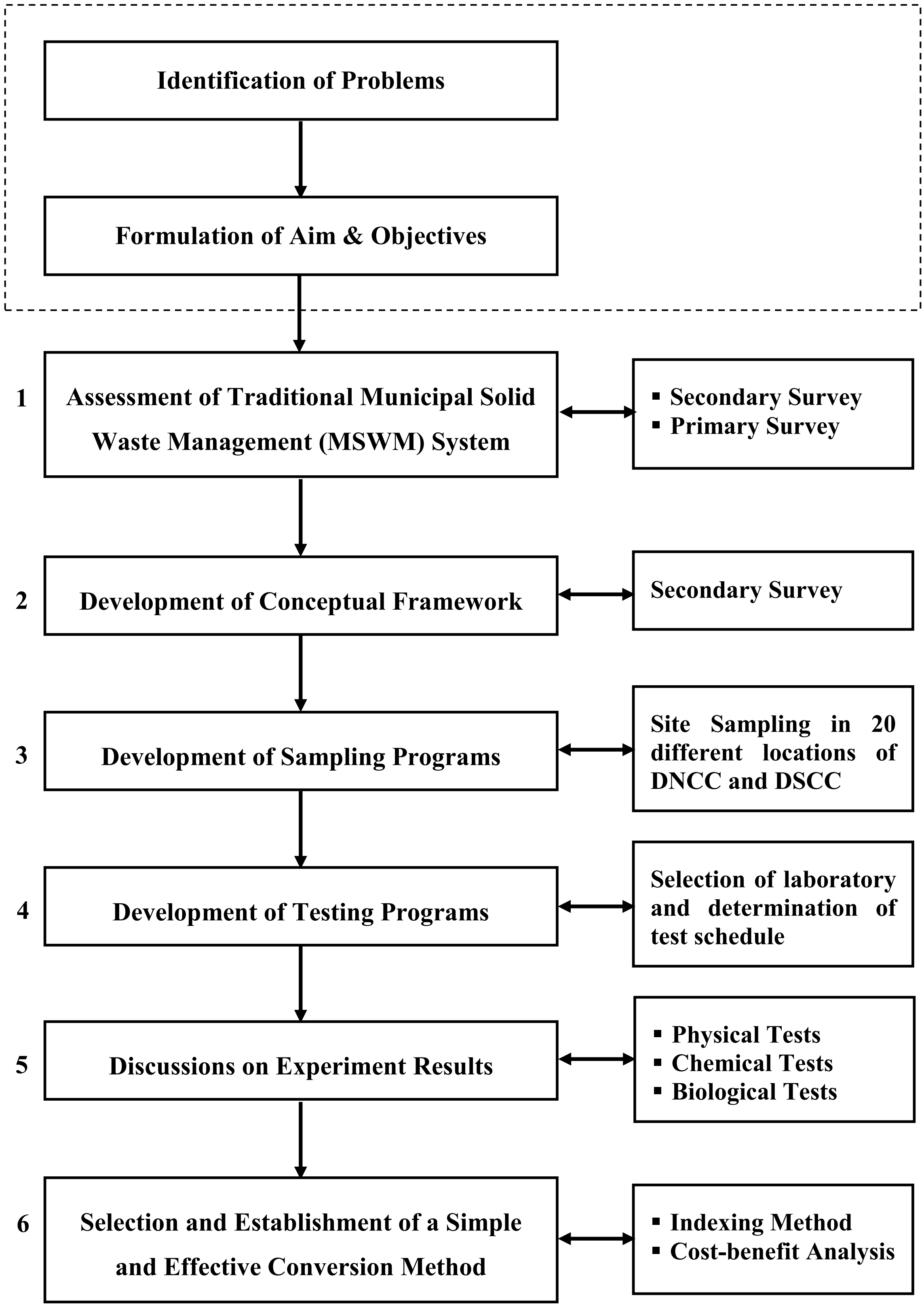


Figure-1.1: Flow Chart of Research Methodology

2) Secondly, a detailed search of the literature has been undertaken on landfilling techniques, stabilizing additives, key parameters for the experiments, and also on some technological aspects for selection of some alternative waste conversion options.

3) Thirdly, samples of municipal solid waste has been collected from twenty different locations (eighteen secondary collection points and two permanent dumping stations) of DNCC and DSCC in separate poly bags. Physical analysis of municipal solid waste therefore has been carried out to estimate the share of organic and inorganic materials in waste stream.

4) Fourthly, a Sample Matrix has been developed with organic waste treated with soil and additives by mixing at different proportions. The treated samples have been preserved in separate containers for further experiments. Various physical, chemical, and biological parameters have been set to experiment the improvement of treated samples at different stages. Physical parameters have been set to recognize physical developments and chemical parameter has been fixed to understand the prospective chemical reactions of the treated samples at the field level. Bacteriological parameters have been set to discover the scale of risks of groundwater contamination near the landfill site by the samples developed.

5) Fifthly, the experiment results of more than 60 specimens which were tested at predetermined intervals at Environmental Microbiology Laboratory of ICDDR'B, Soil Resource Development Institute of Ministry of Agriculture, and Department of Soil, Environment & Water of DU, have been discussed elaborately. These discussions paved a way to determine the development of treated samples with time.

6) Finally, a conversion technique has been selected after the cost-benefit analysis. Keeping in mind the developed technique, a layout plan for landfill site and a solid waste management system has been developed. Apart from that, the conversion cost of per tonne MSW has been estimated.

1.5 Tools & Techniques

1) Regarding solid waste management of DNCC and DSCC, primary information have been collected from key informants of respective city corporations, while some secondary information have been gathered from previous studies. Conceptual framework has been developed with secondary information such as, scientific articles, books, studies conducted earlier, website information, and so on. BUET library and internet have been found as useful sources of secondary information.

2) Sample of municipal solid waste has been collected from twenty different locations (eighteen secondary collection points and two permanent landfilling sites) of DNCC and DSCC through Site *Sampling*. Physical properties of the collected MSW has been analyzed manually in the R&D lab of IAT, BUET. Afterwards, the analysis result has been compared to some previous studies with a view to identifying the changing consumption pattern and the discrepancies among available data.

3) Organic composite of waste from all collected samples has been gathered altogether and mixed with lime, cement, and gravellier soil at different proportions to form a *Sample Matrix*. The treated samples have been preserved in different containers to determine *Moisture Content, Temperature, Hydraulic Conductivity* as physical parameters; pH *value* as chemical parameters; *Total Coliforms, Faecal Coliforms,* and *Escherichia coli* as Bacteriological parameters. Moisture Contents has been analyzed at Soil Resource Development Institute (SRDI) under the Ministry of Agriculture, Hydraulic Conductivity test has been conducted at Department of Soil, Water & Environment of DU, and Temperature has been measured at R&D lab of IAT. Moreover, pH values have been determined at SRDI, while Bacteriological tests have been carried out at ICDDR'B.

4) Physical, chemical and biological tests results has been evaluated by *Comparative Analysis* and illustrated with both tabular and graphical formats. *Cost-benefit Analysis* has been used to determine the appropriate conversion technique.

5) Finally, the selected conversion technique has been underpinned with a layout plan and a proposed waste management system.

1.6 Organization of the Thesis

This thesis consists of eight chapters those reflect the entire study step by step. Background of the Study, Problem Statement, Research Aim and Objectives with possible outcome, Methodology, and Tools & Techniques are presented in the first chapter. Second chapter describes the waste scenario of Bangladesh and municipal solid waste management system of Dhaka City with some theoretical concepts. In the third chapter conceptual framework has been illustrated by reviewing literatures to collect information regarding land filling and waste stabilization techniques. Fourth chapter encloses an inventory on municipal solid waste in Dhaka city as well as describes the facts of collection of MSW for further experiments. Fifth chapter encompasses detail experimental design including testing parameters, methods, test schedule, and so on. Sixth chapter comprises the tests results with proper discussions. Seventh chapter encapsulates comparative evaluation and cost benefit analysis in order to determine an appropriate conversion technique. This chapter also includes a proposed waste management system and a layout plan for the establishment of the developed conversion technique in Bangladesh, particularly in Dhaka context. The eighth chapter concludes the thesis with summary and limitations.

CHAPTER-2: MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM IN BANGLADESH

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2.1 Introduction

This chapter contains a brief explanations on municipal solid waste as well as its management system, and a short descriptions of waste scenario in Bangladesh. In addition to that an analytical overview of the organizational, legal, financial, and management aspects regarding solid waste management practices in Dhaka city has been narrated here. For the discussion and further study Dhaka, the largest and capital city of Bangladesh has been selected due to its size and importance in national context as well as its ill repute as one of the most polluted cities in the world in waste management context. The entire study of this chapter is developed mainly based on secondary information but a substantial number of primary information has been collected to update and to verify the information received from secondary sources.

2.2 Municipal Solid Waste (MSW)

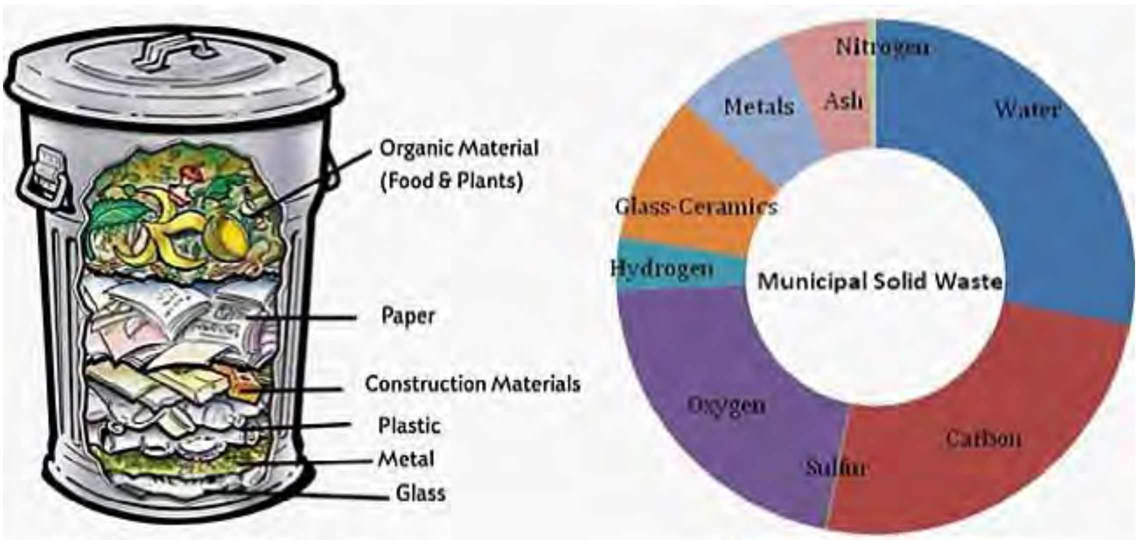
The definition of 'municipal waste' used in different countries varies, reflecting diverse waste management practices. For the purposes of national yearly reporting of municipal waste to [33], 'municipal waste' is defined as “Municipal waste is mainly produced by households, though similar wastes from sources such as commerce, offices and public institutions are included. The amount of municipal waste generated consists of waste collected by or on behalf of municipal authorities and disposed of through the waste management system”.

Chapter 21.3 of Agenda 21 (United Nations Conference on Environment and Development, Rio de Janeiro, June 14, 1992) defines municipal solid wastes- “include all domestic refuse and non-hazardous wastes such as commercial and institutional wastes, street sweepings, and construction debris”. UNEP [34] refers “Municipal Solid Waste (MSW) is a term usually applied to a heterogeneous collection of wastes produced in urban areas, the nature of which varies from region to region. The characteristics and quantity of the solid waste generated in a region is not only a function of the living standard and lifestyle of the region's inhabitants, but also of the abundance and type of the region's natural resources". Urban wastes can be subdivided into two major components -- organic and inorganic. MSW primarily comes from households, but also includes wastes from offices, hotels, shopping complexes/shops, schools, institutions, and from municipal services such as street cleaning and maintenance of recreational areas [34].

The primary sources of MSW are residential, institutional and commercial waste, and municipal services wastes (street sweeping). Residential wastes are high in quantity and vary with time and season whereas the compositions of industrial and commercial wastes remain relatively steady over the years [35], [36]. Rouse & Ali [37] explored, the main constituents of solid waste in urban areas are organic waste (including kitchen waste and garden trimmings), paper, glass, metals and plastics, where ash, dust and street sweepings can also form a significant portion.

2.2.1 Waste composition

Composition of waste is usually discussed in two categories, namely, *Physical Composition* and *Chemical Composition*. Physical and chemical composition of solid wastes varies depending on sources and types of solid wastes. **Figure-2.1** shows physical and chemical composition of typical MSW.



(a) Physical Composition
Source: Adapted from [38]

(b) Chemical Composition
Source: Adapted from [39]

Figure-2.1 (a, b): Physical and Chemical Composition of Typical MSW

As observed by [37], waste characterization data would prove useful in planning disposal options. They also found the quantities of waste generated helps to decide what volume of landfill site is required and, according to trends in waste production, helps to project its lifespan. As stated in [16], the nature of the deposited waste in a landfill would affect gas and leachate production and composition by virtue of relative proportions of degradable and non-degradable components, the moisture content and the specific nature of the bio-degradable element.

According to AIT estimation, most of the developing Asian countries have high percentage (50 to 80%) of organic matter in their waste stream with high moisture content making them unsuitable for incineration [40]. Over the years, many plastics and paper wastes had finds its way into the municipal waste stream due to the rapid economic expansion [1]. Both physical and chemical composition of waste are described in the following sections.

2.2.1.1 Physical composition

Information and data on the physical composition of solid wastes are important in the selection and operation equipment and facilities, in assessing the feasibility and resources and energy recovery and in the analysis and design of disposal facilities [16]. According to [1], waste compositions, as well as the classifications used to collect data on waste composition in MSW vary widely in different regions and countries. AIT developed some waste categories [41] for physical composition, which is shown in **Table-2.1**.

Table-2.1: Physical Composition of Typical Municipal Solid Waste (MSW)

Waste category	**Waste components**
Organic matter	Waste from foodstuff such as food and vegetable refuse, fruit skin, stem of green, corncob, leaves, grass, and manure.
Paper	Paper, paper bags, cardboard, corrugated board, box board, newsprint, magazines, tissue, office paper, and mixed paper (all paper that does not fit into other category).
Plastic	Any material and products made of plastics such as wrapping film, plastic bag, polythene, plastic bottle, plastic hose, and plastic string.
Textile and wood	Has its origin from yarn, wood, and bamboo such as cotton, wool, nylon, cloth, desk, chair, bed board, toy, and coconut shell.
Leather and rubber	Any material and products made of rubber or leather such as ball, shoes, purse, rubber band, and sponge.
Metal	Ferrous and non-ferrous metal such as tin can, wire, fence, knife, bottle cover, aluminum can and other aluminum, foil, ware and bi-metal.
Glasses and ceramics	Any material and products made of glass such as bottles, glassware, light bulb, and ceramics.
Other	Yard waste, tires, batteries, large appliances, nappies/sanitary products, medical waste, miscellaneous.

Source: Adapted from [41]

2.2.1.2 Chemical composition

IPCC opined that chemical composition is one of the main factors influencing emissions from solid waste treatment, as different waste types contain different amount of Degradable Organic Carbon (DOC) and Fossil Carbon [42]. Chemical composition reveals the share of different compounds and elements in solid waste. **Table-2.2** shows the percentage of different chemical substances in typical MSW.

Table-2.2: Chemical Composition of Typical Municipal Solid Waste (MSW)

Components	Percentages
Water	28%
Carbon	25%
Sulfur	0.10%
Oxygen	21%
Hydrogen	3.30%
Glass-Ceramics	9.30%
Metals	7.20%
Ash	5.50%
Nitrogen	0.50%
Total	**100.00%**

Source: Adapted from [43]

2.2.2 Solid waste management

Solid waste management has become a major priority practice for many developing countries in order to secure the public health and environment while promoting justifiable economic and social development as reported by [44]. Solid waste management (SWM) involves the collection, storage, transportation, processing, treatment, recycling and final disposal of waste. Systems need to be simple, affordable, sustainable (financially, environmentally and socially), and should be equitable, providing collection services to poor as well as wealthy households [37]. **Figure2.2** illustrates a design of typical SWM process.

Many developed countries have formal door-to-door collection systems. However, in low-income countries waste generators (e.g. householders), domestic helpers or private waste collectors carry waste to transfer points. This stage is indicated by (2), and is referred to as 'primary collection' [37]. A transfer point is an intermediate place at which waste is deposited and stored before being transported to the final disposal site. Local authorities then collect waste from the transfer point and convey it to the final disposal site. This stage is indicated by (3) and is referred to as 'secondary collection' [37].

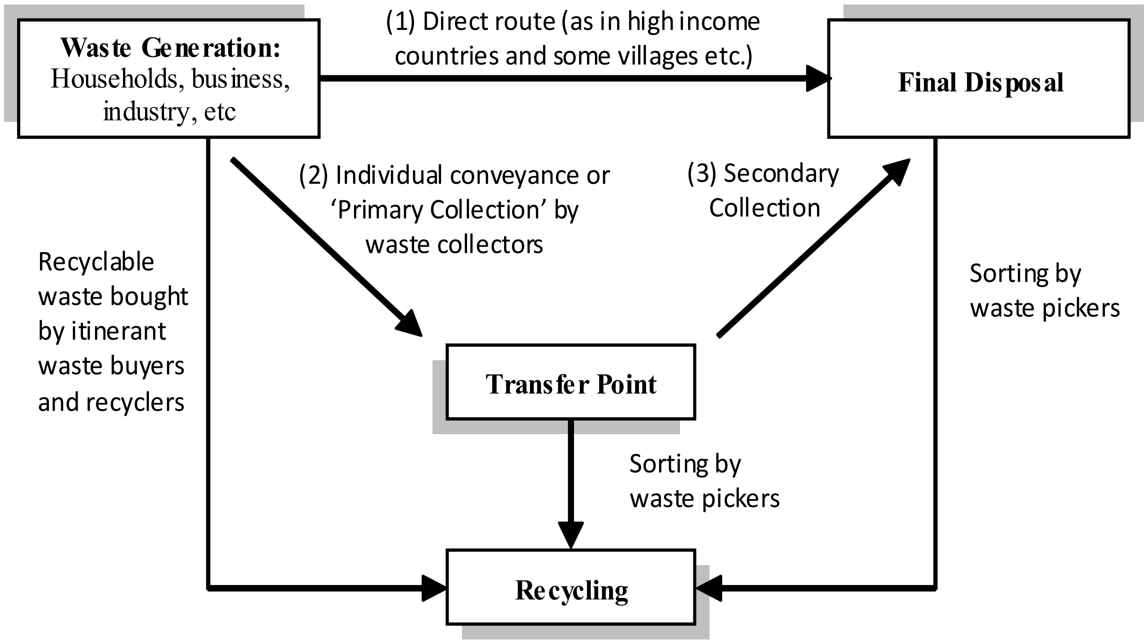


Figure-2.2: Solid Waste Management Process Diagram adapted from [45]

Finally, waste is disposed of to a variety of standards according to available resources and knowledge. This stage is called final disposal. Recyclable materials may be extracted from the waste stream from the points of generation, transfer or disposal [37]. In reality there are many variations on **Figure2.2**, for example, sometimes large private sector companies manage everything [37].

According to AIT, final disposal in most of the economically developing countries is usually a matter of transporting the collected waste to the nearest available open space and discharging them [40]. Nowadays municipalities are forced to find new methods for waste disposal due to critical environmental problems from old landfills and a lack of land availability caused by a fast growing population and a higher rate of waste-production. It is still the most common form of disposal in the vast majority of cases [46].

2.3 Waste Scenario in Bangladesh

Unplanned urbanization and associated density of population, and industrial and commercial activities that are taking place with the pace of economic growth, are the contributing factors of increasing waste generation in Bangladesh [6]. Alam & Sohel figured out solid waste generation in Bangladesh has increased proportionately with the growth of urban population [47]. The country comprises 532 urban centers [22] including 321 municipalities and 11 City Corporations as of February 2015 (Field Survey, 2015), which are hubs of rapid economic development and population growth, generate thousands of tonnes of waste from domestic, industrial, commercial, health care facilities and agricultural sources that must be managed daily [25].

2.3.1 MSW generation in urban areas of Bangladesh

Based on the total estimated urban population of 2005, Waste Concern Study assessed that total waste generated in the urban areas of Bangladesh was about 0.013 million tonnes/day accumulating to over 4.87 million tonnes/year [48]. **Table-2.3** shows the amount of waste generated in different city corporations, municipalities, and other urban areas for the year 2005 estimated separately by Waste Concern based on different per capita waste generation rates. After the JICA study, [49] observed that during the wet season the rate of waste generation increases by 46%. Alamgir & Ahsan projected that the Waste Generation Rate would increase to 0.60 kg/cap/day in 2025 [24].

Table-2.3: Total MSW Generation in Urban Areas of Bangladesh in 2005

City/Town	Waste Generation (kg/cap/day)	No. of City/ Town	Estimated Population (2005)	Total Population* (2005)	TWG** (Tonne/day)		Average TWG (Tonne/ day)
					Dry season	Wet season	
Dhaka	0.56	1	6,116,731	6,728,404	3,767.91	5,501.14	4,634.52
Chittagong	0.48	1	2,383,725	2,622,098	1,258.61	1,837.57	1,548.09
Rajshahi	0.30	1	425,798	468,378	140.51	205.15	172.83
Khulna	0.27	1	879,422	967,365	261.19	381.34	321.26
Barisal	0.25	1	397,281	437,009	109.25	159.51	134.38
Sylhet	0.30	1	351,724	386,896	116.07	169.46	142.76
Paurashavas	0.25	298	13,831,187	15,214,306	3,803.58	5,553.22	4,678.40
Other Urban Centers	0.15	210	8,379,647	9,217,612	1,382.64	2,018.66	1,700.65
Total	**0.41(Avg.)**	**514**	**32,765,516**	**36,042,067**	**10,839.75**	**15,826.04**	**13,332.89**

Source: Adapted from [48]; [*Including10% increase for floating population; **TWG=Total Waste Generation, which increases 46% in wet season from dry season]

The average density of urban solid waste at collection point is estimated by [49] as 288 kg/m^3. They also estimated that the average on-truck density is 575 kg/m^3 and average landfill density without any compaction is 1152 kg/m^3 [49]. The density may vary depending on the season [6] and variation of compaction.

2.3.2 Waste disposal system in Bangladesh

Waste Concern study [48] revealed that in Bangladesh, disposing of solid waste in open dumps is the most common method used for final disposal of urban solid waste. In some cities and towns there are designated dumping sites where the collected waste is dumped in unsanitary manner. No waste segregation, waste compaction or daily top seal are used in these dumpsites as reported by [48].

Cointreau [50] estimated without any compaction density of waste at landfill sites in this sub-continent is 1.10 tonne/m^3. **Table-2.4** presents landfill area required per year with 4 meters depth in different urban areas in Bangladesh for disposing the generated waste with existing (estimated in 2005) and 100% collection efficiency are 136.25 acres (55.14 hectares) and 273.21 acres (110.56 hectares) respectively [48].

Table-2.4: Landfill Area Requirement per year with 4 meters depth for Municipal Solid Waste Disposal in Bangladesh in 2005

City / Town	Total Waste Generation (Tonne/day)	Waste collection efficiency (%) in 2005	Landfill area required with 4m depth	
			With existing (2005) collection efficiency (acre per year)	With 100% collection efficiency (acre per year)
Dhaka	4,634.52	37.00	35.14	94.97
Chittagong	1,548.09	70.00	22.21	31.72
Rajshahi	172.83	56.67	2.01	3.54
Khulna	321.26	47.70	3.14	6.58
Barisal	134.38	44.30	1.22	2.75
Sylhet	142.76	76.47	2.24	2.93
Paurashava	4,678.40	54.42	52.17	95.87
Urban Center	1,700.65	52.00	18.12	34.85
Total	**13,332.89**	**-**	**136.25**	**273.21**

Source: Adapted from [48]

2.3.3 Green House Gas (GHG) Emission Potential by Urban Solid Waste

Enayetullah, et al. [49] estimated in 2005, about 2.19 million tonne CO_2e is emitted per year from the total urban waste generated in six major cities (as shown in Map-1.1), paurashava and other urban centers of Bangladesh. **Table-2.5** presents the scenario of GHG emission potential by municipal solid waste in different urban parts of the country in 2005. Subsequent calculations reveal that about 0.45 tonne of GHG (CO_2e) was emitted from the total municipal solid waste generated in Bangladesh in 2005.

Table-2.5: Green House Gas (GHG) Emission Potential by MSW in 2005

City/Town	Total Waste Generation (Tonne/day) in 2005	GHG emission potential (Million tonne CO_2 e / year)	GHG emission potential from per tonne of MSW (Tonne CO_2 e / year)*
Dhaka	4,634.52	0.76	0.45
Chittagong	1,548.09	0.25	0.44
Rajshahi	172.83	0.03	0.48
Khulna	321.26	0.05	0.43
Barisal	134.38	0.02	0.41
Sylhet	142.76	0.02	0.38
Paurashava	4,678.40	0.77	0.45
Other Urban Centers	1,700.65	0.28	0.45
Total	**13,332.89**	**2.19**	**0.45**

Source: Adapted from [51]; * developed by Author after [51]

In Bangladesh, besides landfilling some alternate options such as, composting, recycling, and resource recovery have been introduced in only a limited way. These projects are running with the help of internal, external, and some private initiatives.

2.3.4 Legal aspects related to waste management in Bangladesh

According to DoE [25], there is no specific policy for waste management in Bangladesh. However, several rules and policies are being drafted for specific types of wastes [25] which are listed in **Table-2.6**.

Table- 2.6: Legal Aspects related to Waste Management in Bangladesh

Date	Title
	Act
1995	Bangladesh Environmental Conservation Act (amended in 2000, 2002 & 2010)
2009*	Local Government (City Corporation) Act (amended in 2011)
2009*	Local Government (Paurashava) Act (amended in 2010)
	Rule
1997	Bangladesh Environmental Conservation Rules (amended in 2002 & 2010)
2010*	Draft Final Solid Waste Management Handling Rules
	Policy
1998	National Policy for Water Supply and Sanitation
1998	Urban Management Policy Statement
2014*	Draft National Urban Policy
	Strategy
2005	National CDM Strategy
2005	Poverty Reduction Strategy Paper (PRSP)
2005	National Sanitation Strategy
2009	National Strategy for Accelerated Poverty Reduction II
	Action Plan
1995	National Environmental Management Action Plan (NEMAP)
2005	Dhaka Environment Management Plan
2005	Solid Waste Management Action Plan for Eight Secondary Towns in Bangladesh
	Others
2004	Private Sector Infrastructure Guideline
2004	Dhaka Declaration on Waste Management by SAARC countries during 10–12 October 2004
2005	Private Sector Housing Development Guideline

Source: Adapted from [25]; * Author

2.4 MSW Management by Urban Local Bodies (ULBs) in Bangladesh

All the municipalities and city corporations, the Urban Local Bodies (ULBs) in Bangladesh, work under Local Government Division (LGD) of Ministry of Local Government Rural Development and Cooperatives (MoLGRD&C). All the rules and regulations, acts, ordinances and government orders regarding the issues of municipalities and city corporations are prepared and then disseminated by LGD [52]. In 2009, the Government of Bangladesh was promulgated two important acts, namely, Local Government (City Corporation) Act, 2009 (amended in 2011) for city corporations and Local Government (Paurashava) Act, 2009 for other municipalities (Paurashava). By these acts, solid waste management are entrusted to the urban local government bodies. However, according to the BMDF, both the acts are almost identical and provide minimal guideline regarding solid waste management [52].

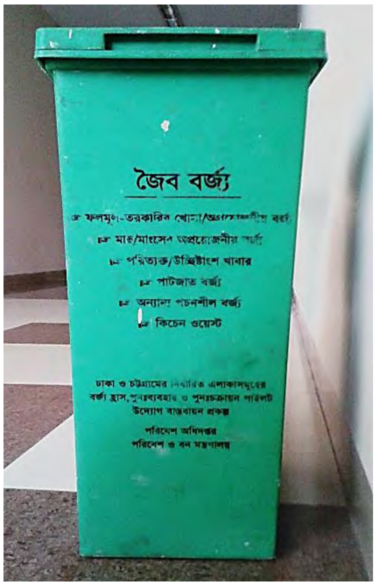
Conservancy tax attached to the holding tax was collected by the city corporations and municipalities for managing the municipal solid waste within their jurisdiction. BMDF opined that most of these urban local bodies practice the primitive open dumping without taking any environmental protection, which ultimately involves various environmental hazards for those cities and towns [52]. Besides, according to prevailing rule, the city corporations or municipalities are not bound to collect waste from households; they are responsible to collect waste from dustbins and designated points and dispose it. In fact, urban local government bodies are very much restricted in what they can do with their meager resources and their actual activities depend upon what is required by the central government [52].

2.5 External Support for Solid Waste Management in Bangladesh

A detail study conducted by BMDF found that a project titled “Promotion of Source Separation of Waste in Dhaka and Chittagong was being implemented by DoE in partnership with two Dhaka city corporations and Chittagong city Corporation [52]. This project was implemented as part of the National 3R strategy to promote segregation of waste at source and promote recycling. The project was financed by Climate Change Trust Fund of Government of Bangladesh to promote segregation of waste [52]. From April of 2012, the 3R pilot project was launched in Dhaka's Gulshan, Baridhara, Gonobhaban (Mohammadpur), Dhanmondi, Minto Road and Chittagong's

Nasirabad, Shugandha Housing, Hill View Housing, Khulshi, North Khulshi, Panchlaish Housing Society, Moushumi Residential Area and Jamalkhan Area [52]. As part of the project, three bins were provided for 50,000 households in Dhaka and Chittagong and an awareness raising campaign was also undertaken under this project as reported by [52]. **Photograph-2.1** shows the picture of three types of bins provided under this project for segregation of waste at source. The study [52] also revealed that segregated waste would be composted and based on the results of the pilot project, it would be gradually extended all over the city. It is observed by the Author during field study (2015), the project did not become successful due to the lack of public awareness and separate storage facilities at the secondary collection points.

a) Different Colors of bins for different Waste



b) Green bin for Organic Waste

Photograph-2.1 (a, b): Bins provided for Segregation of Waste at Source in Dhaka and Chittagong under the 3R pilot project (2012) adapted from [52]

External support agencies such as ADB, GIZ, World Bank and KfW are providing financial support to municipalities on solid waste management as part of urban development project through LGED or LGD as reported by [52]. With financial and technical assistance from the Japan International Cooperation Agency (JICA), Dhaka designed a Solid Waste Master Plan in 2005 that set out to transform the municipal solid waste management system by 2015 [53]. The Plan sought to develop a participatory waste management program and to build government capacity in waste management. Moreover, JICA has also provided grants to improve the crude dumping site in Dhaka into a controlled landfill site and provided 100 reconditioned compactor truck for waste collection [52]. Detail waste management system of Dhaka city has been presented in the following sections to assess different stages of the supply chain of waste management in a rapid growing city.

2.6 Municipal Solid Waste Management (MSWM) in Dhaka City

2.6.1 Background of Dhaka North and Dhaka South city corporations

Dhaka, the capital of Bangladesh is ranked ninth among the megacities of the world [54] having more than 55,500 people per sq. km. [55] that ultimately makes Dhaka the most densely populated city in the world. Forbes [56] estimated in 2013, population of Dhaka is nearly 14.4 million within its city area of 165.63 sq. km [55]. The population of Dhaka city has been increasing rapidly at a rate of almost 3.72% annually [57] in urban land terms. Every day 10% of total population migrates to Dhaka for their different activities [27].

Dhaka actually experienced dramatic turns upward and today it has become one of the fastest growing mega cities of the world. Its existence as a major urban agglomeration has been consistent over a period of 400 years [58]. Dhaka City Corporation was established as the Dacca Municipality on August 1, 1864. It gained status as Dhaka Municipality Corporation in 1978 and it was renamed as Dhaka Municipal Corporation in 1983. Finally in 1990, it was renamed as Dhaka City Corporation [58]. In late 2011, by the Local Government (City Corporation) Act' 2009 (Amendment in 2011), Dhaka City Corporation was divided into Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) for administrative convenience.

2.6.1.1 Administrative boundary of DNCC & DSCC

Dhaka North City Corporation (DNCC) is situated in the northern part of Dhaka City which consists of 36 wards [60]. The total area of DNCC is about 75 sq. km (Field Survey, 2015). Dhaka North City Corporation consists of 36 wards covering the thanas of Mirpur, Mohammadpur, Sher-E-Bangla Nagar, Pallabi, Adabor, Kafrul, Dhaka Cantonment, Gulshan, Banani, Badda, Uttara & some others [59]. Ward no. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 54, & 55 of erstwhile DCC are now under the jurisdiction of DNCC [60].

Dhaka South City Corporation (DSCC) consists of 57 wards [60] within its 42 sq. km area (Field Survey, 2015) covering the thanas of Dhaka Kotwali, Motijheel, Sutrapur, Ramna, Bangsal, Wari, Gendaria, Chwokbazar, Lalbagh, Hazaribagh, Dhanmondi, Shahbagh, New Market, Khilgaon, Kamrangirchar & some others [59]. DSCC comprises ward no. 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 48, 49, 50, 51, 52, 53, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, & 92 of erstwhile DCC [60]. **Map-2.1** illustrates location and administrative boundary of Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC).

2.6.1.2 Organizational setup of DNCC & DSCC

Both Dhaka North City Corporation & Dhaka South City Corporation have same Organizational structure which is headed by either an elected Mayor or an Administrator appointed by the Government. The Chief Executive Officer (CEO) a senior level bureaucrat deputed by the Government, is responsible for overall management. **Figure-2.3** shows the Organogram of Dhaka North and Dhaka South City Corporations.

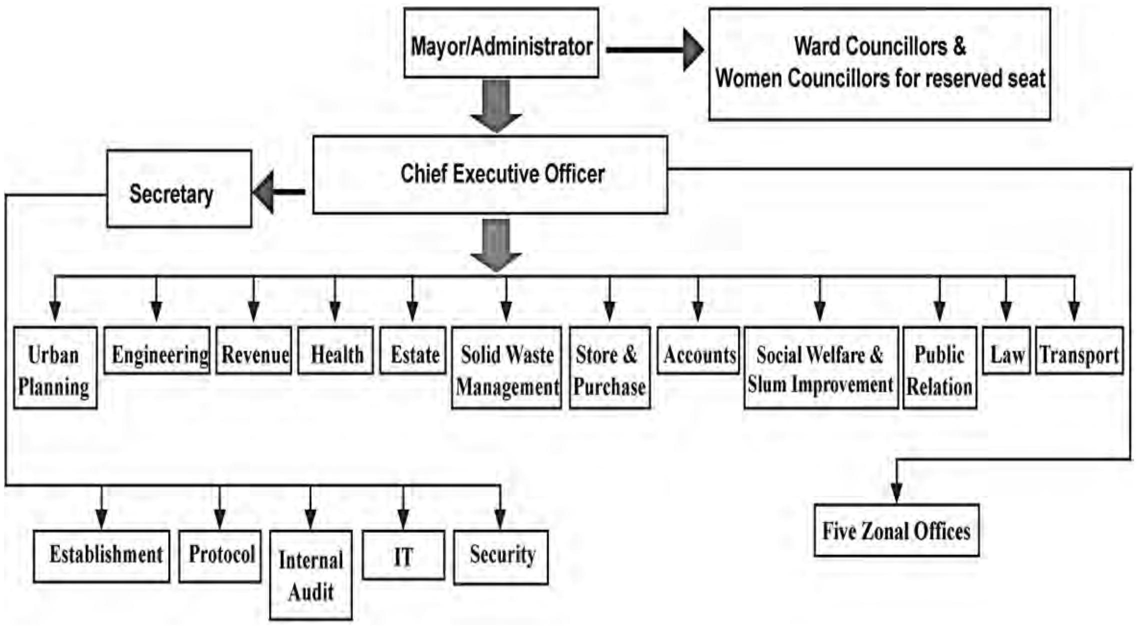
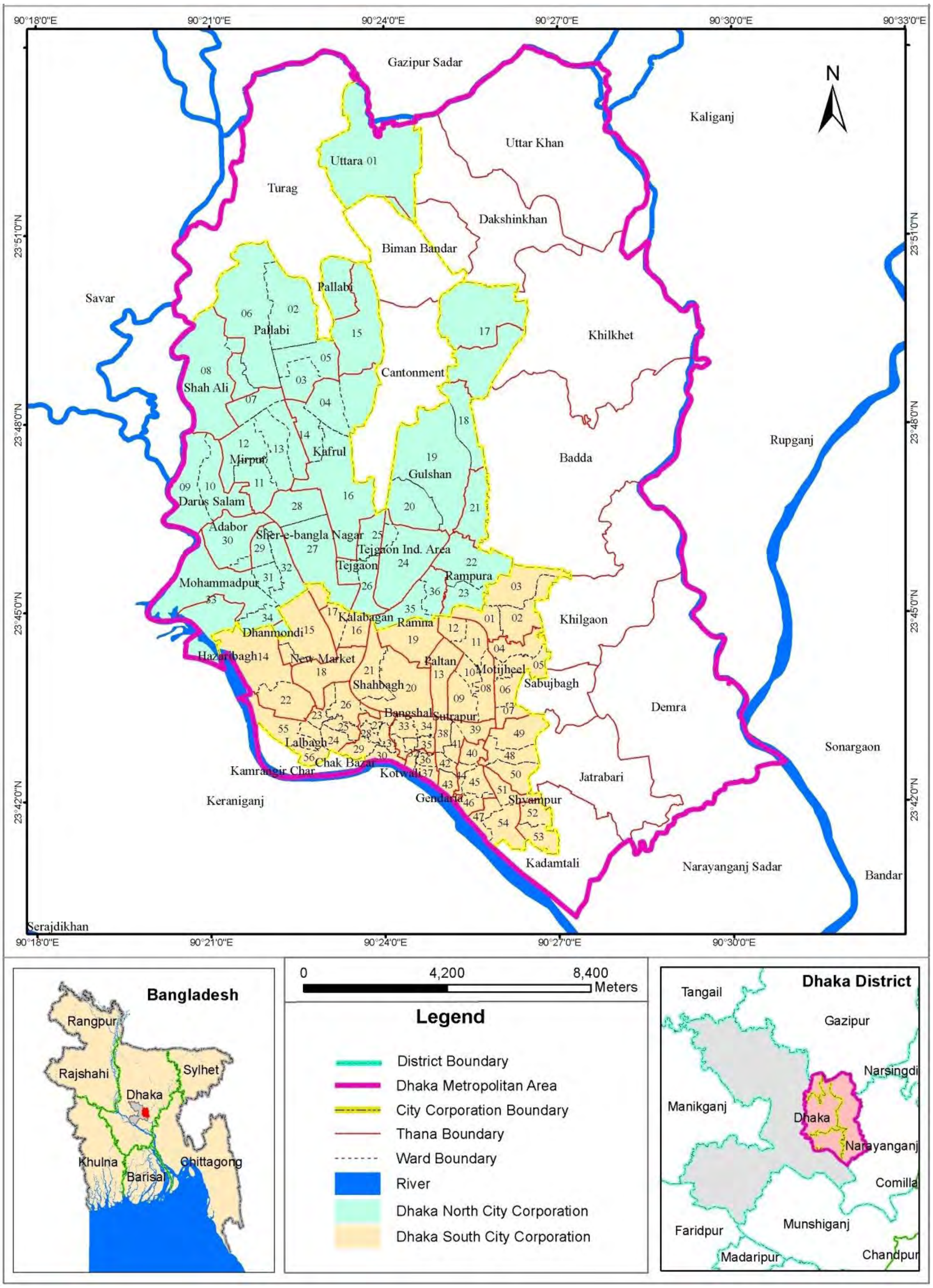


Figure-2.3: Organogram for each of the DNCC & the DSCC collected from Field Survey, 2014

Map-2.1: Location and Administrative Boundary of DNCC & DSCC



Source: Developed by Author, 2015

2.6.2 Current state of municipal solid waste (MSW) in Dhaka

Dhaka, the capital city of Bangladesh is facing serious problem with urban solid waste management. Alamgir & Ahsan estimated that waste generation rate is ranging from 0.325 to 0.485 kg/cap/day, while highest rate is 0.485 kg/cap/day in Dhaka City [24]. They also reported that about 78% solid waste is coming from residential sector and 20% from commercial sector, 1% from the institutional sector and rest from other sectors [24]. Rahman et al. estimated in Dhaka, 45 to 55% of the total waste (2,200 tonnes/day) is unmanaged waste (less than 4 m depth) and dumped in open space [27]. In another study it is estimated that 7,000 tonnes of MSW was generated daily in the Dhaka City in 2009, of which only 1200–1500 tonnes was disposed in the landfills and the rest left unattended or locally dumped [9]. **Photograph-2.2** compiles some snaps of MSW, captured at different primary dumping points in Dhaka city.

(a) Banglamotor in April, 2013

(b) Banani DOHS in August, 2014

(c) Banani Bazaar in August, 2014

(d) Uttara Sector 12 in December, 2014

Photograph-2.2 (a-d): Pictures showing MSW, captured during Field Survey at Different Secondary Collection Points in Dhaka City

In 2005, the JICA study team conducted waste generation source survey in dry and wet seasons to obtain the unit waste generation rate of domestic waste and business waste. The average waste generation rate from domestic source proved to be 0.34 kg/cap/day [10]. The total generation amount in Dhaka City stood at 3,200 t/d with the amount from fixed sources shared by domestic source and business source at 65% and 35% respectively as estimated by [10] in 2005.

High moisture content and low calorific value characterized the solid waste properties in Dhaka City as observed by [29]. Over time, municipal solid waste is not only increasing but the composition is also changing. The organic wastes are decreasing and the paper and plastics are increasing in the waste stream, indicating the growing preference for consumption of packaged food in recent years [29].

2.6.2.1 Moisture content

The moisture content analyzed by JICA ranges from 65% to 80% for the mixture of waste on average [10]. Yousuf & Rahman opined that higher moisture content indicates the possibility of the development of anaerobic conditions in the disposal site that causes obnoxious odors and quicker rotting [29]. The composting potential apart from the fraction of the organic wastes depends on the chemical characteristics such as the concentration of carbon (C) and nitrogen (N) and the consequent C/N ratio. The ideal C/N ratio is about 20:1 to 25:1. A ratio higher than 30:1 may slow down the composting process and a ratio lower than 15:1 may lead to loss of nitrogen causing neither growth nor multiplication of micro-organisms [35, 36]. BCSIR study estimated that the C/N ratio is 16:1 for residential waste and 39:1 for commercial waste, which indicates that the waste needs some C/N ratio balancing before executing composting process [61].

The combustion is expressed by the term calorific value of waste, which is a quantitative estimation of heat energy released by burning. The calorific value (Hu) of waste and moisture content can be ascertained by the relationship that calorific value decreases with the increment of moisture content. Higher calorific value indicates the combustion of waste with a lesser amount of auxiliary fuel support [10]. To facilitate self-combustion of waste it requires 5,024 kJ/kg of Hu and at least 6,280 kJ/kg of Hu for power generation as estimated by [29]. According to JICA, based on the value of the moisture contents, the lower calorific value is calculated at 2,303–3,559 kJ/kg which indicates that the waste in Dhaka does not sustain combustion [10].

2.6.2.2 Apparent bulk density

JICA Study [10] revealed that apparent bulk density ranges from 0.1 to 0.2 t/m^3 for domestic waste and 0.1 to 0.6 t/m^3 for business waste throughout the year. The average of apparent bulk density is 0.24 t/m^3. The survey results are shown in **Table-2.7**.

Table-2.7: Apparent Bulk Density of Waste in Dhaka City Corporation

<table>
<tr><th>Survey Time</th><th>Source category</th><th>Income Level</th><th>Bulk Density (t/m^3)</th><th>Average (t/m^3)</th></tr>
<tr><td rowspan="8">Dry Season</td><td rowspan="3">Domestic waste by income group</td><td>Upper group</td><td>0.14</td><td rowspan="8">0.24</td></tr>
<tr><td>Middle group</td><td>0.12</td></tr>
<tr><td>Lower group</td><td>0.10</td></tr>
<tr><td rowspan="4">Business waste</td><td>Restaurant</td><td>0.62</td></tr>
<tr><td>Shop, Hotel</td><td>0.19</td></tr>
<tr><td>Market</td><td>0.42</td></tr>
<tr><td>Public Facility</td><td>0.09</td></tr>
<tr><td colspan="2">Street waste</td><td>0.24</td></tr>
<tr><td rowspan="8">Wet Season</td><td rowspan="3">Domestic waste by income group</td><td>Upper group</td><td>0.13</td><td rowspan="8">0.23</td></tr>
<tr><td>Middle group</td><td>0.20</td></tr>
<tr><td>Lower group</td><td>0.11</td></tr>
<tr><td rowspan="4">Business waste</td><td>Restaurant</td><td>041</td></tr>
<tr><td>Shop, Hotel</td><td>0.22</td></tr>
<tr><td>Market</td><td>0.11</td></tr>
<tr><td>Public Facility</td><td>0.36</td></tr>
<tr><td colspan="2">Street waste</td><td>0.35</td></tr>
</table>

Source: Adapted from [10]

2.6.3 Waste Management Practice in DNCC & DSCC

The erstwhile Dhaka City Corporation had been working to improve the overall solid waste management of Dhaka city with the technical assistance of the Japan International Cooperation Agency (JICA) in 2000. A master plan on solid waste management titled *Clean Dhaka Master Plan* was formulated in 2005 and included a target year of 2015 to make the city of Dhaka clean [10]. The master plan stressed on public awareness raising, primary collection, secondary collection, transportation and final disposal as well as administration and financial management. For the implementation of Clean Dhaka Master Plan, a technical cooperation project consisting of the dispatch of experts started in February 2007 and completed in February 2011 implemented by then DCC and JICA Expert Team [62].

Both the DNCC and the DSCC collect municipal wastes which are accumulated in corporations' bins or containers. **Table-2.8** presents basic information of solid waste management at Dhaka North and Dhaka South City Corporations. From that table it can be seen in June 2012, total waste generation amount estimated for the DNCC was about 2186 t/day and for the DSCC was about 1938 t/day. The table also reveals that the DNCC was able to collect about 1100 tonnes of waste/day in June, 2012 whilst the waste collection capacity of the DSCC at that time was about 1400 t/day.

Table-2.8: Basic Information of Solid Waste Management at DNCC and DSCC

Items	DNCC	DSCC
Population (2011)	39,56,302	30,13,803
Geographical area (square kilometer)	75	42
Number of Zones	5	5
Number of Wards	36	57
Waste Generation Amount (June, 2012)	Approx. 2186 t/day	Approx. 1938 t/day
Waste Collection Amount (June, 2012)	Approx. 1100 t/day	Approx. 1400 t/day
Location of Existing Waste Disposal Site	Amin Bazar	Matuail
Area of Existing Waste Disposal Site	20 hectare	40 hectare
No. of Ward SWM Offices	7	10
Number of Waste management Officials (including drivers)	257	352
Workshop	At Dholpur	

Source: Adopted from WMD of DNCC and WMD of DSCC in December, 2015

2.6.3.1 Waste management department (WMD) of the DNCC and the DSCC

Each component of Dhaka's solid waste management system was implemented by separate government offices. Without an overlaying regulatory framework or unifying authority, harmonizing plans and operations proved challenging [53]. Therefore, recently a Waste Management Department has been formed in the light of the *Clean Dhaka Master Plan* to oversee waste operations. The Waste Management Department ultimately became responsible for solid waste management and is in charge of street and drain cleaning, carrying street and drain waste to dustbins/containers, and loading and unloading of waste to and from truck at places of dustbins/containers and disposal sites.

Establishment of Waste Management Department aims at integrated solid waste management by one department with a unified chain of commands. With coordinated annual operation plans and budgets, effective and efficient solid waste management can be achieved. With one department, integrated management throughout waste stream, from waste generation to final disposal can be realized [63]. Each of the Waste Management Departments of DNCC and DSCC comprise a predominant portion of field workers and very few officers for planning and administration at headquarters. **Figure-2.4** shows Organogram of the Waste Management Department at each of the Dhaka City Corporations (North & South).

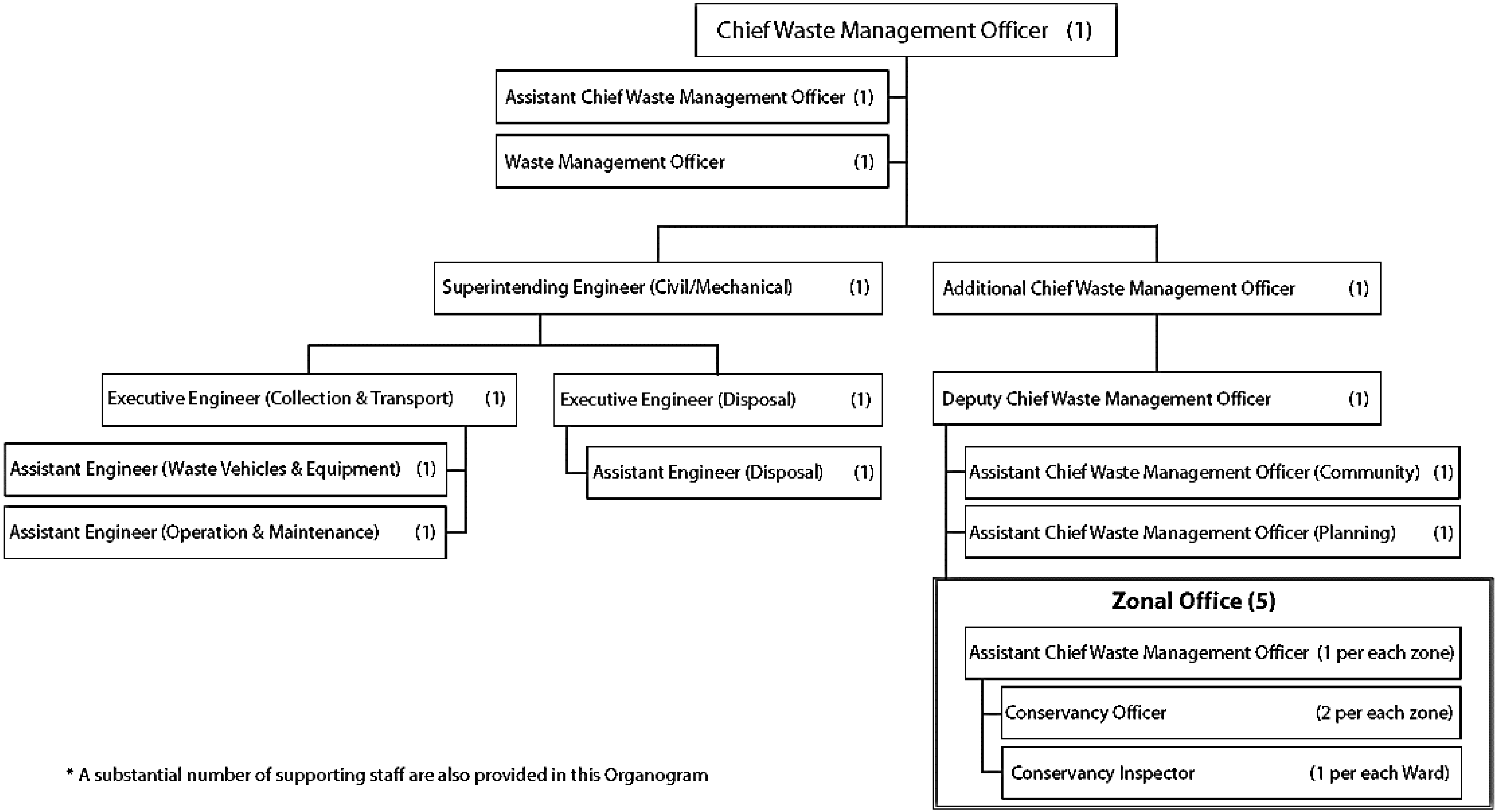


Figure-2.4: Organogram of the WMD at each of the Dhaka City Corporations (North & South) as observed during Field Survey (2015)

Each of the city corporations were divided into 5 Zones for zone wise collection and transportation of solid waste in Dhaka City. **Map-2.2** shows different waste collection zones of Dhaka city with existing landfill sites. Each of the zone has a zonal office consists of one Assistant Chief Waste Management Officer, two Conservancy Officers, one Conservancy Inspector for each ward, and two supporting staff. Apart from that waste cleaners and waste management drivers are distributed among the zonal offices and they work under the direct supervision of respective zonal office. **Figure-2.5** shows the organogram of waste management zonal offices at the DNCC and the DSCC.

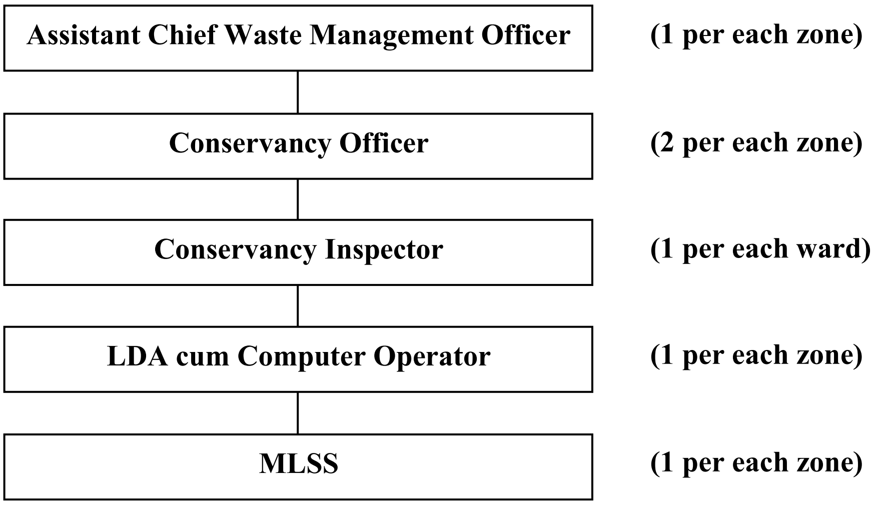
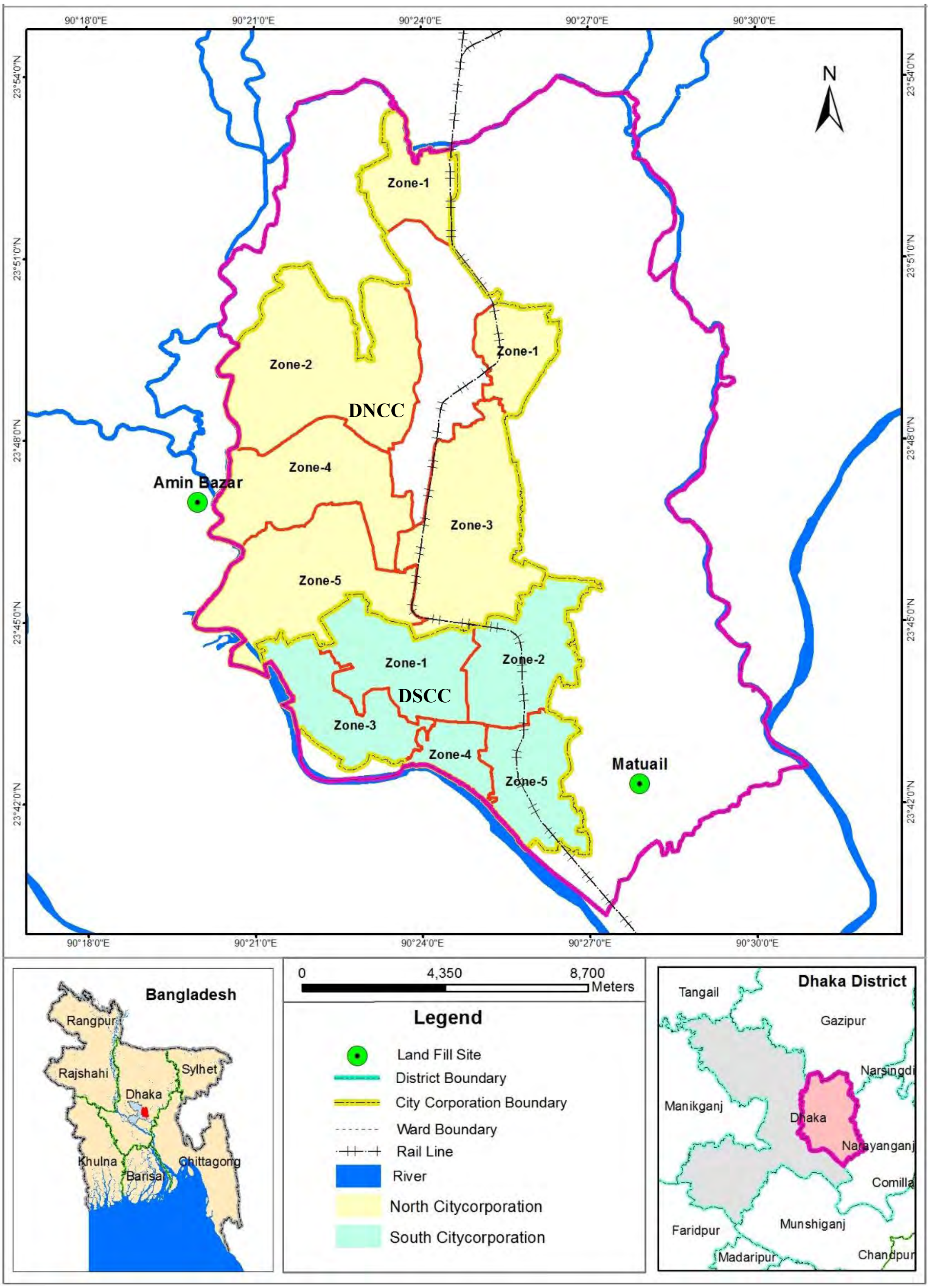


Figure-2.5: Organogram of each of the Zonal Offices under the WMD at Dhaka North & Dhaka South City Corporations as observed during Field Survey (2015)

In addition to this, **Section 50** of the Local Government (City Corporation) Act, 2009 (Amendment in 2011) reads that the corporation shall form a standing committee in its first meeting of the year or as early as possible, on some specific issues including waste management. Each of those committees shall consist of some members selected among the councilors of the corporation, where the Mayor shall be a member of each committee as ex-officio. Each committee shall function for a period of 2 years and 6 months, which shall be formed afresh just after the tenure. But till now (March, 2015) no such committee has been formed as no election was held in both DNCC and DSCC after the enactment of this act.

Map-2.2: Waste Collection Zones of Dhaka City with Existing Landfill Sites



Source: Developed by Author, 2015

After inception, following functions are going on under the Waste Management Department (WMD) of the DNCC and the DSCC:

- Ward conservancy activities
- Provide dustbins and other receptacles for accumulating the waste
- Giving permission to PCSP (Primary Collection Service Provider) for door to door waste collection from household by van services
- Skill development program for primary waste collectors
- Establishment of secondary transfer stations
- Development and management of sanitary landfill
- Manage Private, Community and NGO based waste management activities.
- Hospital waste management
- Environmental education activities
- Repairing and maintenance of vehicles and equipment used for waste collection
- Promote projects for Gas to Power and Compost from Waste

According to the city corporations, the success ascertained by the waste management department are [63]:

- Single chain of command for operation at field and landfill.
- Actual number of trips going to landfill has increased.
- Wastes dumped at landfill site is controlled in a scientific manner
- Bottom up budget preparation has started to practice

2.6.3.2 Collection of municipal solid waste

Like most of the cities around the world, in Dhaka waste collection consists of two parts, namely, primary collection and secondary collection. Both of these collection systems are illustrated in **Figure-2.6** and later described below.

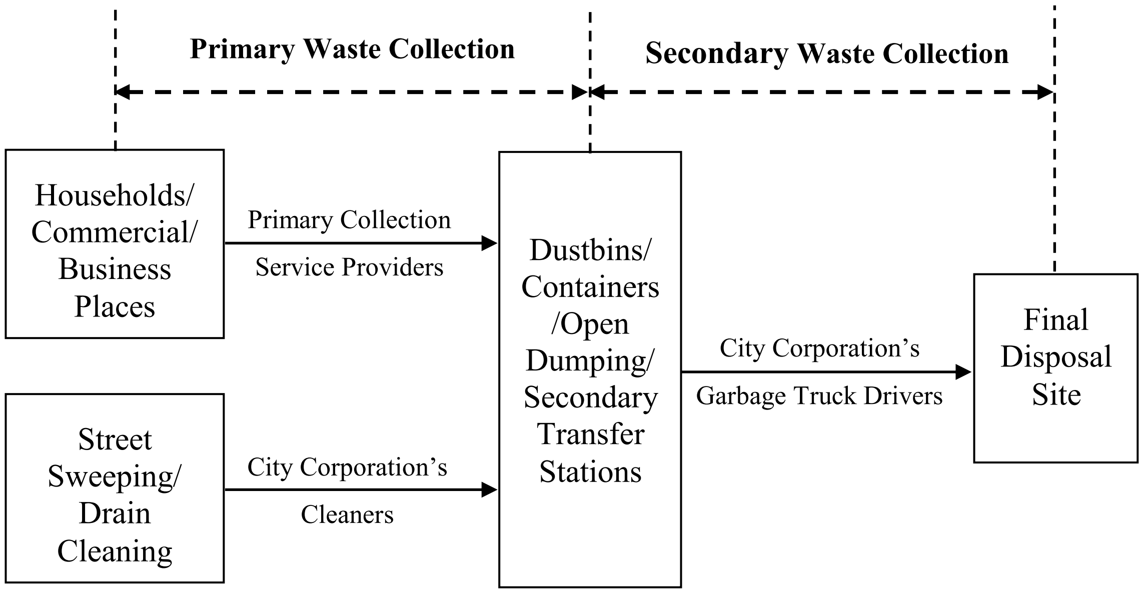


Figure-2.6: Waste Collection System of DNCC & DSCC, developed by Author after [10]

A. Primary collection and road/drain cleaning

Though residents are responsible for bringing their waste to secondary waste collection points, NGOs/CBOs/private sector provide the door-to-door primary collection services and transport the waste to nearby designated dumping points using rickshaw vans. **Photograph-2.3** shows Rickshaw Van is used for primary collection of MSW.

Photograph-2.3: Rickshaw Van is used for Primary Collection of Municipal Solid Waste was observed at Banani DOHS, Dhaka during Field Survey in August, 2014

NGOs/CBOs/private initiative in primary collection services are now (2015) prevalent in wide areas of Dhaka city. Every morning cleaners sweep main roads, alleys footpath and put together the whole waste in a common place. Then bring it to the designated point/dustbin/container by hand trolley. Every day a team contains 10 to 12 cleaners send to the different location of ward for cleaning open drain/deep drain/surface drain and storm sewerage line [65].

B. Secondary collection/transport

The city corporations are responsible for secondary waste collection to remove waste from its dustbins/containers, and transport the waste to final disposal sites. Field Survey found that all garbage of the DSCC is transported to Matuail landfill site while the DNCC uses Amin Bazar landfill site. **Photograph-2.4** shows different types of Garbage Trucks for secondary collection of municipal solid waste in Dhaka city.

Photograph-2.4: Different types of Garbage Trucks for Secondary Collection of MSW were observed at Zonal Office (Zone-4, Mirpur) of DNCC during Field Survey in December, 2014

For the secondary collection, the government procured 132 modern waste collection vehicles, including 40 compactors and 27 container carriers, to retrieve waste from the collection points and transport waste to the disposal site as stated in [53]. The Japanese government funded much of Dhaka's waste management fleet-the Environmental Grant

Aid Program (EGAP) donated 100 vehicles, valued at US$ 5 million [53]. The Japanese government also cancelled the debt incurred by Bangladesh for the purchase of 27 container carriers through the Debt Cancellation Fund [53]. Carrying capacity of different types of vehicles used for secondary waste collection vary from 1.5 tonne to 7 tonne depending on its size. But actually, open trucks and container carriers can carry in an average 80% of its rated capacity while compactor can carry 100% of its rated capacity (Field Survey, 2015). Usually the City Corporations used compactor and open trucks in the day time and container carriers at night. Because, it is convenient to upload the waste to compactors and trucks in broad daylight. On the other hand, container carrier needs comparatively more space for its movement, which can create traffic congestion in day time. Some photographs of those vehicles are shown in **Appendix-A**.

Efficiency of EGAP vehicles received under the grant of Japanese government was found 4.05 tonnes/trip while efficiency of other DNCC/DSCC vehicles was found 2.75 tonnes/trip as estimated by the city corporations [63]. **Figure-2.7** illustrates percentage of trips generated by different types of vehicles per day and **Figure-2.8** presents percentages of waste carried by different types of vehicles per day to Matuail and Amin Bazar landfills.

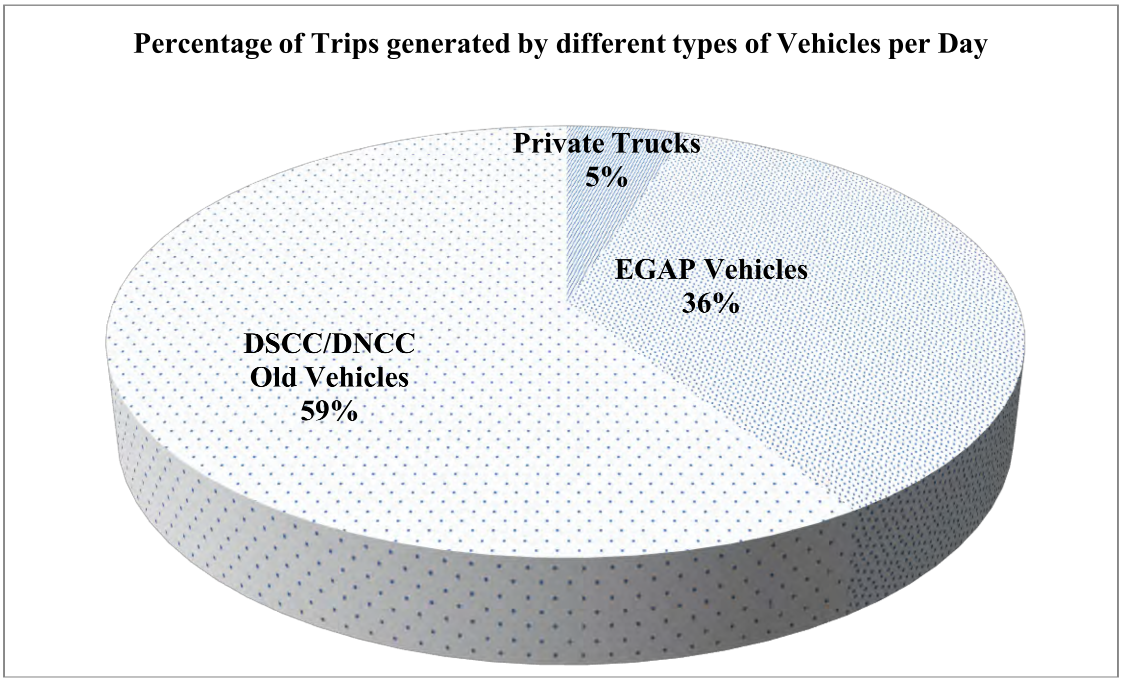


Figure-2.7: Percentage of Trips Generated by Different Types of Vehicles per Day to Matuail and Amin Bazar landfills adapted from [63]

Figure-2.7 reveals 59% of trips are generated by city corporations' old waste collection vehicles and 36% are by EGAP vehicles and 5% are by private trucks. **Figure-2.8** exhibits city corporations' old vehicles carry 47% of total waste collected per day, where private trucks carry 11% and EGAP vehicles carry 42% of daily collected waste.

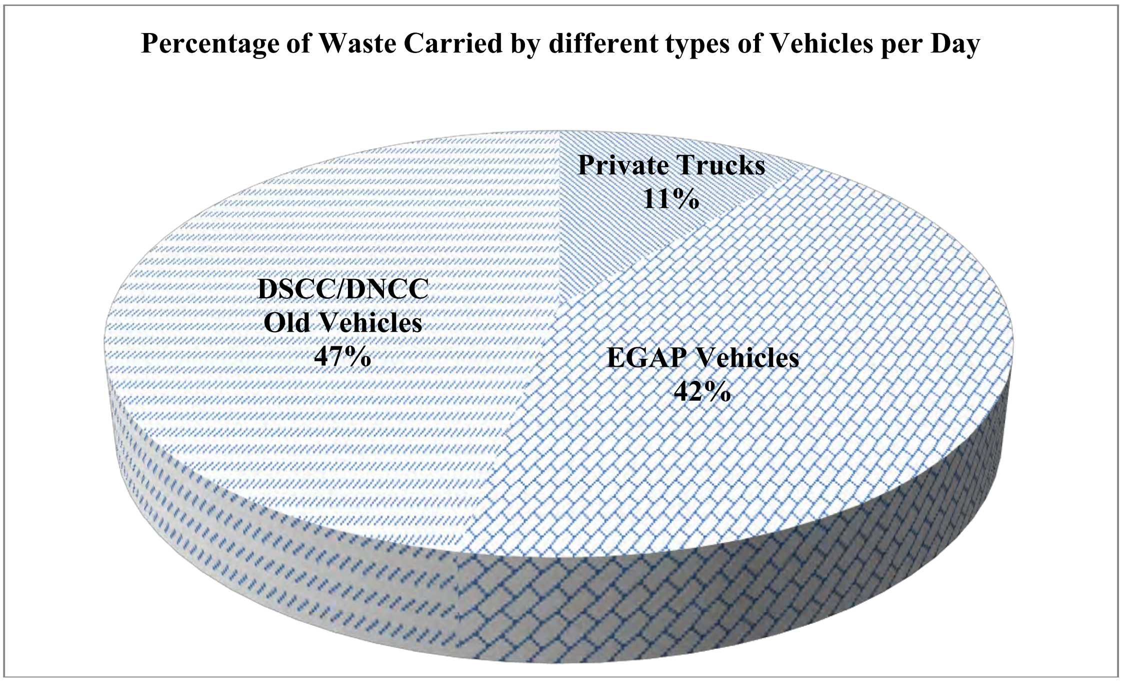


Figure-2.8: Percentage of Waste Carried by Different Types of Vehicles per day to Matuail and Amin Bazar landfills adapted from [63]

2.6.3.3 Zone wise waste storage facilities of DNCC & DSCC

According to Islam, et al. [64], total number of waste storage facilities is 1,089 units, which include 341 units of Dustbins, 346 units of Containers, 402 Temporary Collection Points (TCP) as summarized in **Table-2.9**.

Table-2.9: Zone wise Dustbins and Waste Containers of DNCC & DSCC

Zone	Dustbin	Container	TCP
DNCC Zone-1 (Previous DCC Zone-10)*	-	-	6
DNCC Zone-2 (Previous DCC Zone-8)	3	46	46
DNCC Zone-3 (Previous DCC Zone-9)	3	0	2
DNCC Zone-4 (Previous DCC Zone-7)	10	16	22
DNCC Zone-5 (Previous DCC Zone-6)	40	33	62
DSCC Zone-1 (Previous DCC Zone-5)	41	63	51
DSCC Zone-2 (Previous DCC Zone-4)	29	77	57
DSCC Zone-3 (Previous DCC Zone-3)	73	20	45
DSCC Zone-4 (Previous DCC Zone-2)	91	62	26
DSCC Zone-5 (Previous DCC Zone-1)	51	29	91
Total	**341**	**346**	**408**

Source: Adapted from *Field Survey, 2015 and [64]

It is observed during field survey in December, 2015, both of the City Corporations are planning to develop some Secondary Transfer Stations (STS) at each of the City Corporation Ward. The STSs is an environment-friendly and enclosed facility where the collected MSW will be preserved temporarily before being shifted to the designated landfills. About 185 to 278 sq. m of land is required to develop each of this facility. [Field Survey, 2015]. The number of the STS at each Ward will be depended on the volume of the waste generated in that ward and also on the availability of land for construction of STS. After developing all of these STSs, the necessity of the existing dustbin, containers and TCPs will be vanished.

2.6.3.4 Manpower allocation to collection and transport sector

In Dhaka city, about 7961 cleaners (Field Survey, 2015) are employed for street sweeping and collection of waste found in places other than dustbin, road side, open spaces, ditches etc. by hand trolley [57]. For collection of accumulated waste in 180 containers within 75 sq. km. area, the DNCC has 115 demountable container carrier trucks, where the DSCC has 235 demountable container carrier trucks to collect accumulated waste in 270 containers from its 42 sq. km. area (Field Survey, 2015). Islam [57] revealed that 242 open trucks had been used by DCC (now DNCC and

DSCC) to collect waste from municipal bins at different locations. Manpower allocation to collection and transportation in DNCC and DSCC is summarized in **Table-2.10**.

Table-2.10: Number of Cleaners and Drivers in DNCC & DSCC

Workers category	Number	
	DNCC	DSCC
Cleaner	3586	5300
Waste Management Drivers	108	183
Central Garage	1	1
Numbers of Waste carrying containers	180	270
Number of Waste Collection Trucks	115	235

Source: Information collected by author from the WMD, DNCC and the WMD, DSCC

2.6.3.5 Disposal of waste

A. Dumping of waste at land fill

A study conducted by [3] in 2005 revealed that DCC disposed solid wastes adopting crude dumping methods and thereby, creates environmental hazards and health risks. Their study also found that dumped solid wastes were dressed irregularly by pay loaders, excavator, tire dozer, chain dozer etc. [3]. Most of solid waste was disposed of at landfill sites without any intermediate treatment in Dhaka as reported by JICA [10] in 2005. **Photograph-2.5** shows unsanitary crude dumping of municipal solid waste done previously by DCC.

(a) Diabari Moar, Dhaka in April 2013

(b) Kachukhet, Dhaka in April 2013

Photograph-2.5: Unsanitary Crude Dumping of MSW by DCC to Fill up Low-lying Land was observed during Field Survey

In parallel with the technical cooperation activities, the Government of Japan supported other SWM activities in DCC including the improvement and expansion of Matuail landfill site and the construction of Amin Bazar landfill site under the Japan Debt Cancellation Fund (JDCF) as reported by [62]. According to JICA [10], in 2005 DCC used three landfill sites, namely, Matuail, Beri Band (Embankment) and Uttara. Hai & Ali found six dumping sites (1) Kulsi, (2) Chalkbari-Mirpur, (3) Gabtoli-Mirpur, (4) Lalbagh Shosan Ghat, (5) Mugdapara and (6) Jatrabari of DCC had already been abandoned after filling to their capacities [3]. After bifurcation, all garbage of DSCC is transported to Matuail landfill site while DNCC uses Amin Bazar landfill site for waste disposal (Field Survey, 2014).

As stated about Matuail Landfill site by [29], major sanitary landfill components introduced under the project were the leachate collection and gas venting systems, surface drainage improvement, systematic operation of waste disposal facilities by daily covering, slope reformation, working roads, weighbridge operation, and vehicle washing facilities. A semi-aerobic landfill system was adopted to reduce the polluting load on the environment and to speed up the stabilization of the disposed waste. A perforated pipe network for leachate collection and gas venting was installed for the proper collection of the leachate and the provision of an air supply system [29]. Same sorts of facilities were found in the Amin bazar landfill site during the field survey (2013). **Figure-2.9** illustrates layout plan of gas venting system of Matuail landfill site.

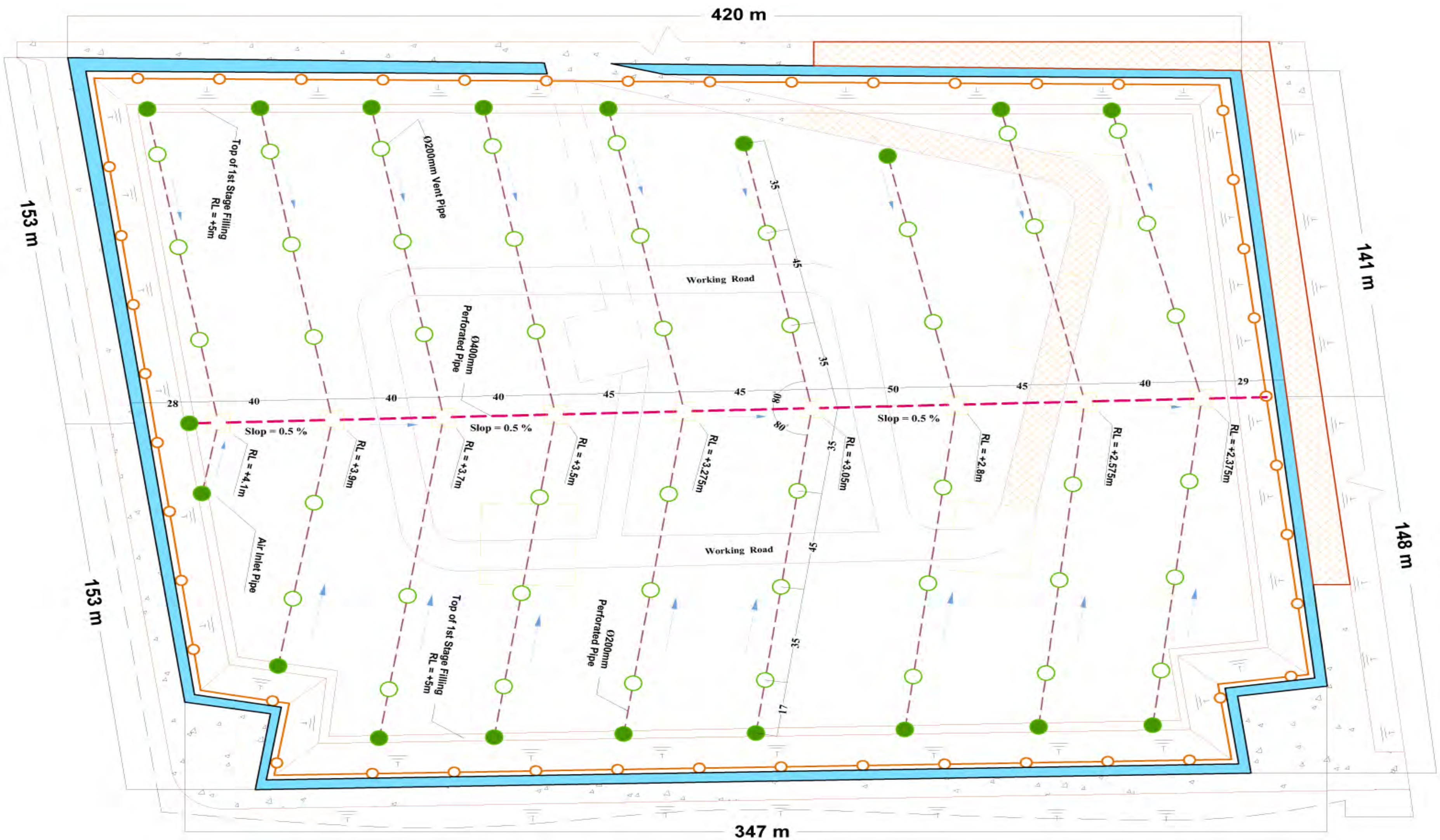


Figure-2.9: Layout Plan of Gas Venting System of Matuail Landfill Site Collected From WMD of DSCC

Though Matuail and Amin Bazar landfill sites have modern waste management facilities, those cannot be classified as sanitary landfill but controlled landfill. The dozer, chain dozer, scraper are being used to spread the waste regularly, hence waste pickers salvage reusable materials from those dumping site. **Photograph-2.6 (a, b)** shows the worn-out situation of two permanent dumping stations in Dhaka.

(a) Matuail, Dhaka in April 2013 (b) Aminbazaar, Dhaka in April 2013

Photograph-2.6 (a, b): Worn-out Situation of two Permanent Dumping Stations in Dhaka City was observed during Field Survey

Incoming waste amount to disposal sites

According to the DNCC official websites, total 450 trips were generated to Matuail disposal site during September, 2012 where at the same time, 245 trips were generated to the Amin Bazar disposal site [63]. **Figure-2.10** illustrates number of trips generated per day to Matuail and Amin Bazar disposal sites.

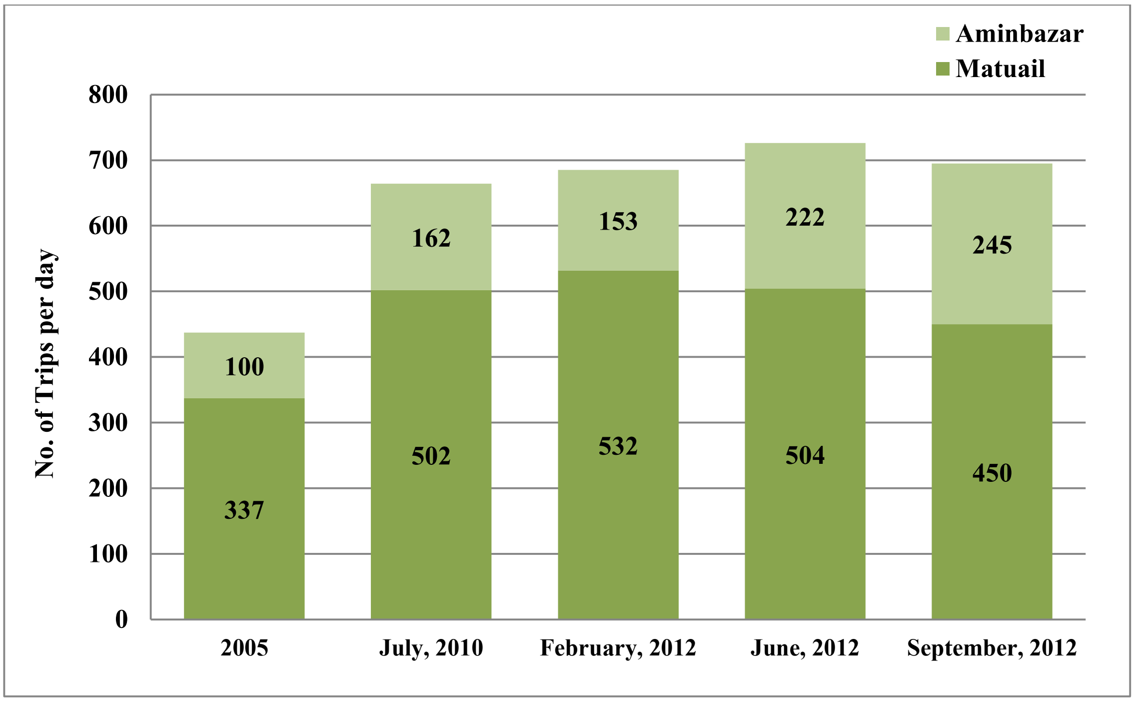


Figure-2.10: Number of Trips Generated per day to Disposal Sites adapted from [63]

The city corporation also reveals that incoming waste amount to Matuail disposal site was 1352 tonnes/day during September, 2012, when Amin Bazar received 1034 tonnes of waste per day [63]. **Figure-2.11** shows incoming waste amount (tonne/day) to Matuail and Amin Bazar disposal sites.

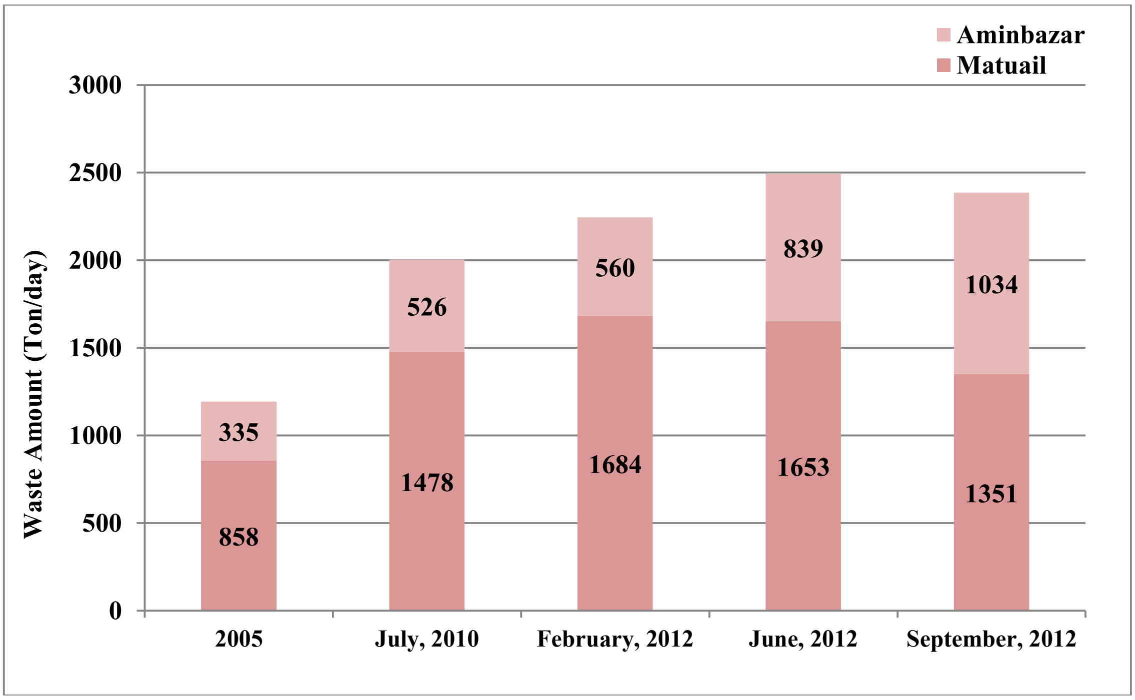


Figure-2.11: Incoming Waste Amount (t/day) to Disposal Sites adapted from [63]

Discrepancy of information regarding incoming waste amount to the disposal was found in different study. JICA survey results in 2005 showed that the total incoming waste to the disposal sites varied from 970 t/d in dry season to 1,420 t/d in wet seasons [10] but **Figure-2.9** adapted from the official website of DNCC reveals total incoming waste amount to the disposal sites was 1193 t/d [63]. The official website of DNCC also has difference in the information of incoming waste amount in June, 2012. According to the **Table-2.6**, DNCC was able to collect about 1100 tonnes of waste/day in June, 2012 whilst at that time DSCC collected about 1400 tonnes of waste/day. But **Figure-2.9** shows in June, 2012 incoming waste amount to the Matuail landfill site (DSCC) was1653 tonnes/day where to the Amin Bazar landfill site (DNCC) it was 839 tonnes/day. This difference of information indicates weak data management by waste management department of the city corporations.

Operation and management of landfill site

The operation of these landfill sites has been carried out in a systematic manner where wastes are disposed of in layers, compacted and covered by a layer of matured waste at the end of each day's operation. In Matuail landfill site, mature decomposed waste (3 or more years old) is used as a cover material with a thickness of 30–50 cm to make the operation economical as reported by [29]. For proper data management of the incoming wastes and for controlling unauthorized dumping, a weigh bridge operation has been employed in each of the landfill sites. The working roads are being constructed on the waste using construction debris to facilitate the movement of the waste transporting trucks to go up and dispose wastes. Periodic monitoring of the environmental parameters of the ground and surface water, leachate quality, and landfill gas was introduced as part of the operational measures of the sanitary landfill. Under this semi-aerobic system, the life-time of the landfill is estimated to be 20 years at the present rate of incoming waste of around 1700 tonnes/day [29]. The mentionable facilities of Amin Bazar and Matuail landfill sites are as follows:

- Weigh Bridge and Necessary data base system.
- Vehicle wash facilities.
- Office and conference room.
- Ansar's Barrack.
- Waste water treatment facilities (only in Matuail Landfill)

- Vehicle/spare parts maintenance garage.
- Gas vent pipe.
- Heavy vehicle/spare parts, like: Bulldozer, Excavator and Tyre dozer.

Matuail landfill is well managed and operated as a whole despite the fact that the most of LMU (landfill management unit) staff are deputed or temporary employed. In Amin Bazar landfill site, while LMU has been organized, staffing is quite insufficient and landfill operation is carried out without a site manager and any specific operation plan [62]. The management team comprises managers, reception and control staff, dumping platform instructors, heavy equipment operators, maintenance staff, and guards. The functions of the management unit are to develop the disposal plan, maintain the daily operation records, and manage the heavy equipment operation and daily cover application [29]. Both of these landfills actually operated three shifts per day with these manpower. **Table-2.11** presents the number of staff working at landfill management unit of each landfill sites.

Table-2.11: Staffing of Landfill Management Unit

Designation	Number of Staff	
	Amin Bazar	Matuail
Executive Engineer (Civil)	01	01
Assistant Engineer (Civil)	01	01
Sub-assistant Engineer (Civil)	01	02
Sub-assistant Engineer (Mechanical)	01	01
Sub-assistant Engineer (Electrical)	01	01
UDA cum Accountant	03	03
Office Assistant cum Computer Operator	07	07
Waste Managment Inspector	03	03
Assistant Mechanic	01	02
Assistant Store Keeper	-	01
Pump Operator	-	02
Electrician	02	02
Mechine Operator	09	12
Helper	09	12
MLSS	02	02
Total	**41**	**52**

Source: Information collected by author from the WMD, DNCC and the WMD, DSCC

Waste management workshop

In the Clean Dhaka Master Plan. JICA suggested that the city corporation must own a workshop to repair and maintenance of vehicles and equipment used for waste collection to conduct the waste management activities smoothly. One workshop (at Dhalpur) has been set up for two city corporations with training room and spare parts under Japan treasury coverage. **Table-2.12** shows the staffing of the waste management workshop.

Table-2.12: Staffing of the Waste Management Workshop

Title	Number of Approved Persons
Executive Engineer (Mechanical)	01
UDA cum Accountant	01
Office Assistant cum Computer Operator	01
M.L.S.S	01
Garbage Collection and Transport Assistance/Spare Parts Purchase Section	
Assistant Engineer (Mechanical)	01
Sub-assistant Engineer (Mechanical)	01
Office Assistant cum Computer Operator	01
Store Keeper	01
Assistant Store keeper	01
M.L.S.S	01
Garbage Collection and Transport Assistance/Spare Parts Conducting and Maintenance Section	
Assistant Engineer (Mechanical)	01
Sub-assistant Engineer (Mechanical)	01
Transport Supervisor	01
Office Assistant cum Computer Operator	01
Main Mechanic	01
Driver (Heavy)	108
Assistant Store Keeper	01
Assistant Mechanic	05
M.L.S.S	

Source: Information collected by author from the WMD, DNCC and the WMD, DSCC

B. Organic diversion

Chowdhury, et al. [31] observed, only a small portion of Dhaka's organic waste is diverted before being transported to the city' landfills or deposited in open spaces. However, one small-scale, private composting company is currently (2014) collecting (for a fee) and processing approximately 100 metric tonnes of organic waste per day, and selling the compost to local farmers [31]. Dhaka has preliminary plans to develop a larger Integrated Resource Recovery Center at one of the city's landfills to process waste into compost and to generate electricity using landfill gas as reported by [31].

C. Recycling

According to [31], Dhaka has historically relied on the informal recycling sector (e.g., waste pickers, of whom there are an estimated 12,000) for the recovery of non-organic materials. In an effort to recover more recyclable materials, the city launched a source separation pilot program in 2012 [31].

2.6.4 Waste Management Costs

For cost-recovery projects, such as land development, sanitation and solid waste management, the central government extends external loan proceeds under subsidiary loan agreements [66]. In addition to that DNCC and DSCC charge conservancy tax of 2% based on property's annual rental value. There is always negative correlation between income and expenditure. The expenditure of SWM is 52.87% more than the income [57]. JICA study revealed in 2005 that the cost for landfill shares only 1.5% of total expenditure. The final disposal is paid very little attention by DCC administration, which is apparent from its very poor budget and manpower allocation [10].

The sum of O&M Cost until 2015/16 is estimated by JICA at Tk 6,058 million [10]. The unit cost is assumed to decrease continuously in spite of growing amount of waste collection as summarized in the **Table-2.13**.

Table-2.13: SWM O&M Cost per Tonne

Item	Unit	Actual	Master Plan			
		2004/05	2005/06	2010/11	2015/16	Average
SWM O&M Cost	Tk in million	487	509	532	594	-
Collected Solid Waste Amount	1000 tonne/year	511	548	749	1030	-
Tk/Tonne		953	929	710	577	703

Source: Adapted from [10], [Estimated by the JICA Study Team in 2005 based on various information and data of DCC]

Table-2.13 shows the average O&M costing of MSW is estimated as Tk 703 for per tonne of waste. Again, the average of apparent bulk density was found by JICA as 0.24 t/m^3 (presented in **Table-2.7**) which indicates 4.17 m^3 space is required for storing 1 tonne of waste with the given compaction system. From this estimation, it can be said that Tk 703 is required for operation and management of 4.17 m^3 of waste or approximately Tk 169 for per m^3 of waste.

According to the revised budget of DNCC in the fiscal year 2013-14, the city corporation paid Tk 22 million for landfill operation, maintenance and development purpose during the fiscal year 2013-14 (Field Survey, 2015). In this year, DNCC actually expended Tk 58.29 for per tonne (or around Tk. 13.98 for per m^3) of waste in that fiscal year as Figure-2.3 shows the average incoming waste is 1351 tonne per day. On the other hand, DSCC spent Tk 29.1 million for landfill operation, maintenance and development purpose during the fiscal year 2013-14 (Field Survey, 2015). It is apparent that Tk. 59 was expended for per tonne (or around Tk. 14.15 for per m^3) of waste in that fiscal year as Figure-2.3 shows the average incoming waste is 1351 tonne per day. Both the city corporations have spent very little of actual cost estimated by JICA [10], which clearly indicates the incompetence of both city corporations of managing MSW in terms of financial, infrastructural, manpower, and managerial capability. The situation worsen the ambient of the city by increasing environmental pollution that ultimately escalate the health risk of the city dwellers.

2.6.5 Participation of Private Sector in Solid Waste Management in Dhaka

As reported by [53], the JICA Master Plan manages municipal solid waste throughout its lifecycle and encourages public and private sector participation as cross-cutting themes. A National 3R (Reduce, Reuse, Recycle) Strategy was passed in 2010 establishing a 3R Wing at the Ministry of Environment and Forests to implement waste prevention activities, and an inter-ministerial committee to coordinate activities across ministries [53]. To stimulate private sector investment in waste recycling and treatment plants, the strategy calls for the government to provide tax holidays, soft loans, and land to site the facilities [53].

2.6.5.1 Private solid waste management using PPP

Private solid waste management in Dhaka City is approaching for Public Private Participation (PPP). Dhaka North City Corporation fully privatizes its conservancy works in Uttara, Gulshan, Banani, Baridhara, Mohakhali and Tejgaon areas. These areas cover the northern part of the city, like zone 1, 3 the private parties are handling this works very smoothly [65]. The Urban Planning Department introduced this project for the first time. Then the project was handed over to the Waste Management Department of DNCC. The Private parties do the street sweeping, Drain cleaning, Door-to-door waste collection, dustbin cleaning, waste transportation, and final disposal [65].

2.6.5.2 Composting project in Dhaka using PPP

A BMDF study [52] found that in 2012 Waste Concern (an award-winning Bangladesh Social Business Enterprise for waste recycling, leading to environmental improvement, renewable energy, and employment generation for the urban poor) was operating a large scale compost plant in Dhaka, Bangladesh, using PPP. The organization submitted the waste composting CDM project for approval to Designated National Authority in March, 2006 and the project was approved in July 2006. Subsequently, a 15 year concession agreement was signed with Dhaka City Corporation (DCC) in 2007 [52]. The delay in signing the PPP contract was due to lack of guideline of GoB on PPP for waste sector. The project started operation in the last quarter of 2008. This is the first concession agreement in solid waste recycling in Bangladesh. Under this project Waste Concern can collect up to 700 tonnes/day of organic waste (not mixed, only vegetable waste) incrementally starting from 100 tonnes/day [52]. Land for composting is arranged by the Waste Concern along with collection of organic waste. No waste collection fee or tipping charge is provided to Waste Concern by the municipality. Moreover, if Waste Concern fails to collect waste there is a penalty clause of Tk 250/tonne for non-collection of waste. All the vegetable markets are under the jurisdiction of Waste Concern for collection of waste [52]. However, for the first plant of 100 tonnes per day capacity, DCC has allowed Waste Concern to collect waste from six vegetable markets of Dhaka and a daily monitoring is done by the municipality on amount of waste collected by Waste Concern as stated in [52]. This CDM project aimed to earn Certified Emission Reduction (CER) credit by reducing carbon emission at landfill site. But in recent years, the credit rate has been dropped dramatically, which made the project no more feasible. Eventually, Waste Concern breached the contract in February, 2015.

2.6.5.3 Waste to energy project in Dhaka using BOO

BMDF study [52] revealed that LGD under MoLGRD&C had signed an agreement with SRL Via Priore Berengario of Italy to install a 10 MW power plant in which primary fuel would be the waste generated in Dhaka City Corporation (DCC). The power plant would use 1,000 tonnes of waste per day generated in DCC. The project would be implemented using Build Own Operate (BOO) system [52]. Under that project, DCC would provide the company with land at the landfill site and purchase electricity from the plant at a price agreed by the parties. The selected company would have to sign two separate agreements with DCC and Power Division, one for waste management and another for buying electricity [52]. The project has not been implemented till December, 2015.

2.6.6 Clean development mechanism (CDM) approval for treatment of waste

The Matuail landfill received Clean Development Mechanism (CDM) approval for methane recovery and utilization, and was projected to reduce 99,000 tonnes of CO_2-equivalent per year, directly and indirectly, in 2012. The city's composting facility was the first ever to receive CDM approval, and was projected to reduce 177,000 tonnes of CO_2-equivalent per year upon completion. The facility is also expected to create up to 1,000 new jobs [53]. Both CDM projects were financed by a Dutch corporation as stated by CCAP [53] and reportedly the project is in progress till December, 2015.

2.6.7 Awareness raising campaign

According to [53], the community-based approach to waste collection engaged residents to expand and improve services and improved the working conditions of service providers, thereby reducing occupational health hazards. Increased rates of collection and disposal have improved water and air quality, and expansion of the solid waste management system created opportunities for employment [53]. Following awareness building activities are done by the city corporations as reported by DNCC [63]:

1. Community meeting at ward level,
2. Conduct training program for community people with a view to developing the waste management system at their local community,
3. Arrange programs such as, rally and campaigning, distribution of leaflet and sticker, organize cultural program among different community,
4. Conduct environmental education program, and model school program to increase the awareness about environment among the student at primary level,
5. Publish quarterly newsletter.

2.6.8 Drawbacks of WMD in waste management

According to the city corporations [63] major drawbacks of waste management are:

- Manpower shortage in many layers of WMD, especially in management and technical positions.
- Shortage of manpower in zonal level hampers extension of modern waste management systems including separation of waste at source and community based waste management.
- Insufficient infrastructure facilities at headquarter and some zonal offices
- Lack of integrated effort of the related departments inside city corporations
- Lack of awareness of the residents (poor environmental education)
- Insufficient regulations about waste management.
- Weak enforcement of existing waste management related laws.

2.7 Conclusions

Municipal Solid Waste Management is a complex system considering its inclusion of various stakeholders from waste generation to management end. Apart from that, a number of technical issues are correlated with the waste management system. Reportedly, in Bangladesh the waste generation rate is increasing due to rapid urbanization. The increasing amount of waste raises the demand of land for landfilling and also increases the emission of GHG. In this chapter an overall waste scenario in Bangladesh has been presented. Simultaneously, a descriptive study on MSW management system of Dhaka is narrated in details to assess the practical experience of waste management by urban local body. Dhaka, the largest and capital city of Bangladesh has been selected for its importance in national context as well as its ill repute in the world in waste management context. While induction, acceptance, managing capacity, organizational strength, cost of each segment of supply chain must be considered for sustainability and viability of the proposed technology. This chapter depicts the supply chain of solid waste management system of Dhaka city which is necessary to establish the proposed conversion technique.

CHAPTER-3: CONCEPTUAL FRAMEWORK

CHAPTER-3: CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter has been structured with literatures to review the science underpinning the land filling technology. A number of publications such as books, reports, scientific journals published by key organizations and individuals across the world have been reviewed carefully. BUET library and internet were found as effective source of secondary information. These reviews, thus, intend to provide a resource of technical information regarding land filling to conduct the research on due course.

3.2 Solidification and Stabilization

Solidification is the process of producing from liquid, sludge, or loose solids a more or less monolithic structure having some integrity. Occasionally, solidification may refer to the process that results in a soil-like material rather than a monolithic structure. Solidification does not necessarily reduce leaching of hazardous materials. However, when a waste is solidified, its mass and structure are altered, decreasing migration of solutions within the mass [67]. Stabilization generally refers to a purposeful chemical reaction that has been carried out to make waste constituents less leachable. This is accomplished by chemically immobilizing hazardous materials or reducing their solubility by a chemical reaction [67].

3.3 Land filling: Science and Engineering Aspects

'Landfill' is the term to describe the physical facilities used for the disposal of solid wastes and solid waste residuals in the surface soils of the earth [68]. According to the World Bank [69], there are three general ways of forming a landfill- 'trench', 'ramp' or 'area' methods depending on local topography and landscape. A *trench landfill* is usually located in an area of flat land where the soil has been excavated and waste is deposited into the void. The stockpiled soil is then used to cover the waste [69].

A *ramp landfill* is defined by the World Bank [69], is usually where a low bank is present, or has been created, waste is deposited along one side, and soil excavated from the front of the face of the ramp is used to cover the waste. The World Bank also marked the *area landfill* is the most common type of landfill that may be constructed in a natural depression, in excavated mineral workings or built above the ground into a hill [69]. Moreover, the World Bank suggested that the landfill design must include access to and around the site, as well as the construction of waste reception facilities [69].

3.3.1 Sanitary landfill

All definitions of "sanitary landfill" call for the isolation of the land filled wastes from the environment until the wastes are rendered innocuous through the biological, chemical, and physical processes of nature. Major differences between the various definitions are in the degree of isolation and means of accomplishing it, as well as in the requirements for monitoring and closing the fill and in maintaining the fill after its active life [34].

UNEP [34] also observed that sanitary landfilling, which is the controlled disposal of waste on the land, is well suited to developing countries as a means of managing the disposal of wastes because of the flexibility and relative simplicity of the technology. Sanitary landfilling controls the exposure of the environment and humans to the detrimental effects of solid wastes placed on the land. Through sanitary landfilling, disposal is accomplished in a way such that contact between wastes and the environment is significantly reduced, and wastes are concentrated in a well-defined area [34]. The practice of sanitary landfilling, however, should be adopted in accordance with other modern waste management strategies that emphasize waste reduction, recycling, and sustainable development [34].

As stated in [34], in order to be designated a sanitary landfill, a disposal site must meet the following three general but basic conditions: 1) compaction of the wastes, 2) daily covering of the wastes (with soil or other material) to remove them from the influence of the outside environment, and 3) control and prevention of negative impacts on the public health and on the environment (e.g., odors, contaminated water supplies, etc.). However, meeting all specific aspects may be technologically and economically impractical in many developing countries. Therefore, the short-term goal should be to meet the more important aspects to the extent possible under the existing set of technical and financial circumstances. The long-term goal should be to eventually meet all of the specific aspects of the design and operating conditions [34].

According to [34], the basic design and operating aspects of a sanitary landfill in terms of routes of impact outside the fill and of meeting the three basic conditions are illustrated in **Figure-3.1**.

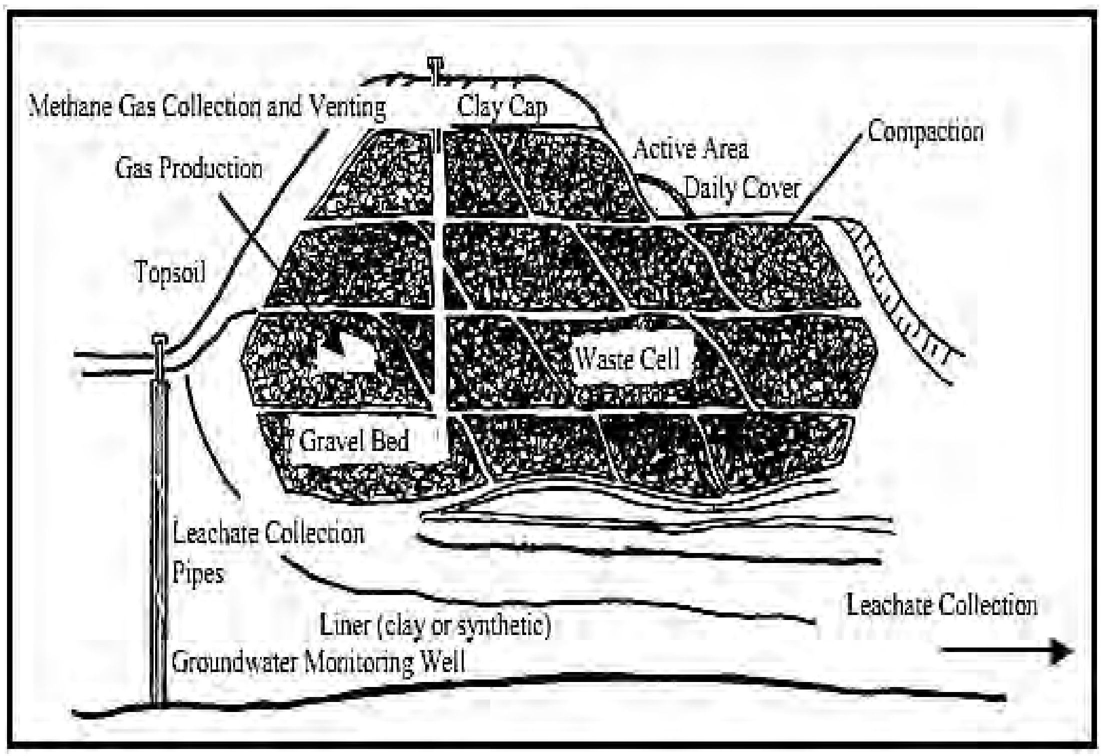


Figure-3.1: Schematic Diagram of Basic Aspects of a Sanitary Landfill adapted from [34]

3.3.1.1 Planning for a landfill

UNEP explored that planning involves the collection of information on type, amount, generation rate, and characteristics of the wastes to be accepted for landfilling [34]. Acquisition of this information is a prerequisite to rational design and efficient and effective development of a landfill. At the same time, physical, chemical, and biological processes in a landfill site must be considered before planning [34]. Moreover, UNEP observed, of the three types, the biological processes probably are the most significant and strongly influenced by the physical and chemical processes [34].

A. Physical process

In general, significant physical reactions in the fill are in one of three very broad forms: compression (compaction), dissolution, and sorption [34]. Compaction is an ongoing phenomenon that begins with compression and size reduction of particles by the compacting machinery and continues after the wastes are in place. The continuing compression is due to the weight of the wastes and that of the soil cover (burden). Sifting of soil and other fines is responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition) [34]. Of the physical phenomena, adsorption is more important because it brings about the immobilization of living and non-living substances that could pose a problem if allowed to reach the external environment. It could play an important part in the containment of viruses and pathogens and of some chemical compounds [34].

B. Chemical process

UNEP monitored that oxidation is one of the two major forms of chemical reaction in a fill [34]. The second major form of chemical reaction includes the reactions that are due to the presence of organic acids and carbon dioxide (CO_2) synthesized in the biological processes and dissolved in water (H_2O). Reactions involving organic acids and dissolved CO_2 are typical acid-metal reactions. Products of these reactions are largely the metallic ions and salts in the liquid contents of the fill [34].

C. Biological process

As reported in UNEP, the importance of biological reactions in a fill is due to the following two results of the reactions [34]:

1. The organic fraction is rendered biologically stable and, as such, no longer constitutes a potential source of nuisances.
2. The conversion of a sizeable portion of the carbonaceous and proteinaceous materials into gas substantially reduces the mass and volume of the organic fraction.

The wide variety of fill components that can be broken down biologically constitute the biodegradable organic fraction of MSW. This fraction includes the garbage fraction, paper and paper products, and "natural fibers" (fibrous material of plant or animal origin). Biological decomposition may take place either aerobically or anaerobically. Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated fill characteristics [34].

3.3.1.2 Cell design and construction

UNEP remarked from the experience that no one method of landfilling is best for all sites, and a single method is not necessarily the optimum for any given site [34]. Selection of a method depends upon the physical condition of the site, amount and types of solid waste to be disposed, and the relative costs of the various options. All true sanitary landfills consist of elements known as "cells" as shown in **Figure-3.2** [34]. A cell is built by spreading and compacting the solid waste into layers within a confined area. At the end of each working day, or during the working day as well, the compacted refuse is covered completely (including the working face) with a thin, continuous layer of soil [34]. The soil cover also is compacted. The compacted waste and its daily soil cover make up a cell (**Figure-3.2**). A series of adjoining cells at the same elevation constitute a "lift". A completed fill may consist of one or several lifts [34].

The cells are designed based on the quantity of wastes requiring disposal. The basic elements of a cell are: height, length, width of working face, slope of sidewalls, and thickness of daily cover. The height of a cell is a function of the quantity of waste, thickness of daily cover, stability of slopes, and degree of compaction. Typical heights vary between 2 and 4 m [34]. The minimum width of the cell or minimum width of the working face depends upon the type of equipment used. It is generally recommended that the minimum width of the cell be about 2 to 2.5 times the width of the blade used for building the cell. The minimum recommended cell widths based on rate of waste delivery are: 8 m for up to 50 tonne/day, 10 m for 51 to 100 tonne/day, 12 m for 101 to 225 tonne/day, and 15 m for 226 to 500 tonne/day [34].

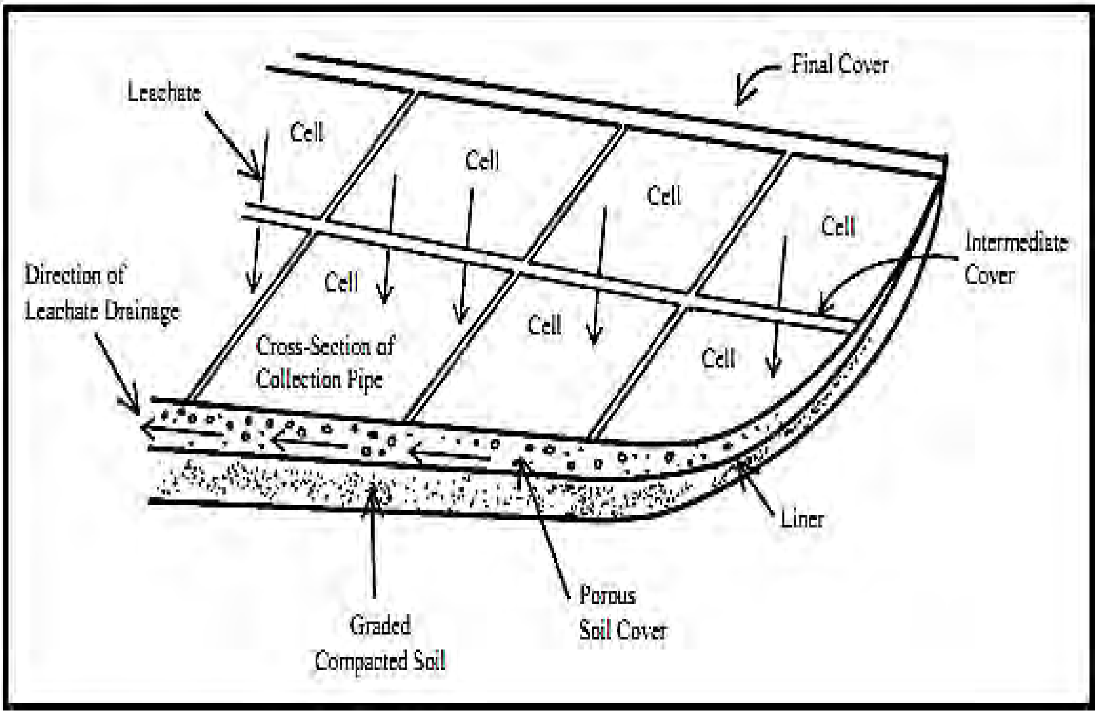


Figure-3.2: Cellular structure of a landfill adapted from [34]

As described in UNEP, the width of the working face also is dictated by the maximum number of vehicles arriving at the disposal site at the peak hour [34]. The width of the working face (in meters) can be calculated by multiplying the maximum number of vehicles arriving at the peak hour by about 4. The width of the working face is one of the major weaknesses in the operation of a land disposal facility in economically developing countries [34].

Generally, the working face is excessively wide in order to accommodate the maximum number of vehicles and to avoid long delays. However, the width is such that it is extremely difficult to achieve any type of control. In practice, one should attempt to operate a landfill using the smallest practical area for the working face [34]. The slope of the cell is the inclined plane upon which the wastes are distributed. The maximum recommended slope is 1 to 3 (vertical to horizontal). Slopes less than about 1 to 6 result in an undesirably large area for the working face. The trench method has only one working face. On the other hand, the area and combined methods may have two working faces [34].

3.3.2 Decomposition phases of MSW in the landfill site

Most of the authors including Pohland & Harper [14], UNEP [34], and Shearer [7] believed that stabilization of waste in a landfill occurs in five phases: Lag phase, Transition phase, Acid Formation phase, Methane Fermentation phase, and the Maturation phase which are defined by their characteristic leachate and gas compositions. **Figure-3.3** illustrates five phases of landfill stabilization as stated by [7].

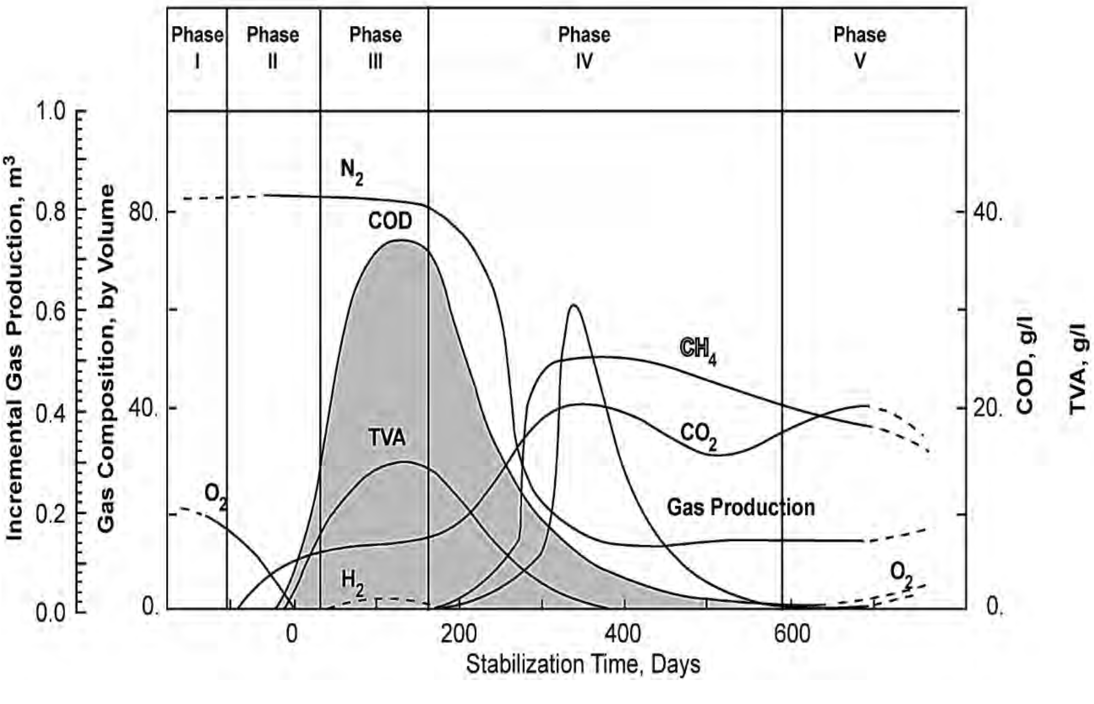


Figure-3.3: Five Phases of Landfill Stabilization adapted from [7]

Shearer observed that the lag phase is the period during which aerobic microbes are becoming established and moisture is building up in the refuse [7]. Once moisture content is sufficient to support microbial growth, aerobic degradation of the refuse begins. This marks the beginning of the transition phase. During transition phase, aerobic degradation consumes the molecular oxygen and conditions go from aerobic to anaerobic. Consequently, a transition toward a reducing environment in which chemical oxygen demand (COD) and volatile organic acids (VOA) begin to form [7]. As demonstrated in [7]:

$$\text{Degradable waste} + \text{oxygen} \Rightarrow CO_2 + H_2O + \text{heat} + \text{biomass} + \text{Acetic Acid} + \text{Residuals}$$

$$CO_2 + H_2O \Rightarrow H_2CO_3 \text{ (Carbonic Acid)}$$

According to Shearer, increases in COD and VOA signal the beginning of the Acid Formation phase [7]. The VOAs formed during this phase are metabolic intermediates in the overall degradation of organic material in the refuse. These products form much faster than they are consumed, which leads to a buildup of VOAs [7]. Therefore, the pH of the leachate is reduced and formerly insoluble metals are mobilized. The Methane Fermentation phase begins when the organic acids produced in the Acid Formation phase are consumed. The end products of this anaerobic metabolism include CH_4, CO_2, and H_2O vapors [7]. As reported by Shearer [7]:

$$4H_2 + CO_2 \Rightarrow CH_4 + 2H_2O \qquad\qquad CH_3COOH \Rightarrow CH_4 + CO_2$$

Shearer [7] proved consumption of acetic and carbonic acid results in an increase in the pH to around 8. This increase in hydroxide concentration is coupled with the reduction of sulfate to sulfide. Both, sulfide and hydroxide form insoluble complexes with metals. Therefore, metal concentrations in the leachate are significantly reduced. Once all these reactions go to completion, there is a reduction in biological activity. This signifies the Maturation phase [7]. A characteristic of this phase is very little gas production, because most of the readily degradable organic matter has been degraded. Nutrients and substrate are limited, but there is still slow degradation of the remaining material, which resembles humic matter [7].

3.3.3 Leachate

Leachate is generated on account of the infiltration of water into landfills and its percolation through waste as well as by the squeezing of the waste due to self-weight. Thus, leachate can be defined as a liquid that is produced when water or another liquid comes in contact with solid waste. Leachate is a contaminated liquid that contains a number of dissolved and suspended materials [70]. The important factors which influence leachate quality include waste composition, elapsed time, temperature, moisture and available oxygen. In general, leachate quality of the same waste type may be different in landfills located in different climatic regions. Landfill operational practices also influence leachate quality [70]. Urban Local Bodies [70] complied data for typical constituents of leachate at MSW landfills reported by Bagchi [71], Tchobanoglous et al. [72], and Oweis and Khera [73], which is presented in **Table-3.1**.

Table-3.1: Typical Constituents of Leachate at MSW Landfills

Constituent		Range		Unit
Type	**Parameter**	**Minimum**	**Maximum**	
Physical	pH	3.7	8.9	-
	Turbidity	30	500	JTU
	Conductivity	480	72500	mho/cm
Inorganic	Total Suspended Solids	2	170900	mg/l
	Total Dissolved Solids	725	55000	mg/l
	Chloride	2	11375	mg/l
	Sulphate	0	1850	mg/l
	Hardness	300	225000	mg/l
	Alkalinity	0	20350	mg/l
	Total Kjeldahl Nitrogen	2	3320	mg/l
	Sodium	2	6010	mg/l
	Potassium	0	3200	mg/l
	Calcium	3	3000	mg/l
	Magnesium	4	1500	mg/l
	Lead	0	17.2	mg/l
	Copper	0	9	mg/l
	Arsenic	0	70.2	mg/l
	Mercury	0	3	mg/l
	Cyanide	0	6	mg/l
Organic	COD	50	99000	mg/l
	TOC	0	45000	mg/l
	Acetone	170	11000	mg/l
	Benzene	2	410	mg/l
	Toluene	2	1600	mg/l
	Chloroform	2	1300	mg/l
	Delta	0	5	mg/l
	1.2 dichloromethane	0	11000	mg/l
	Methyl ethyl ketone	110	28000	mg/l
	Naphthalene	4	19	mg/l
	Phenol	10	28800	mg/l
	Vinyl Chloride	0	100	mg/l
Biological	BOD	0	195000	mg/l
	Total Coliform bacteria	0	100	CFU/l
	Fecal Coliform bacteria	0	10	CFU/l

Source: Adapted from [70]; [Range of constituents observed from different landfills]

Christensen and Kjeldsen claimed that microbial activity would dominate the stabilization of the waste and hence, govern the generation of landfill gas and the composition of leachate [74]. In actively decomposing waste the temperature rises and the pH falls rapidly and many metal ions which are relatively insoluble at neutral pH can become dissolved in the developing leachate [75]. Leachate generation rates are primarily dependent the amount of liquid the waste originally contained, a quantity of precipitation that enters the landfill through the cover or falls directly on the waste. Farquhar [76] assumed chemical character would be affected by the biological decomposition of biodegradable organic materials, chemical oxidation processes, and dissolving of organic and inorganic materials in the waste leachate's chemical composition would change as the landfill goes through the various phases of decomposition similar the changes in methane production.

As stated in Urban Local Bodies, Leachate control within a landfill involves the following steps: (a) prevention of migration of leachate from landfill sides and landfill base to the subsoil by a suitable liner system; and (b) drainage of leachate collected at the base of a landfill to the sides of the landfill and removal of the leachate from within the landfill [70].

3.3.4 Liner system

Liner systems comprise of a combination of leachate drainage and collection layer(s) and barrier layer(s). A competent liner system should have low permeability, should be robust and durable and should be resistant to chemical attack, puncture and rupture. A liner system may comprise of a combination of barrier materials such as natural clays, amended soils and flexible geo-membranes [70]. According to Shearer [7], two types of barriers are used as liners: compacted soil barriers and geosynthetic barriers. A compacted soil barrier is a layer of soil, usually clay, at least two feet thick, and compacted so that the hydraulic conductivity is less than 10^{-7} cm/sec. A geosynthetic barrier is usually a geomembrane, which is a sheet of plastic that is resistant to chemical degradation [7].

The most common type of material used as a geomembrane is High Density Polyethylene (HDPE), because it is highly impermeable to liquids and vapors. When a soil barrier and a synthetic barrier are used together it is called a composite liner [7]. **Figure-3.4** shows the Cross-section of a composite liner.

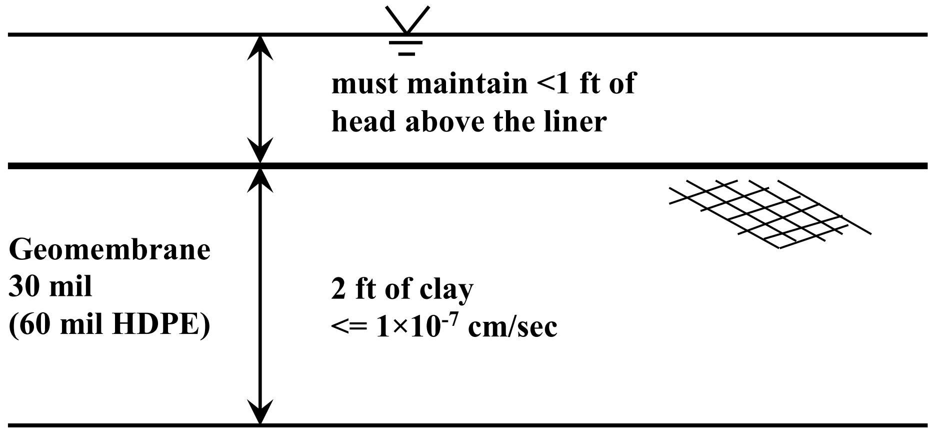


Figure-3.4: Cross-Section of a Composite Liner adapted from [7]

Urban Local Bodies recommended that on a basis of review of liner systems adopted in different countries, the following single composite liner system be adopted (waste downwards) as the minimum requirement for all MSW landfills [70]:

(a) A leachate drainage layer 30 cm thick made of granular soil having permeability (K) greater than 10^{-2} cm/sec.

(b) A protection layer (of silty soil) 20 cm to 30 cm thick.

(c) A geomembrane of thickness 1.5 mm or more.

(d) A compacted clay barrier or amended soil barrier of 1 m thickness having permeability (K) of less than 10^{-7} cm/sec.

For landfills which do not receive run-on from outside areas, a very approximate estimate of leachate generation can be obtained by assuming it to be 25 to 50 percent of the precipitation from the active landfill area and as 10 to 15 percent of the precipitation from covered areas. This is a thumb rule and can only be used for preliminary design [70].

3.4 Environmental and Health Hazards of Land Filling

According to the UNEP, the organic fraction of MSW is an important component, not only because it constitutes a sizable fraction of the solid waste stream in a developing country, but also because of its potentially adverse impact upon public health and environmental quality. Unless an organic waste is appropriately managed, its adverse impact will continue until it has fully decomposed or otherwise stabilized [34]. Uncontrolled or poorly managed intermediate decomposition products can contaminate air, water, and soil resources. These impacts are not confined merely to the disposal site. On the contrary, they pervade the area surrounding the site and wherever the wastes are generated, spread, or accumulated [34].

Reportedly, the main component of LFG is methane, which is an explosive greenhouse gas. Carbon dioxide is another major constituent in LFG and is also a greenhouse gas [7]. As demonstrated in [77], methane only stays in the atmosphere around 8-12 years while carbon dioxide can last for centuries. But methane (CH_4) has a bigger effect in its short time—methane is responsible for 75% as much warming as carbon dioxide measured over any given period of 20 years [77]. Global emissions of methane from land filled waste have been estimated at approximately 40 million tons per year. The waste sector is accountable for approximately 5% of the global green house; about 1300 $MtCO_2$-eq in 2005 as reported by IPCC [42].

Moreover, direct field measurements of landfill CH_4 emissions at small scale ($<1m^2$) can vary over seven orders of magnitude (0.0001– >1000 g $CH_4/m^2/d$) depending on waste composition, cover materials, soil moisture, temperature and other variables [78]. It is worth noting that one of the most important problems associated with the design, operation and long-term care of landfills is managing leachate that is formed when water passes through the deposited waste. The leachate generated from municipal solid waste is a mixture of organic and inorganic, and dissolved and colloidal solids. It contains products of decomposition of organic materials and soluble ions which present a potential pollution problem for surface and ground waters [76].

Metro Manila Solid Waste Management Studies conducted in 1982 shown that a high percentage of workers who handle refuse, and of individuals who live near or on disposal sites, are infected with gastrointestinal parasites, worms, and related organisms. Contamination of this kind is likely at all points where waste is handled [34]. Although it is certain that vector insects and rodents can transmit various pathogenic agents (amoebic and bacillary dysenteries, typhoid fever, salmonellosis, various parasitoses, cholera, yellow fever, plague, and others), it often is difficult to trace the effects of such transmission to a specific population [34].

3.5 Key Parameters those must be considered for Landfilling

3.5.1 Hydraulic conductivity

The hydraulic conductivity (K) of a porous media (like waste) is a measure of the ability of the material to transmit fluid when subjected to a hydraulic gradient [79]. A number of factors control the hydraulic conductivity of waste. Waste composition is important, but for compressible MSW type wastes the degree of compaction, or the density of the waste in the ground is usually the most dominant controlling influence [79]. In addition, the hydraulic conductivity of MSW varies spatially and with time depending on the extent of the degradation of waste, resulting in significant change in the composition and size distribution of the waste components [80]. Sharma and Reddy [81] suggested that the hydraulic conductivity of municipal solid waste MSW must be estimated for the design of the landfill containment systems.

Reddy et al. [80] conducted some hydraulic conductivity tests on both fresh and landfilled MSW. Their tests results confirmed that for fresh MSW, hydraulic conductivity varies in a range of 2.8×10^{-3}–11.8×10^{-3} cm/s with dry unit weight varied in a narrow range between 0.39–0.51 gm/cm^3 [80]; and for landfilled MSW, hydraulic conductivity ranges between 0.6×10^{-3}–3.0×10^{-3} cm/s for 0.45–0.55 gm/cm^3 dry unit weights [80]. For these experiments, fresh waste was collected by [80] from the working phase, while the landfilled waste was exhumed from a borehole in a landfill cell subjected to leachate recirculation for approximately 1.5 years.

3.5.2 Moisture content

The moisture content of solid wastes usually is expressed as the weight of moisture per unit weight of wet or dry material. In the wet-weight method of measurement, the moisture in a sample is expressed as a percentage of the wet weight of the material; in the dry-weight method, it is expressed as a percentage of the dry weight of the material [16]. For most municipal solid wastes, the moisture content will vary from 15 to 40 percent, depending on the composition of the wastes, the season of the year, and the humidity and weather conditions, particularly rain. Most micro-organisms including bacteria require a minimum of approximately 12% moisture for growth [82].

3.5.3 pH

The value of pH is a measure of the acidity or alkalinity in soils. A pH below 7 is acidic and above 7 is alkaline. Materials with low pH can be detrimental to the setting of cement/lime stabilized materials. To overcome this problem the acidic material needs to be neutralized. This can either be achieved by increasing the quantity of lime or cement binder used, or an alternative alkaline material could be used, such as chalk dust [11]. Normally, excess calcium hydroxide is added to a soil stabilization mixture to assure complete reaction and to allow for soil in homogeneity. Normally the lime dosage amounts to 6% or less of the soil mass. This is thoroughly mixed in the treated layer thickness. Prompt mixing and compaction reduce the amount of lime exposed to the environment. After reaction and compaction, only small amounts of lime are accessible to rainfall or run-on water [83]. Kasali and Watson-Craik [84] argued methanogens are only active between a pH of 6.8 and 7.4, thus control of pH is important is establishing methanogenesis. Buffering is particularly important in early stages of degradation; when excess acids are produced and pH levels can drop quickly. Since low pH is typically the problem, the alkalinity is increased by adding lime or sodium hydroxide to the leachate during storage [85].

3.5.4 Micro-biological development in MSW

As reported by UK Environment Agency, micro-organisms require a supply of nutrients and favorable environmental conditions to maintain optimal performance [11]. Nutrient requirements include carbon, oxygen (or other electron acceptor), nitrogen, hydrogen and phosphorus. Key environmental conditions include moisture content, temperature, pH, and salt concentration (affects osmotic uptake of nutrients). Degradation can take place under aerobic or anaerobic conditions, with the rate of degradation generally being faster for the former [11]. Pepper and Josephson reported that the number of bacteria is 10^8 in per gram of soil [86]. Cement or lime S/S treatment of soil will cause an increase in pH that may arrest or significantly reduce the rate of biodegradation of organic contaminants. The impact of this must be evaluated when considering S/S treatment for soil with organic or mixed contaminants [11].

3.5.4.1 Coliform bacteria

The coliform organism is a very common rod-shaped bacterium, not thought of as disease causing to humans. Because pathogenic bacteria in wastes and polluted waters are usually much lower in numbers and much harder to isolate and identify than coliforms, which are usually in high numbers in polluted water [87]. However, their presence indicates that disease-causing organisms (pathogens) could be in the sample. Testing of all possible pathogens is complex, time-consuming, and expensive. It is relatively easy and inexpensive to test for coliform bacteria. There are three different groups of coliform bacteria; each has a different level of risk [88]. Municipal Solid Waste, which includes produce waste, kitchen waste (vegetative), and table waste (mixed food waste containing meat, grease and dairy products), may include the following pathogens as reported by ODEQ [88]:

A. Total Coliform.

These organisms are not prolific in the soil/waste. Their presence neither necessarily imply contamination from waste nor the presence of other sanitation-based health risks [89]. Total coliforms are used as a general indicator of potential contamination with pathogenic organisms [90].

B. Fecal Coliform.

This is a subset of the total coliform group. Fecal coliform bacteria generally originate in the intestines of mammals. They have a relatively short life span compared to other coliform bacteria. Their presence could be related to improper disposal of waste [89]. Fecal coliforms are a good indicator of contamination from human or other animal waste products and they indicate greater risk of exposure to pathogenic organisms than total coliforms [87].

C. Escherichia coli (E. coli).

E. coli is a normal inhabitant of the intestines of all animals, including humans. A minority of E. coli strains is capable of causing human illnesses. It has been associated with undercooked or raw meat, vegetables, fruit, juices, and cheese. As the other fecal coliform, their presence indicates a strong likelihood that human or animal wastes are entering the systems [90].

Total Coliforms and Faecal Coliform are good candidates for assessing MSW, which are used for this purpose. Escherichia coli can also be considered as both pathogens and indicators for other parasitic populations [91]. According to Dr. Zahid Hayat Mahmud, Associate Scientist of Environmental Microbiology Laboratory, Center for Food and Waterborne Diseases, ICDDR'B, laboratory tests are prerequisite to identify the presence of Coliform organisms. When the sample is tested, the results are usually given as the number of colony forming units per gm (CFU/gm).

3.5.4.2 Temperature

The microorganisms that carry out degradation of waste in a landfill prefer a certain temperature. In general, degradation rates increase with temperature up to an optimum temperature, specific for that particular microbe [7]. Gurijala and Suflita reported 40^{o}C as optimum with significant inhibition over 55^{o}C. Temperature control is very difficult and is currently not widely practiced because of economic inefficiency [92].

3.6 Binders and their Interactions with Soils

Binders can impart both chemical stability and physical solidity to the treated product. The high pH induced by the addition of the most common binders, such as lime and cement, results in the precipitation of many contaminant species and a corresponding reduction in mobility (stabilization) [11]. Secondly, the ability of the binder to set into a solid mass encapsulating the contaminant, results in a physical immobilization process (solidification). Many binders rely on the presence of free CaO for this, although the use of additives is common for modification of the hydration/setting processes [11].

3.6.1 Importance of soil properties for land filling

UNEP observed that soil properties influence contaminant migration and at the same time, increase the strength of the entire filling materials [34]. As stated by Environment Agency, the physical properties of soils such as grain size, moisture content and plastic properties are important in determining the choice of S/S systems; and the chemical properties of soils also have a significant influence on the choice of binder system [11]. Reportedly, the limited solubility of lime and the accessible volume of the compacted soil limit the alkaline agent available for pH adjustment of adventitious water [83]. Recarbonation of the excess lime near the surface forms calcium carbonate, the principal mineral in limestone, which has a pH of 7.8 – 8.4. Good practice dictates that every effort is made to promptly mix the lime with the soil should excess rainfall and off-site drainage take lime solids to a body of water; the saturated calcium hydroxide pH of 12.4 can kill aquatic life [83]. U.S. Environmental Protection Agency determined that clay loam has less permeability {$(8 \pm 3) \times 10^{-8}$} and higher Moisture Content {(17.3 ± 0.3) %} with medium density {(1731 ± 16) kg/m^3} comparing to other sorts of soil classes [93].

3.6.2 Lime

Lime is a general term for the various forms of calcium oxide or hydroxide and of less eramounts of magnesium oxide and/or hydroxide. Lime products have been used extensively in the treatment of waste for over one hundred years. Soil stabilization using lime is widely established in the UK [94], [95], & [96]. The interactions of cement and lime on soils are broadly similar; despite cement having a lower stabilization is readily available [96].

3.6.3 Cement

Cement is a binder, a substance that sets and hardens independently, and can bind other materials together [97]. Solidification and stabilization of wastes provide one of the largest uses of cement outside the traditional concrete markets as reported by [67]. The wide use of cement in S/S systems has come about because it has many advantages, including versatility, over other materials. S/S technology using cement provides solidification, stabilization, and, to a limited extent, some sorption of liquids. It can be used by itself or with additives [67].

3.6.4 Interactions of binders with soils

It is worth to mention that when using cementitious binder systems, waste or soil particles are both encapsulated chemically and physically in the treated product. The interaction of binders with soil is complex [11]. Although soils are a complex mixture of materials, it may be possible to assess the likely behavior of a soil upon cement addition by considering its type [11]. It is well known that organic matter may affect the cementing process in soils [98]. USEPA found some advantages and disadvantages of stabilization techniques with cement and lime [99], which is presented in the **Table-3.2**.

Table-3.2: Advantages and Disadvantages of Soil Stabilization Techniques with Cement and Lime

Technique	Advantages	Disadvantages
Cement	• Amount of cement used can be varied to produce a geotechnically favorable product or reduce permeability. • Reagents are plentiful and inexpensive. • Technique is proven and specialized labor is not required. • Extensive drying/dewatering of feedstock is not required; cement addition can be adjusted to existing water content or inert fine fillers added. • System is tolerant of most chemical variations e.g. low pH, strong oxidizers (nitrates or chlorates etc.) • Pre-treatment confined only to substances retarding or interfering in setting process. • Leaching properties can be improved where necessary by adding sealant.	• Large additions of cement increase the volume of material to be handled. • Leaching characteristics may not be acceptable for some contaminant types. • Borates, sulfates and other inorganic contaminants may affect setting and strength development. • Some organic contaminants e.g. sugars, solvents and oils may impede setting and strength development. • Volatile materials (e.g. VOCs, ammonia) may be driven off during processing.
Lime	• Lime can be used to de-water and produce a geotechnically favorable product. • Permeability is improved in the longer term. • Lime is readily available and inexpensive. • Technique is proven and specialized labor is not required. • System is tolerant of most chemical variations e.g. low pH, strong oxidizers (nitrates or chlorates etc.) • Pre-treatment confined primarily to substances retarding or interfering in setting process.	• Large additions of lime increase the volume of material to be handled. • Leaching characteristics may not be acceptable for some contaminant types. • Some inorganic contaminants may affect setting and strength development. • Some organic contaminants may impede setting and strength development. • Volatile materials (e.g. VOCs, ammonia) may be driven off during processing. Ignition may occur with some organic contaminants with a low flash point. May render waste hazardous.

Source: Adapted from [99]

However, increasing the pH of a soil by the addition of cement (or lime) may cause significant morphological change to the organic matter. Lime and cement will undergo a primary reaction process where the plasticity of soils is affected and strength is increased by cation exchange reactions [11]. Andersson and Nilsson reported that chemical fractionation in dissolved organic matter as a result of pH change due to the addition of lime to soil [100]. However, a study [101] by Arman and Munfakh concluded that organic soil-lime mixtures produce cementitious products similar to those reported for inorganic soil-lime reactions and that the organic matter does not appear to block the reaction that results in an increase in the soil strength.

3.7 Technological Aspects of Waste Treatment

Technological aspects of municipal solid waste management (MSWM) system include technological planning and design of waste collection systems, transfer systems, and waste recovery and disposal systems. Since the treatment of municipal solid waste is an inclusive technological process, it is necessary to assess the process in technological perspective.

3.8 Conclusions

A detailed search of the literature has been undertaken in this chapter to develop a conceptual framework in support of the research aim. The issues discussed here, for instance, sanitary landfilling, stabilizing additives, and several environmental and technological aspects pertinent to this study have been acquired from different secondary sources for establishing the research output from technical point of view. These discussions have been worked as a guideline throughout the study and helped to discuss precisely in the forthcoming chapters.

CHAPTER-4: SAMPLING PROGRAMS

CHAPTER-4: SAMPLING OF MUNICIPAL SOLID WASTE

4.1 Introduction

Municipal Solid Waste (MSW) was collected through *Site Sampling* with a view to determining the physical composition of waste stream as well as gathering organic waste for further experiments. Total twenty sites in and around Dhaka city were selected such a way that enough heterogeneity of municipal solid waste could be found. After physical analysis of the collected MSW, the result was compared with some published literatures to observe the discrepancies of waste stream varies due to time and location variances.

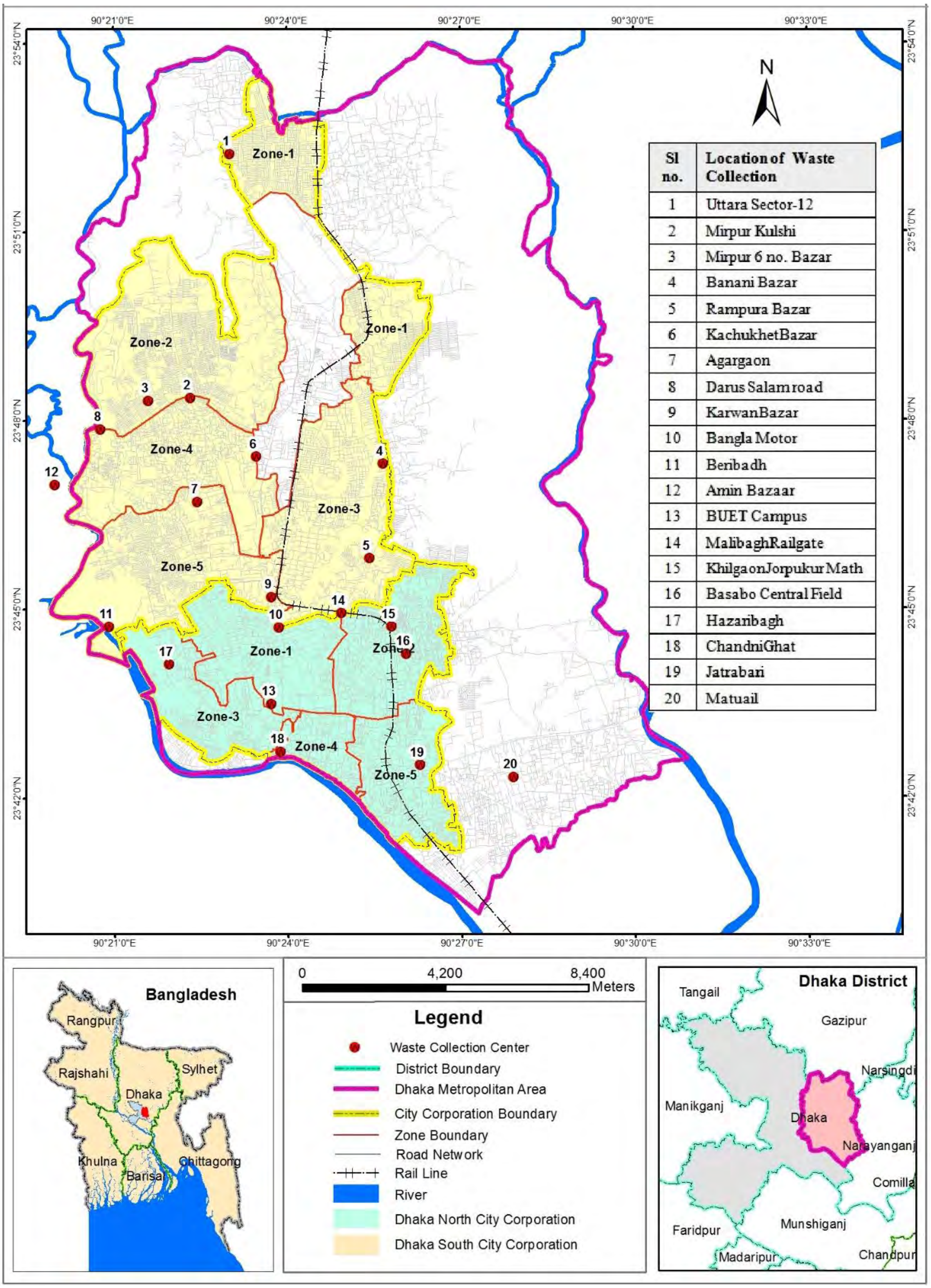
4.2 Collection of Samples and Screening Out

4.2.1 Field protocol

From April 27 to April 30 in 2013, roughly 1 kg of fresh municipal solid waste was collected in separate polythene bags from each of eighteen secondary collection points and two permanent dumping stations of Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). From five zones of DNCC, eleven secondary collection points and one landfill site were chosen, particularly, Zone-1 (Uttara Sector-12), Zone-2 (Kulshi, 6 No. Bazaar), Zone-3 (Banani Bazar, Rampura Katcha Bazar,), Zone-4 (Kachukhet Market, Agargaon, Darus Salam road), Zone-5 (Karwan Bazar, Bangla Motor, Beribadh), and Amin Bazaar (Permanent).

At the same time, seven secondary collection points and one landfill site from five zones of DSCC were selected, in particular, Zone-1 (BUET Campus), Zone-2 (Malibagh Railgate, Khilgaon Jorpukur Math, Basabo Central Field), Zone-3 (Hazaribagh), Zone-4 (Chandni Ghat), Zone-5 (Jatrabari), and Matuail (Permanent). **Map-4.1** is pointed out the location of sampling sites.

Map-4.1: Location of Sampling Sites



Source: Developed by Author, 2015

4.2.2 Laboratory protocol

The waste samples collected from different sites were processed within 3–5 hour of collection to minimize saprophytic developments. At first, the samples were weighted discretely before segregating. Portions of the waste were sorted manually and placed on a sorting table to record the share of organic and inorganic composites. Subsequently, the separated organic waste was treated with additives and reserved in some identified containers in a preset manner for further experiments. The containers were kept open to maintain an aerobic environment till the end of the experiment i.e. January, 2014. **Photograph-4.1** shows MSW collection and weighing process for this study.

(a) MSW Sample Collection Process

(b) Weighing of MSW Sample

Photograph-4.1: MSW Collection and Weighing Techniques for this Study

4.2.3 Screening of collected municipal solid waste

After collection, Municipal Solid Waste (MSW) was separated and weighted according to *Sampling Techniques of Municipal Solid Waste* developed by the AIT (as shown in **Table-2.1**). From the primary survey, it is again proved that the lion's share of municipal solid waste is organic matter which ranges from 49% to 61%. The share of plastic is at second position ranges from 11% to 18.35%, while paper was found about 9.29% to 15%. Detail compositions of collected MSW samples, with location name and date are presented in **Table-4.1**.

Table-4.1: Composition of Municipal Solid Waste Collected from Different Dumping Points in Dhaka City

Sl no.	Location of Waste Collection Point	Date	Waste Category (%)							
			Organic	Paper	Plastic	Textile and wood	Leather and rubber	Metal	Glass and ceramics	Other
1	2	3	4	5	6	7	8	9	10	11
1	Uttara Sector-12	27/4/2013	55.96	11.63	14.71	2.68	2.27	1.79	1.92	9.04
2	Mirpur Kulshi	27/4/2013	59.81	11.95	12.43	1.91	1.32	0.78	1.1	10.7
3	Mirpur 6 no. Bazar	27/4/2013	51.96	9.29	18.35	7.92	0.1	2.36	1.4	8.62
4	Banani Bazar	27/4/2013	53.78	11.69	16.23	6.09	2.23	2.77	0.09	7.12
5	Rampura Bazar	27/4/2013	61.02	10.50	11.02	5.92	1.06	1.09	1.92	7.47
6	Kachukhet Bazar	27/4/2013	54.69	11.23	15.90	5.95	1.55	1.47	1.9	7.31
7	Agargaon	27/4/2013	55.44	14.86	15.34	2.09	0.61	0.88	0.91	9.87
8	Darus Salam road	28/4/2013	56.33	14.52	13.67	3.39	2.05	1.16	0.5	8.38
9	Karwan Bazar	28/4/2013	59.98	12.14	13.50	3.27	0.78	1.62	0.82	7.89
10	Bangla Motor	28/4/2013	52.23	14.5	15.89	3.84	1.76	1.16	0.78	9.84
11	Beribadh	28/4/2013	51.57	12.78	17.06	5.44	2.29	1.87	0.56	8.43
12	Amin Bazaar	28/4/2013	56.45	14.53	12.90	4.4	2.04	1.55	1.01	7.12
13	BUET Campus	29/4/2013	55.44	14.86	15.34	3.09	0.61	0.88	0.91	8.87
14	Malibagh Railgate	29/4/2013	48.92	12.06	14.05	7.7	2.4	2.89	1.9	10.08
15	Khilgaon Jorpukur Math	29/4/2013	57.76	12.1	13.90	5.15	1.1	0.9	1.1	7.99
16	Basabo Central Field	29/4/2013	51.65	14.05	13.74	5.9	2.2	2.5	1.6	8.36
17	Hazaribagh	30/4/2013	54.12	10.99	13.87	7.9	1.07	1.03	1	10.02
18	Chandni Ghat	30/4/2013	51.22	13.52	17.19	4.5	1.56	1.01	1.93	9.07
19	Jatrabari	30/4/2013	53.80	12.23	13.22	4.14	1.81	2.3	0.9	11.6
20	Matuail	30/4/2013	56.33	12.52	15.67	3.39	2.05	1.16	0.5	8.38
Average			**54.92**	**12.60**	**14.70**	**4.73**	**1.54**	**1.56**	**1.14**	**8.81**

Source: Field Survey, 2013

4.2.4 Baseline composition of collected solid waste

The average waste composition for the entire waste stream in Dhaka city has been calculated from **Table-4.1** and is presented graphically in **Figure-4.1**. As compared to other fractions, the biodegradable fraction (organic matter) is normally very high, which was about 55%. The share of other fraction combined from all locations was about 14.7% plastic, 12.6% paper, 4.73% textile and wood, 1.54% leather and rubber, 1.56% metal, 1% glass and ceramics, and 8.81% other waste.

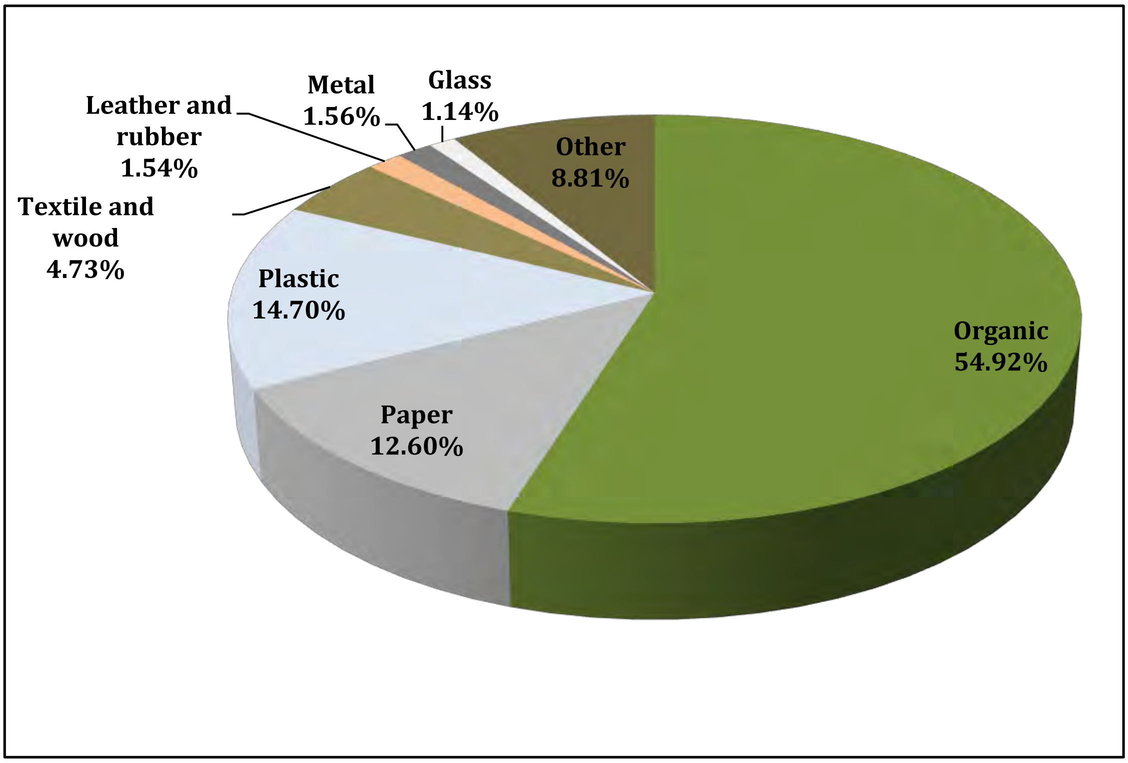


Figure-4.1: Physical Composition of Collected Municipal Solid Waste
Source: Field Survey, 2013

4.3 Comparison with Other Studies Carried Out on MSW Composition of Dhaka City

Several studies have been conducted by different authors to determine the composition of MSW generated in Dhaka city. **Table-4.2** shows a comparison of the present study with different studies conducted earlier on municipal waste composition. As reported in the previous studies, organic matters varied over a wide margin ranging from about 62% to 88% during 1993-2005 in Dhaka city whereas, paper and plastic varied from about 1% to 11% and 1% to 7% respectively [24].

Table-4.2: Comparison of Waste Composition with other studies in Dhaka city

Data sources	Composition (% by wet wt.)							
	Organic matter	Paper	Plastic	Textile and wood	Rubber and leather	Metal	Glass and ceramics	Other
Present Study, 2013	54.92	12.60	14.70	4.73	1.54	1.56	1.14	8.81
*Alamgir, et al., 2005	68.3	10.7	4.3	2.2	1.4	2.0	0.7	10.4
*Moqsud, 2003	80.0	8.0	6.0	0.5	0.5	2.0[b]		3.0
*BCSIR, 1998[1]	70.0	9.2	5.0	0.2	1.1	0.1	0.25	14.2
*BCSIR, 1998[2]	65.8	4.1	6.8	6.4	0.7	6.0[b]		10.2
*BCSIR, 1998[3]	62.3	4.7	5.4	7.4	0.2	1.2[b]		18.8
*BCSIR, 1998[4]	73.7	3.4	3.5	3.6	1.2	6.8[b]		7.8
*BCSIR, 1998[5]	67.2	9.6	5.1	4.7	0.8	2.9[b]		9.7
*Rahman, 1993	65-88	1-7	1-2	1-2				7-15[a]

[[a] Includes glass, metal and other; [b] Includes metal, glass and woods; [1]Mirpur areas; [2]South Kamlapur areas; [3]Mugda fish wholesale market areas; [4]Matuail areas; [5]Kachukhet bazaar areas]

Source: Field Survey, 2013; *Adapted from [24]

4.4 Comparative Study on Waste Composition at different Urban Areas of Bangladesh

Composition of municipal solid waste generated in different cities in Bangladesh is necessary to be studied for identifying the deviation of waste composition within the country. Different studies were carried out on this matter to date, so secondary data were used here for further study. Alamgir & Ahsan [24] studied composition of MSW in major cities in Bangladesh. Their studies and current study are presented in **Table-4.3**.

Table-4.3: Physical Composition of MSW generated in different City Corporations in Bangladesh

Waste category	MSW composition (% by wet wt.)*							Current Study (%)
	DCC	CCC	KCC	RCC	BCC	SCC	All waste stream	
Organic matter	68.3	73.6	78.9	71.1	81.1	73.5	74.4	54.92
Paper	10.7	9.9	9.5	8.9	7.2	8.6	9.1	12.60
Plastic	4.3	2.8	3.1	4.0	3.5	3.5	3.5	14.70
Textile and wood	2.2	2.1	1.3	1.9	1.9	2.1	1.9	4.73
Leather and rubber	1.4	1.0	0.5	1.1	0.1	0.6	0.8	1.54
Metal	2.0	2.2	1.1	1.1	1.2	1.1	1.5	1.56
Glass and ceramics	0.7	1.0	0.5	1.1	0.5	0.7	0.8	1.14
Other	10.4	7.4	5.1	10.8	4.5	9.9	8.0	8.81
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

[DCC-Dhaka City Corporation; CCC-Chittagong City Corporation; KCC-Khulna City Corporation; RCC-Rajshahi City Corporation; BCC-Barisal City Corporation; SCC-Sylhet City Corporation]

Source: *Adapted from [24]; Field Survey, 2013

Table-4.3 depicts the percentages of organic matters, ranges from 68% to 81%, are highest in the waste streams in respective city corporations. In 2007, Alamgir & Ahsan [24] found more paper than plastic in waste streams, where the current study found more plastic than paper. This indicates the growing preference for consumption of packaged food by the city dwellers in recent times. **Figure-4.2** illustrates composition of MSW generated in city corporations in Bangladesh with current study.

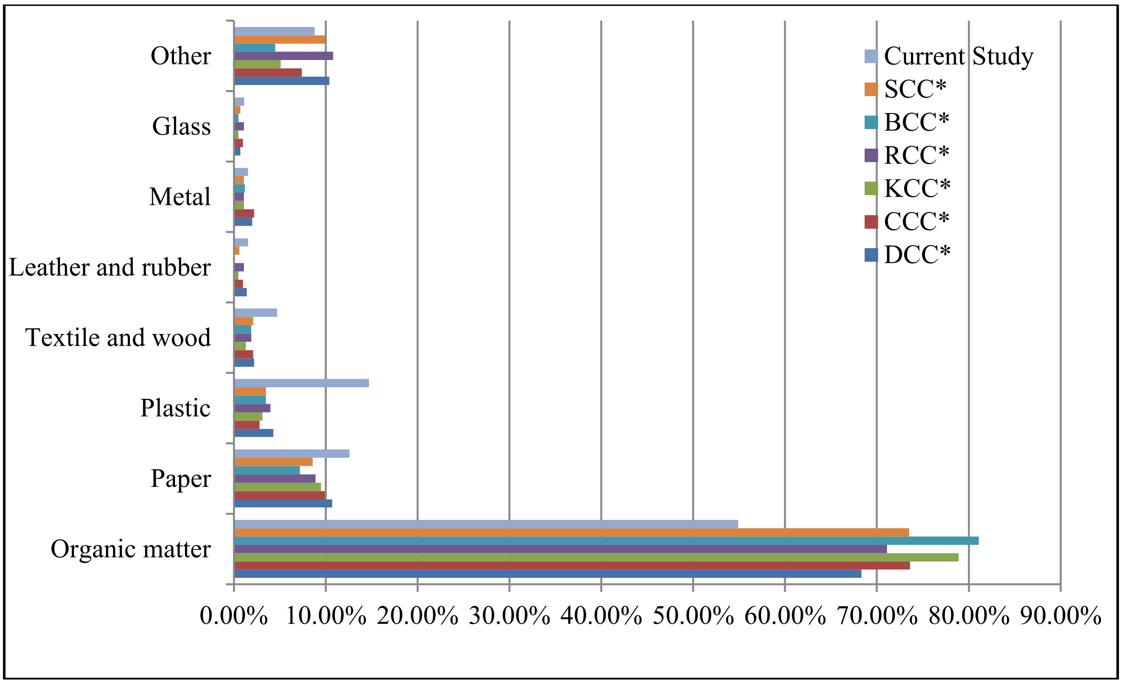


Figure-4.2: Composition of MSW Generated in City Corporations in Bangladesh

Source: *Adapted from [24]; Field Survey, 2013

Waste Concern study [52] in 2009 found in Bangladesh, among total MSW, organic waste shares 76% in city corporations whereas, 77% in municipalities, and 69% in other urban areas. **Figure-4.3** shows the percentage of organic and inorganic waste generated in different urban areas in the country.

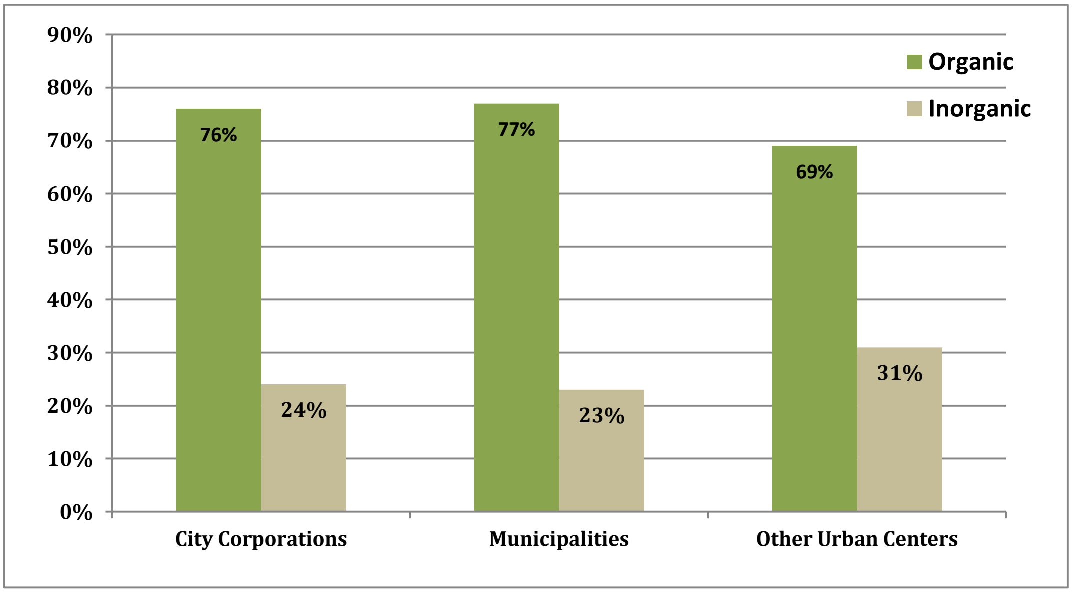


Figure-4.3: Compositions of Waste Generated in different Urban Areas in Bangladesh

Source: Adapted from [52]

4.5 Conclusions

Fresh municipal solid waste was collected from eleven secondary collection points and one permanent landfill site of DNCC, and from seven secondary collection points and one permanent landfill site of DSCC. A laboratory investigation was carried out on the physical composition of MSW and the analysis result was compared with different published literatures carried out on municipal waste of Dhaka city as well as of different urban areas of Bangladesh. This comparison was required to observe the discrepancies of waste in different times and locations, as the composition of MSW varies due to location and changing consumption patterns in course of time.

CHAPTER-5: TESTING PROGRAMS

CHAPTER-5: TESTING PROGRAMS

5.1 Introduction

A systematic way was followed from collection of waste to conduct multifarious experiments at stipulated time frame. MSW were collected in polythene bags from different waste dumping points of DNCC and DSCC. The organic part was mixed with different stabilizing additives at different proportions and then stored in separate containers. Some of each treated samples were sent to the laboratories at predetermined time to observe the improvements. The detail testing program has been described in the following sections.

5.2 Preparation of Sample Matrix

Madhupur Tracts soils were selected for this experiment for it hardness in nature. The soils have clayey texture and contain large quantity of iron and aluminium, which are highly aggregated. The pH value ranges from 5.5 to 6.0 in the topsoil [105]. **Photograph-5.1** illustrates a quick view of the soil used in the experiment. According to [105], the soil can be characterized in -

- clay loam; dry slightly hard;
- average pH 5.2;
- abrupt wavy boundary.
- weak fine to medium subtangular blocky;
- density ranges 1.45 to 1.55 gm/cm^3
- many very fine tubular pores;
- moist friable and wet slightly sticky and slightly plastic;

Photograph-5.1: Madhupur Tracts Soil used in the Experiment

Quick lime and cement are available to buy in the market area, which were collected as well to develop the samples. **Photograph-5.2 (a, b)** shows preparation of different samples for conducting several physical, chemical, and biological experiments.

(a) Weighing Organic Portion of MSW (b) Mixing Organic Waste with Different Addditives

Photograph-5.2 (a, b): Preparation of Different Samples for Experiments

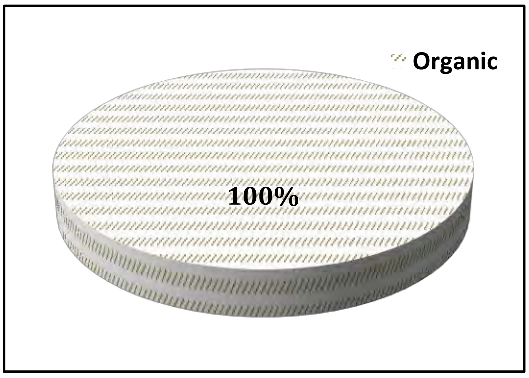
The total isolated organic waste was divided into three core samples, namely, Sample-1, Sample-2, and Sample-3. A small size weigh machine has been used for weighing organic waste and stabilizing additives and these compounds were mixed manually at different proportions to experience the state of solid waste at different situations. Five sub-samples were created from these core samples. Sample-1 was preserved without mixing any compounds, which at the end was considered as Sample-1.1. Sample-2 was divided into two sub-samples, where at each sample lime and Madhupur Tracts soil were added. Sample-3 was also divided into two sub-samples and at Sample-3.1 lime, cement, and Madhupur Tracts soil were added. Sample-3.2 was only developed with lime and cement. The details are presented in **Table-5.1.**

Table-5.1: Development of Sample Matrix for Experiments

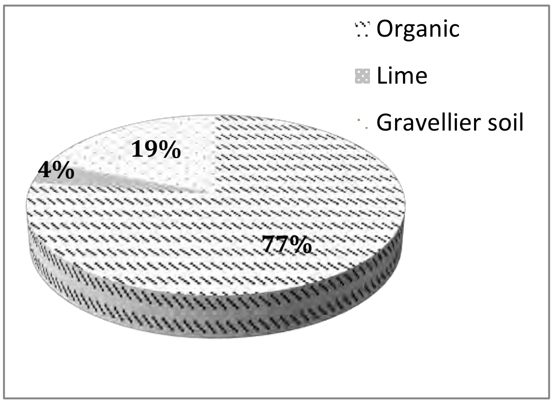
Core Samples	Sample Description		New Samples
Sample-1	Organic (1kg)	-	Sample-1.1
Sample-2		Lime (50g) + Soil (250g)	Sample-2.1
		Lime (100g) + Soil (250g)	Sample-2.2
Sample-3		Lime (50g) + Cement (250g) + Soil (250g)	Sample-3.1
		Lime (100g) + Cement (250g)	Sample-3.2

The percentages of different compounds in each sample are graphically presented in **Figure-5.1 (a-e)**. Sample-1.1 comprises solely organic waste, where Sample-2.1 consists of organic waste (77%), Madhupur Tracts soil (19%), and lime (4%). Sample-2.2 developed with 74% organic waste, 19% soil, and 7% lime. Sample-3.1 has organic waste (65%), soil (16%), cement (16%), and lime (3%). Lastly, Sample-3.2 consists of

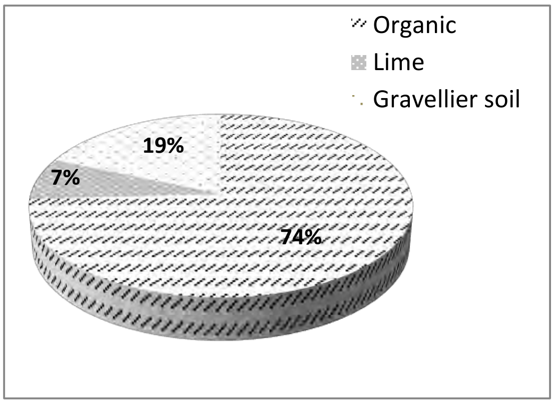
74% organic waste, 19% cement, and 7% lime. Lime has been added in the lowest percentage (5 to 10% of MSW) to keep the alkalinity of the samples as low as possible. Cement and soil have been kept 25% of MSW with a view to enhancing the strength of samples while landfilling.



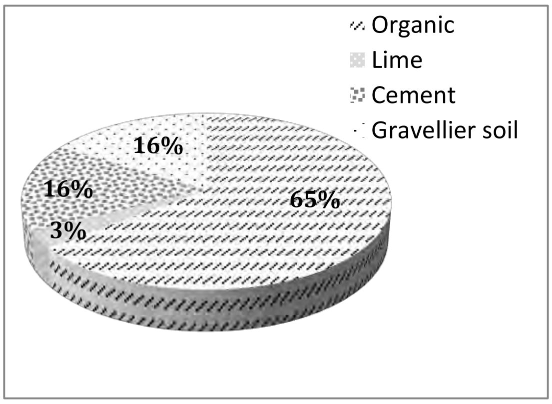
a. Composition of Sample-1.1



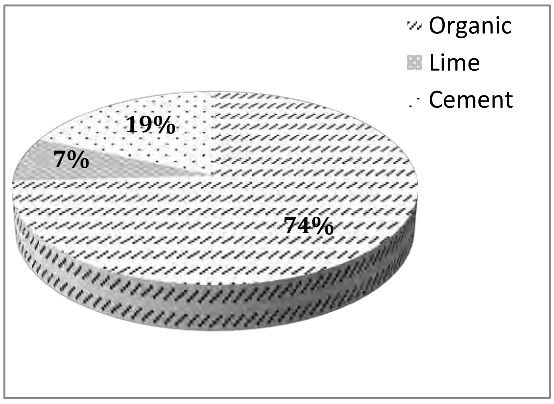
b. Composition of Sample-2.1



c. Composition of Sample-2.2



d. Composition of Sample-3.1



e. Composition of Sample-3.2

Figure-5.1 (a-e): Composition of different Samples

5.3 Sample Preservation

Samples were preserved in separate containers having no cover at the top and labeled accordingly **Table-5.2**. This system was followed till the end of the study. **Photograph-5.3** shows preservation of samples in different containers.

Photograph-5.3: Samples Storage in Different Containers

5.4 Testing Types and Laboratory Selection

Different physical, chemical, and microbiological parameters were set to determine the potentiality of air pollution and groundwater contamination by treated samples in the field level. Laboratories, having expertise and reputation in national and international level, were selected to carry out the experiments. The samples were sent to the laboratories according to their required packaging technique with preset label. All the samples were analyzed for relevant and essential physical, chemical, and biological parameters followed by internationally accepted procedures and standard methods. The parameters were set for the experiments include moisture content, saturated hydraulic conductivity with density, temperature, pH, and coliforms bacteria. A number of zip lock plastic bags have been used for sending samples to the laboratories for moisture content, pH, and bacteriological testing. Core has been used for sending samples for conducting hydraulic conductivity tests. Temperature was measured with digital thermometer. The following sections present details of different testing types, parameters, and laboratories selected for these experiments. **Photograph-5.4 (a-d)** presents laboratories used for this study, whilst **Photograph-5.5 (a, b)** shows packing of samples for laboratory testing.

(a) Soil Resource Development Institute, Ministry of Agriculture, Government of Bangladesh

(b) International Centre for Diarrhoeal Disease Research, Bangladesh

(c) Department of Soil, Water & Environment, University of Dhaka

(d) R&D Lab, Institute of Appropriate Technology, BUET

Photograph-5.4 (a-d): Laboratories used for this Study

(a) Packing of Samples in Plastic Bags for Moisture Content, pH, and Bacteriological Testing

(b) Packing of Samples in Core for Hydraulic Conductivity and Density Testing

Photograph-5.5 (a, b): Packing of Samples for Laboratory Testing

A. Physical testing

Three types of Physical tests were conducted in different laboratories. Those are-

Parameters	**Laboratories**
Moisture content	Soil Resource Development Institute (SRDI) Ministry of Agriculture, Government of Bangladesh
Saturated Hydraulic Conductivity with Density	Department of Soil, Water & Environment University of Dhaka
Temperature	R&D lab, Institute of Appropriate Technology, BUET

B. Chemical testing

Only pH Value was calculated in this category. Soil Resource Development Institute (SRDI) of Ministry of Agriculture, Government of Bangladesh was set to carry out this test at different intervals.

C. Biological testing

Indicator bacteria are mainly Coliform bacteria. There are a number of subsets within the Coliform group. The presence of bacteria from each progressively smaller subset heightens the concern that disease-causing organisms may also be present in the samples. These organisms are prolific in the soil. The presence of these organisms does not imply an imminent health risk but does indicate. Three indicator microorganisms- total coliforms, faecal coliforms, E. coli were studied at Environmental Microbiology Laboratory of ICDDR’B laboratory. Usually, total coliform is tested at first. If total coliform is present then fecal coliform and E. coli are tested.

5.5 Test Schedule

As observed by [27], the organic waste converted completely into methane (CH_4) at land filled site, so the improvement of the treated organic samples within eight months were decided to be observed for this study since the study aims to develop a conversion technique within twelve months' time-frame. But keeping the budget constraint in mind, laboratory experiments could not be planned to conduct rigorously. All the samples were treated with lime, cement, and soil at different proportion in May, 2013 and four samples were developed for further experiments. Moisture Content, pH value, and bacteriological tests were scheduled twice; temperature was measured at every two weeks; and Hydraulic Conductivity test was set to carry out only once at the end of the experiment. Changes in odor and particle size of solid waste were also observed at every two weeks intervals up to eight months. The detail experiment schedule was presented in **Table-5.2**.

Table-5.2: Schedule of Laboratory Experiment

Test types	Schedule			
	In October, 2013	**In December, 2013**	**In January, 2014**	**In every two weeks**
Physical Testing	• Moisture content	• Moisture content	• Hydraulic Conductivity with Density	• Temperature
Chemical Testing	• pH value	• pH value		
Bacteriological Testing	• Total Coliforms • Faecal Coliforms • Escherichia coli	• Total Coliforms • Faecal Coliforms • Escherichia coli		

5.6 Purpose of Selections of Parameters

In the present study, a set of parameters were determined to conduct experiments on the samples developed earlier. Though, so many parameters could be set, only essential parameters were selected taking into account the budget and timeframe of this study. All these parameters were set to determine the situation of municipal solid waste at field condition.**Table-5.3** presents the reason behind the selection of the preferred parameters for this study.

Table-5.3: Purpose of Selection of the Parameters

Parameter	Purpose
Physical	
Particle size*	To determine pre-treatment and materials handling requirements, mixing characteristics, and the suitability of treated waste as land filling material.
Moisture content*	To determine pre-treatment materials handling requirements, biodegradation possibilities of the organic waste, and reagent formulation.
Saturated Hydraulic Conductivity with Density	To calculate the degree of saturation of different samples in the field condition
Temperature*	To identify any prospective impacts on process performance.
Chemical	
pH*	To predict reaction conditions, impact on leaching characteristics.
Bacteriological	
Total Coliforms	To determine the potential contamination with pathogenic organisms, to identify contamination of waste by human or other animal excreta and to understand the possible link of groundwater contamination.
Faecal Coliforms	
Escherichia coli	

* Adapted from [106]

5.7 Record Keeping

Records were kept with preset formats in different stages so that the data could be analyzed easily to reach a conclusion. The formats of data collections are attached in the **Annexure-B**.

5.8 Conclusions

From April 27, 2013 to April 30, 2013, municipal solid waste was collected from different temporary and permanent dumping sites of Dhaka city. The organic and non-organic portion of MSW was separated right after the collection. Later, the separated organic waste was mixed with soil, lime and cement at different proportions and reserved in some identified containers. All treated samples were maintained an aerobic environment with room temperature and later carried to the laboratories at predetermined intervals for physical, chemical, and biological testing. The total experiments was followed a specific guideline developed at the initial stage of the study. In addition to this, experiments results were recorded in a precise method for further analyzing. The procedure was followed till the end of the experiment in January, 2014.

CHAPTER-6: ANALYSIS OF LABORATORY RESULTS AND DISCUSSIONS

CHAPTER-6: ANALYSIS OF LABORATORY RESULTS AND DISCUSSIONS

6.1 Introduction

This chapter comprises a comprehensive laboratory study performed to investigate the physical, chemical, and bacteriological changes in the treated samples. Laboratory testing was conducted in specific intermission according to the several parameters set earlier of the study. Experimental methods, results, and discussions of tests results are presented in this chapter with several graphical and tabular formats. Copies of test results are also attached in **Appendix-C**.

6.2 Methods used for Different Experiments

Considering the nature and category, the predetermined tests have been carried out in different methods at different laboratories. **Table-6.1** lists up different parameters with laboratory names and methods applied for the experiments.

Table-6.1: Methods used for different Experiments

<table>
<tr><th colspan="2">Parameters</th><th>Laboratory name</th><th>Experimental Method</th></tr>
<tr><td rowspan="3">Physical</td><td>Moisture content</td><td>Soil Resource Development Institute (SRDI)
Ministry of Agriculture, Govt. of Bangladesh</td><td>Gravimetric method</td></tr>
<tr><td>Hydraulic Conductivity</td><td>Department of Soil, Water & Environment
University of Dhaka</td><td>Constant Head method</td></tr>
<tr><td>Temperature</td><td>R&D lab,
Institute of Appropriate Technology, BUET</td><td>Manually</td></tr>
<tr><td>Chemical</td><td>pH</td><td>Soil Resource Development Institute (SRDI)
Ministry of Agriculture, Govt. of Bangladesh</td><td>Gravimetric method</td></tr>
<tr><td rowspan="3">Bacteriological</td><td>Total Coliforms</td><td rowspan="3">Environmental Microbiology Laboratory
ICDDR’B</td><td rowspan="3">Membrane Filtration & Spread Plate</td></tr>
<tr><td>Faecal Coliforms</td></tr>
<tr><td>Escherichia coli</td></tr>
</table>

6.3 Results and Discussions

6.3.1 Physical tests

Physical tests have been conducted to study the external progresses of the samples. The external development is quite important as it fixes the strength of a material that will be used for land filling. Three types of parameters, in particular, Moisture Content, Saturated Hydraulic Conductivity with Density, and Temperature were fixed for this study. All the samples were treated with lime, cement, and soil at different proportion in May, 2013 for the experiment purpose and later experimented under these parameters at different intervals. Moisture Contents in the treated samples were analyzed twice- first in October, 2013 and second in January, 2014. Both experiments were carried out at Soil Resource Development Institute (SRDI) using Gravimetric method. Constant Head method was used to determine Hydraulic Conductivity of the studied samples with specific density and this experiment was conducted once at the end of the study i.e. February, 2014 at Department of Soil, Water & Environment of DU. Temperature was measured periodically at R&D lab of IAT with a thermometer. Parallel to these, change of particle size and odor were also observed.

6.3.1.1 Moisture content

Moisture contents tests results are presented in **Table-6.2**. Sample-1.1, comprises solely organic material, contained the highest percentage (85.9%) of moisture but later dried rapidly. Moisture content of Sample-2.1 dropped to 13.8% from 56.5%. Sample-2.2 also showed almost similar results- decreased to 20.1% from 52%. Likewise, Sample-3.1 and Sample-3.2 first contained 34.9% and 37.5% moisture respectively, which later decreased to 10.02% and 15.9% correspondingly. **Figure-6.1** illustrates a comparison of moisture content rate in different phases.

Table-6.2: Moisture Content Tests Results

Sample No.	Moisture Content	
	1st Phase (in October, 2013)	2nd Phase (in January, 2014)
Sample-1.1	85.90%	13.00%
Sample-2.1	56.50%	13.80%
Sample-2.2	52.00%	20.10%
Sample-3.1	34.90%	10.02%
Sample-3.2	37.50%	15.90%

Source: Results obtained from the experiments conducted at SRDI

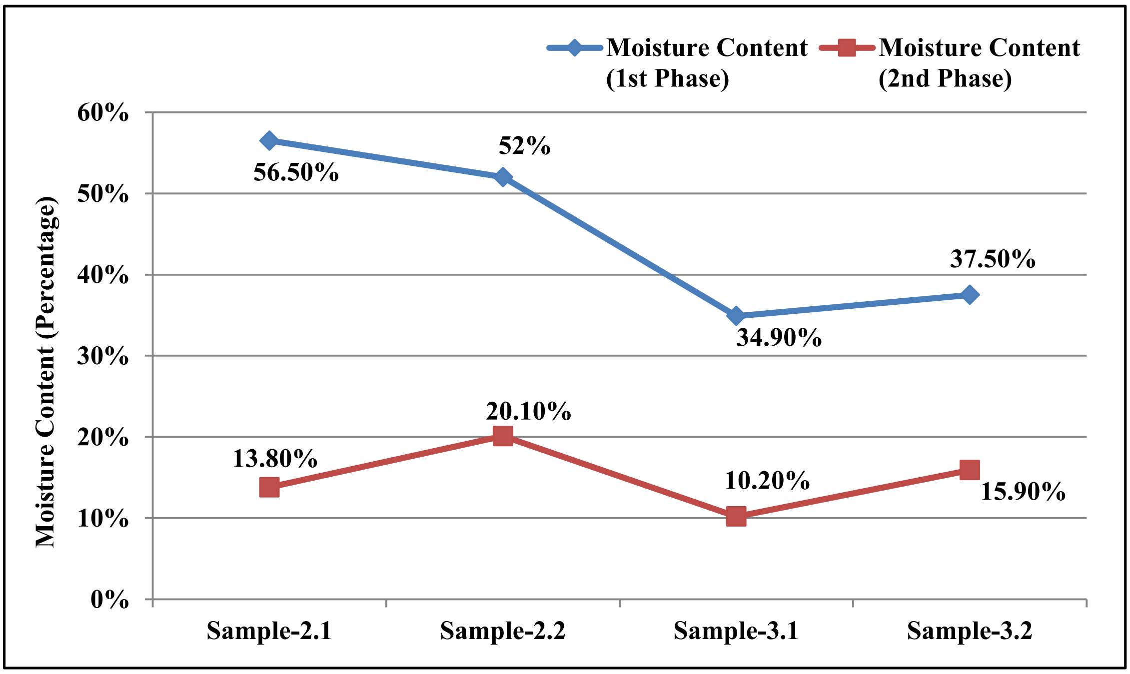


Figure-6.1: Comparison of Moisture Content Rate in First and Second phase of the Experiments

6.3.1.2 Particle size of treated samples

After six months, particle size of the organic waste changed and dried up. With the impact of lime and cement (where added), moisture contained in the waste was decreased, which made the treated waste somewhat granular. All the samples, except Sample-1.1 showed same results. **Photograph-6.1** shows the change of particle size before and after treatment.

(a) Organic Waste at Initial Stage (b) Organic Waste after 6 months of Treatment

Photograph-6.1 (a, b): Difference of MSW Particle Size before and after Treatment

6.3.1.3 Saturated hydraulic conductivity

Saturated hydraulic conductivity test has been conducted along with density test to assume the field condition, since the entire research has been experimented in the laboratory. **Table-6.3** shows the detail results of different samples at saturated condition with exact density. These test results reveal that Hydraulic Conductivity rate of Sample-2.1 will be 8.44×10^{-3} cm/s if it is filled in the ground at 0.625 gm/cm^3. The tests results also show Sample-2.2 has 13.74×10^{-3} cm/s hydraulic conductivity at 0.678 gm/cm^3 density. If Sample-3.1 is dumped in the ground at 0.716 gm/cm^3, the hydraulic conductivity will be found 9.81×10^{-3} cm/s. In addition to that Sample-3.2 will have 9.23×10^{-3} cm/s hydraulic conductivity at 0.647 gm/cm^3 density at per cubic centimeter. **Figure-6.2** graphically presents hydraulic conductivity (cm/1000s) of different samples.

Table-6.3: Saturated Hydraulic Conductivity Tests Results with Density

Sample No.	Saturated Hydraulic Conductivity (cm/s)	Density (gm/cm^3)
Sample-2.1	8.44×10^{-3}	0.625
Sample-2.2	13.74×10^{-3}	0.678
Sample-3.1	9.81×10^{-3}	0.716
Sample-3.2	9.23×10^{-3}	0.647

Source: Results obtained from the experiments conducted in February, 2014 at Department of Soil, Water & Environment of the University of Dhaka

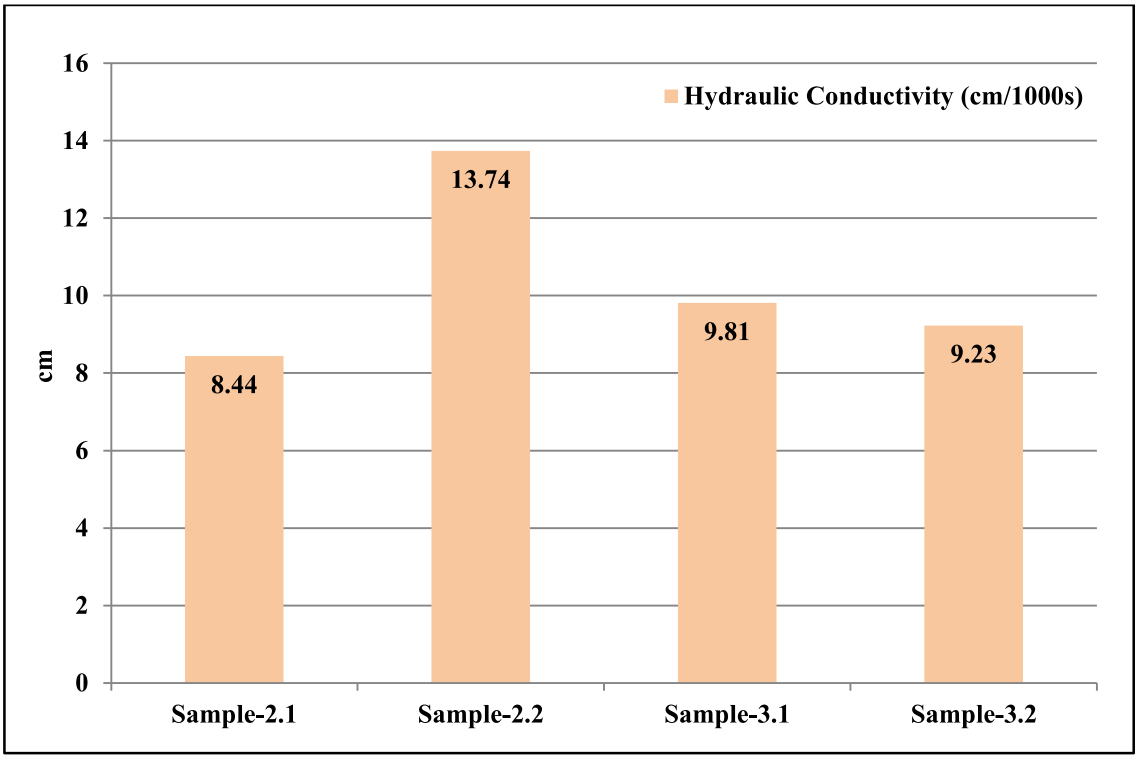


Figure-6.2: Saturated Hydraulic Conductivity Value of the Treated Samples

6.3.1.4 Temperature

Temperatures of different samples were measured periodically at an interval of two weeks with a digital Thermometer. The interaction of lime with organic waste and soil in all samples, except Sample-1.1, results in changes in sample properties. Quicklime reacts with moisture in the waste and soil according to the following equation, which is highly exothermic:

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat} \uparrow$$

Later, temperatures gradually dropped and became equal to room temperature.

6.3.2 Chemical tests

Chemical test, especially pH value is very significant as it specifies the nature of material. In this research, pH values have been determined once in October, 2013 and second in January, 2014 after the treatment of samples in May, 2013. The Chemical test was conducted at Soil Resource Development Institute (SRDI) under the Ministry of Agriculture using Gravimetric method. The purpose of this test was to study the nature of the samples and at the same time, to observe the changes might be happened after some intermission.

6.3.2.1 Analysis of test results of pH value

pH test results have exposed that all the samples are Alkali type in nature. The first phase tests results showed pH value of Sample-1.1 was 9 where Sample-2.1 and Sample-2.2 both had pH 7.3. Sample-3.1 and Sample-3.2 had pH 7.5 and 7.2 respectively. The second phase tests results revealed a bit decrease of pH in all samples, which ranges from 7.0 to 7.3. Details of test results are presented in the **Table-6.4** and comparisons are shown in **Figure-6.3**.

Table-6.4: Tests Results of pH value

Sample No.	pH value	
	1st Phase (in October, 2013)	2nd Phase (in January, 2014)
Sample-1.1	9	7.2
Sample-2.1	7.3	7.1
Sample-2.2	7.3	7.0
Sample-3.1	7.5	7.3
Sample-3.2	7.2	7.2

Source: Results obtained from the experiments conducted at SRDI

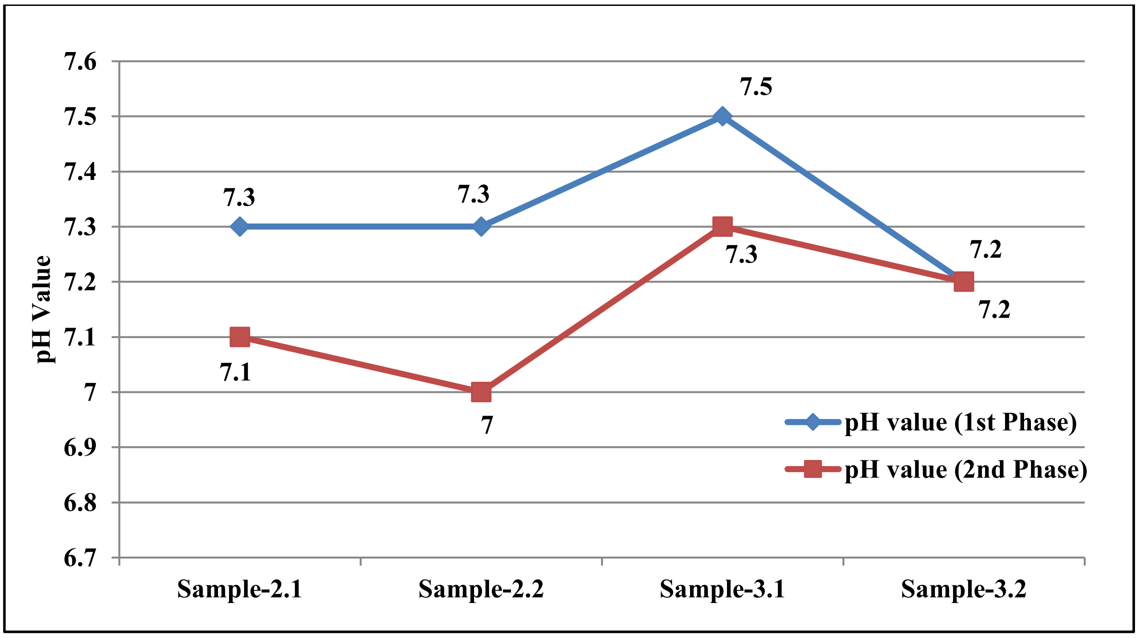


Figure-6.3: Comparison of pH Value of the Treated Samples

6.3.3 Bacteriological tests

Bacteriological test have been carried out to ascertain the presence of pathogens and to observe their progress with a view to determining the possibility of ground water contamination after land filling. Three indicator bacteria have been studied for hygienic evaluation of treated samples at Environmental Microbiology Laboratory of ICDDR’B using Membrane Filtration & Spread Plate.

6.3.3.1 Total coliforms

Total Coliforms tests were conducted first in October, 2013 and later in December, 2013. The tests results showed that the presence of Total Coliforms decreased substantially. The first phase tests results ensured that the amount of Total Coliforms in per gram of Sample-1.1, Sample-2.1, and Sample-2.2 were 1520 CFU, 2090 CFU, and 900 CFU respectively. In Sample-3.1 Total Coliforms were found 2850 CFU/gm, where 1330 CFU/gm were found in Sample-3.2. Detail tests results are presented in **Table-6.5**.

Table 5.5: Total Coliforms Test Result

Sample No.	Amount of Total Coliforms (CFU/gm)	
	1st Phase (in October, 2013)	2nd Phase (in December, 2013)
Sample-1.1	1520	4
Sample-2.1	2090	6
Sample-2.2	900	0
Sample-3.1	2850	4
Sample-3.2	1330	90

Source: Results obtained from the experiments conducted at Environmental Microbiology Laboratory of ICDDR’B

Second phase test results determined that Sample-1.1 and Sample-2.1 had 4 CFU/gm and 6 CFU/gm respectively, where Sample-2.2 had nil. At the same time, the presence of Total Coliforms in Sample-3.1 and Sample-3.2 were found 4 CFU/gm and 90 CFU/gm respectively. The tests results are graphically presented in **Figure-6.4.**

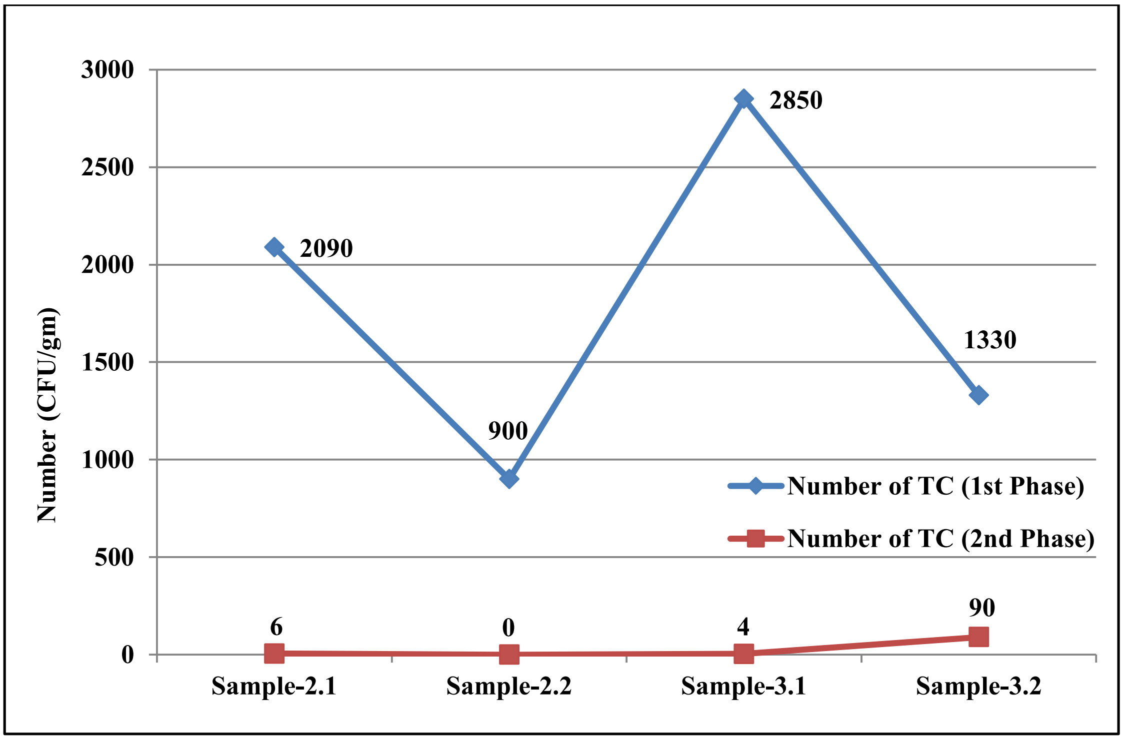


Figure-6.4: Decrease of Total Coliforms (TC) in the Treated Samples

6.3.3.2 Faecal coliforms

The presence of fecal coliform often indicates recent fecal contamination, meaning that there is a greater risk that pathogens are present than if only total coliform bacteria is detected. In the studied samples, the presence of fecal coliforms was not found.

6.3.3.3 Escherichia coli

E. coli is a sub-group of the fecal coliform group. The presence of E. coli indicates a strong likelihood that human or animal wastes are present. In the studied samples, the presence of E. coli was not found.

6.4 Findings of Tests Results

6.4.1 Findings of physical tests

From the experiments, it can be said that moisture content of all samples decreases sharply over time. It became to almost one-third after eight months with comparison to the content rate after six months in each samples. The samples dried up in due course because of the presence of lime and cement but soil also contained some moisture. Saturated Hydraulic Conductivity with density tests indicates that the result will remain same at the highest level of water in field condition, if the land is filled with the material having density asserted in the test results. The tests results reveal that Sample-2.1 has relatively low conductivity, where conductivity of Sample-3.1 and Sample-3.2 is little bit higher. In contrast, conductivity in Sample-2.2 is the highest in comparison to other samples. Except Sample-1.1, temperature of other samples increased due to addition of lime. Lime caused exothermic reactions with moistures presented in the samples and resulted the increase of temperature to above 60^0 centigrade. Later, the temperature decreased and remained same as room temperature. In addition to that, particle size of the treated organic waste became granular due to the presence of lime and cement (where added). Besides these, no bad smell was emitted during the study.

6.4.2 Findings of chemical tests

The experiments revealed, there was slightly shift in pH toward neutral in all treated samples. After six months, pH values of different samples were found ranging from 7.2 to 9. But in eight months pH values varied in a close range of 7.0 to 7.3 for different samples. All samples were found very mild alkali, which is suitable for land filling.

6.4.3 Findings of bacteriological tests

The studied bacteria are prolific in the soil. But despite the presence of soil in the samples, these bacteria were not developed rather decreased in substantial number due to presence of lime. At the end of the study period, the presence of Total Coliforms was found very few in numbers which indicates a very low probability of disease organisms being present. The study also revealed that Fecal Coliforms and E. Coli were fully absent in the studied samples.

6.5 Conclusions

Setting various physical, chemical, and biological parameters, several experiments were performed on five different samples, including Sample-1.1 for acquiring experimental results of this study. Physical parameters were set to recognize the physical characteristics of the studied samples, and chemical parameter was fixed to understand the prospective chemical reactions of those samples at the field level. Bacteriological parameters were set to discover the scale of risks of groundwater contamination near the landfill site, if the studied samples were used as land filling materials. This study was limited to small-scale laboratory testing on treated samples, hence, large-scale laboratory and field studies are required to systematically assess the influence of stabilizing additives on the geotechnical properties of MSW. Nevertheless, the tests results have already confirmed the aptness of using MSW as land filling materials in accordance with the developed techniques. Moisture, temperature, hydraulic conductivity, and alkalinity in the treated samples are found in suitable ranges where the number of harmful bacteria has surprisingly been controlled with the developed techniques.

CHAPTER-7: SELECTION & ESTABLISHMENT OF THE CONVERSION TECHNIQUE

CHAPTER-7: SELECTION AND ESTABLISHMENT OF THE CONVERSION TECHNIQUE

7.1 Introduction

Municipal solid waste was collected from different sites of Dhaka city and subsequently the organic waste was separated and treated following four different techniques. Improvements of those treated samples were observed through laboratory testing at predetermined intervals. Now, critical evaluation of the developed techniques are necessary before finalizing a waste conversion technique. In this chapter, comparative analysis of the developed techniques are done considering the testing parameters set for this study as indices. Apart from that, each of the developed waste treatment techniques have been appraised to determine the potential costs of the treatment. Gradually, a technique has been evolved from the assessments to attain the research goal. Efforts have been made as well to fit the developed technique in Bangladeshi local context.

7.2 Indexing Method

Indexing method was followed only for assessing the experiments results of the treated samples. During this research, different binding materials and soil were added at different proportion to stabilize as well as to improve the physical and chemical properties of the organic waste. Different parameters, in particular, Moisture Content, Hydraulic Conductivity, pH, Total Coliforms, Faecal Coliforms, and Escherichia coli were set to conduct several tests on the treated samples. Those parameters are actually indices which indicates the suitability of the treated samples as safe land filling material. Hence, the experiments results are need to be compared with each other to determine the best conversion technique. **Table-7.1** compiles first and second phase tests results of the treated waste samples.

Table-7.1: Experiments Results of the Treated Sample according to the Selected Parameters

Parameters / Sample No.	Moisture Content (%)	pH Value	Total Coliforms (CFU/gm)	Hydraulic Conductivity (cm/s) With density (gm/cm^3)
	1st Phase (October, 2013)			
Sample-2.1	56.50	7.3	2090	-
Sample-2.2	52.00	7.3	900	-
Sample-3.1	34.90	7.5	2850	-
Sample-3.2	37.50	7.2	1330	-
	2nd Phase (December, 2013)			
Sample-2.1	13.80	7.1	6	8.44×10^{-3} at 0.625
Sample-2.2	20.10	7.0	0	13.74×10^{-3} at 0.678
Sample-3.1	10.02	7.3	4	9.81×10^{-3} at 0.716
Sample-3.2	15.90	7.2	90	9.23×10^{-3} at 0.647

Source: Compiled by Author from the experiment results

Moisture content rate of all treated samples declined over time at a considerable rate, but the results of Sample-2.1 and Sample-3.1 are mentionable. Moisture content rate in Sample-2.1 went down almost one fourth, where in Sample-3.1, it decreased to below one third of previous rate. **Figure-7.1** presents the comparison of moisture content rate in the treated samples.

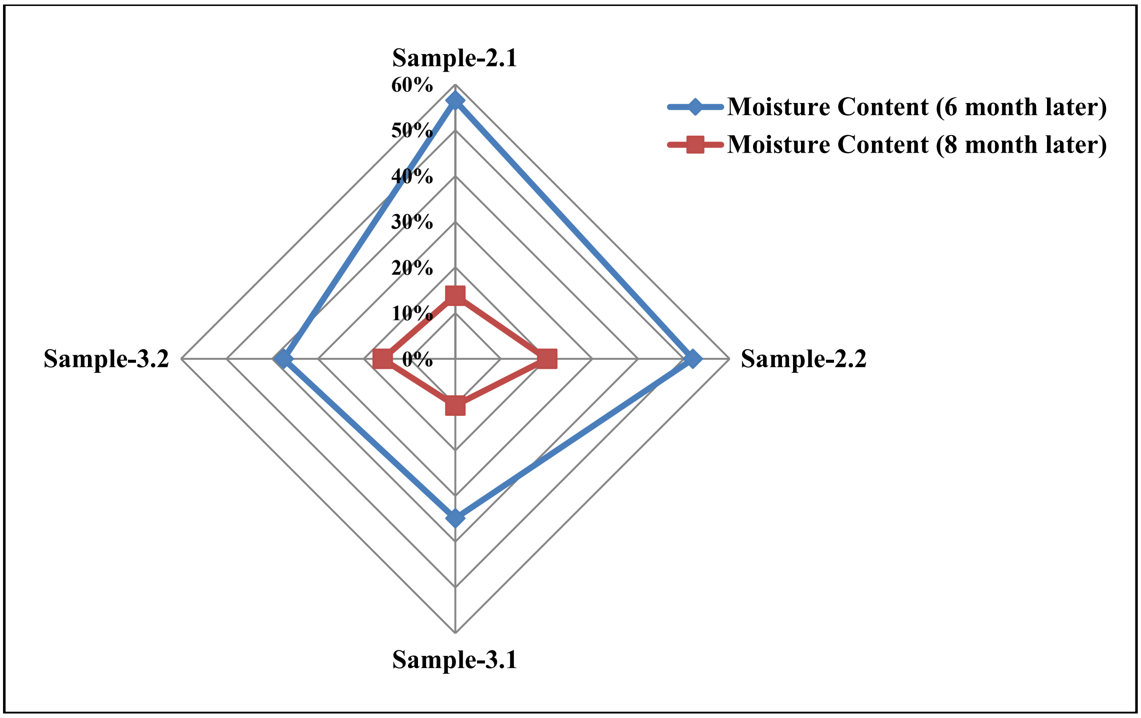


Figure-7.1: Decrease of Moisture Content Rate (%) in the Treated Samples

The hydraulic conductivity tests revealed that Sample-2.1 has the lowest conductivity. Sample-3.1 and Sample-3.2 have almost same results but considering the density Sample-3.1 has lower conductivity than Sample-3.2. The results are shown in **Figure-7.2**.

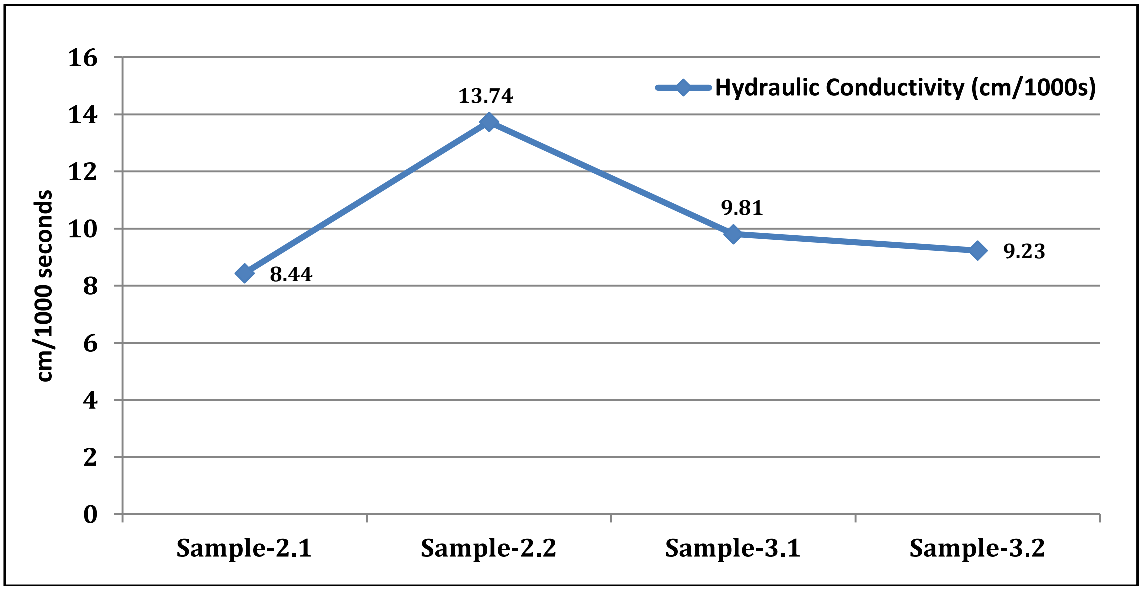


Figure-7.2: Comparison of Hydraulic Conductivity Rate of Treated Samples

pH tests results showed that pH value of all treated samples remained almost same ranged from 7 to 7.5. Sample-2.2 had the lowest pH of 7 and Sample-2.1 had the second lowest pH of 7.1. **Figure-7.3** presents a comparison of decrease of pH value in the treated samples over time.

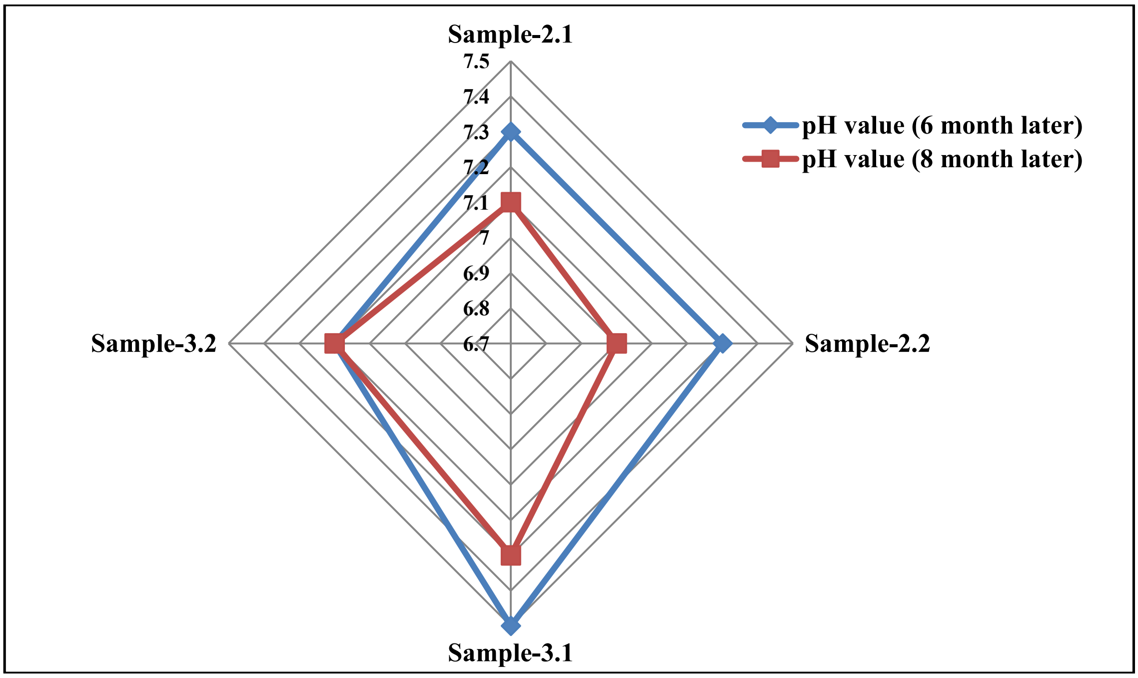


Figure-7.3: Decrease of pH Value in the Treated Samples

Changes in the physical and chemical characteristics of the waste induce changes in its microorganism. It helps to decrease the microbiological elements that cause the degradable of waste and create leacheat. Faecal Coiforms and E. Coli. were not found in the samples, whilst Total Coliforms were present in the samples but the quantity decreased dramatically and became almost zero at the end of the study. About eight months later, 6 CFU/gm of Total Coliforms were found in Sample-2.1, 4 CFU/gm in Sample-3.1, and 90 CFU/gm in Sample-3.2. No Coliforms were found in Sample-2.2 at the end of the study period. **Figure-7.4** illustrates decrease of Total Coliforms (CFU/gm) in the treated sample over the study period.

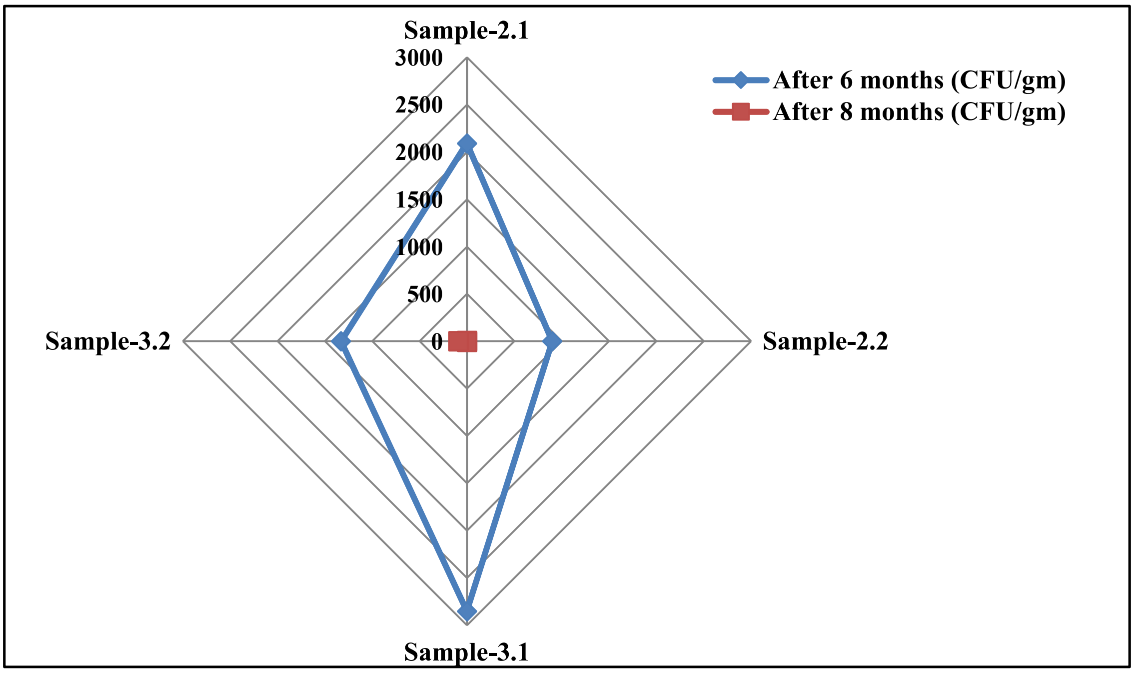


Figure-7.4: Decrease of Total Coliforms (CFU/gm) in the Treated Samples

7.3 Cost-benefit Analysis

Four samples were developed with different techniques-mixing with soil, lime and cement at different proportions, which made the samples hetero in density. For the same reason, the cost of different techniques varies from each other. Moreover, if the treated waste can be sold after 8 months of treatment, say at par Tk 50 for 1 m^3 of treated waste, it will recover a small portion of costing. Apart from that, after JICA study [10], it is already estimated in **Section-2.9** that approximately Tk 169 is currently supposed to be required for operation and management of per m^3 of waste. So, Tk (169+50) or Tk 219 can be deducted from the developed treatment cost. **Table-7.2** presented the proposed and additional treatment costs of organic MSW according to the developed samples.

Table-7.2: Treatment Cost (in Tk) of Organic MSW according to the Developed Samples

Developed Samples		Materials Cost (in Tk) for Treatment of per Tonne of Organic Waste				Treatment Cost (in Tk) for per m³ Volume of Organic Waste	Additional Costing (Extra of Tk 219)	
Sample No.	**Density**	**Lime**	**Cement**	**Soil**	**Total Treatment Cost**		**(in Tk)**	**(in percent)**
1	**2**	**3**	**4**	**5**	**6**	**7***	**8****	**9*****
Sample-2.1	(0.625 t/m^3)	600	-	76	**676**	**423**	**204**	**93%**
Sample-2.2	(0.678 t/m^3)	1050	-	76	**1126**	**763**	**544**	**248%**
Sample-3.1	(0.716 t/m^3)	450	1280	64	**1794**	**1285**	**1066**	**487%**
Sample-3.2	(0.647 t/m^3)	1050	1520	-	**2570**	**1663**	**1444**	**659%**

N.B.: [This cost has been estimated assuming Lime 15 Tk/kg, Cement 400 Tk per bag (50 kg.), and Gravellier Soil 2000 Tk per truck (5 tonnes or 200 cft or 5.66 cubic meter)]

* Calculated by multiplying Column 2 and Column 6

** Calculated by deducting 219 from Column 7

*** Percentage of Column 8 of 219

Source: Estimated by author

The above table depicts that if organic portion of solid waste can be treated in proportion to the techniques developed for treating the samples, it will cost about Tk 676 to Tk 2570 to treat per tonnes of waste. The table also presents that for the same, the cost ranges from Tk 423 to Tk 1663 for per cubic meter volume of waste. Sample-2.1 has the lowest and Sample-3.2 has the highest treatment cost. For Sample-2.1, additional Tk 204, for Sample-2.2 additional Tk 547, for Sample-3.1 additional Tk 1066, for Sample-3.2 additional Tk 1444 will be required for treatment of organic waste.

The current study has been undergone with a view to minimizing the hitch associated to land filling, and converting the municipal solid waste into desired environmentally compatible using simple techniques. Comparatively, land filling requires lowest cost but it occupies a large portion of land which remains unused for next few years. After that more land is required for developing new landfill site. At the same time, the previous land filling site becomes the breeding ground of insects, and creates odor, greenhouse gases, leachate that contaminate nearby groundwater. The research conducted such a way so that the treated waste can be sold after 8 months of treatment as land filling material, and the landfill site can be used for lifetime. The prospective benefits from the proposed methods are highlighted in **Table-7.3**.

Table-7.3: Benefits of Land filling according to the Treated Method

Methods	Odor	Emission of GHG	Water Pollution	Microbiological activities
Sample-2.1	nearly absent	Low	very low	nearly absent
Sample-2.2	nearly absent	Low	very low	nearly absent
Sample-3.1	nearly absent	Low	very low	nearly absent
Sample-3.2	nearly absent	Low	very low	nearly absent

Source: Compiled by author based on the experiments results of the current study

It presents that odor is almost absent in every treated samples, whereas the possibility of GHG emissions is comparatively low than other land filling techniques. Microbiological development was halted by the additives so, water pollution rate was decreased. The main attempt of this study is to convert MSW into safe land filling material in terms of having less air, water and soil pollution. As [23] reported, economical feasibility is not the only factor that drives the waste management system, rather a sustainable waste management system needs to be environmentally sound and socially acceptable. Initially the estimated cost of the developed technique seems high, but if the potential benefits from the proposed methods are considered then the cost will be assumed feasible. Hence, the cost norms here may be considered as an indicative cost.

7.4 Selection of a Conversion Technique

The research specifies that land filling can accept most of the waste generated everyday with very low level technology for handling the waste. The present study went through a systematic procedure, including-field survey, primary and secondary data analysis, conducting several experiments, and comparative and cost-benefit analysis. The experiments outcome revealed that all the treated samples has shown almost same results, i.e. reduction of odor and decrease of microbiological organisms at a mentionable rate. Coupled with these, pH value and hydraulic conductivity rate make those suitable for land filling ensuring the less possibilities of leachate generation.

In addition, all the treatment costs vary a wide range- Tk 423 to Tk 1663 for per cubic meter volume of waste where, Sample-2.1 has the lowest and Sample-3.2 has the highest treatment cost. For Sample-2.1, additional Tk 204, for Sample-2.2 additional Tk 547, for Sample-3.1 additional Tk 1066, for Sample-3.2 additional Tk 1444 will be required for treatment of organic waste. In brief, the experiment results and cost-benefit analysis reveal that the techniques inducted in Sample-2.1 will add comparatively low cost than the other techniques while attaining the same benefits. Hence, it is worthwhile to select the technique inducted in Sample-2.1 for conversion of municipal solid waste as safe land filling material as Bangladesh context.

7.5 Proposed Waste Management System

Segregation at source is found as the main solution in curbing the problem regarding solid waste management, which at the same time help to achieve zero discharge at local level. Waste segregation makes easier to dispose waste by saving time, energy and money. Most of the developed countries used waste reduction at sources technique that means collection of different sorts of wastes in different containers. In contrast, most of the developing countries including Bangladesh follow the traditional method where a substantial amount of recyclable and reusable products are separated from the waste at secondary collection points or at landfill sites. Moreover, waste segregation at source has already been introduced in some part of Dhaka city as pilot basis. The organic waste is collected by some private entrepreneurs for making compost.

In the proposed waste management system, segregation of waste at source is also suggested, where organic waste will be collected in separate container and will be dumped in a specific dustbin or container placed in the secondary collection points. The organic waste then will be transported by waste collection vehicles to the landfill sites. The weigh bridge of the landfill site will keep record of incoming waste and before final disposal, the organic waste will be mixed with lime and soil at exact proportion of Sample-2.1 at a separate area that will be earmarked at the landfill site. **Figure-7.5** illustrates the flow-diagram of proposed waste management system according to the current study.

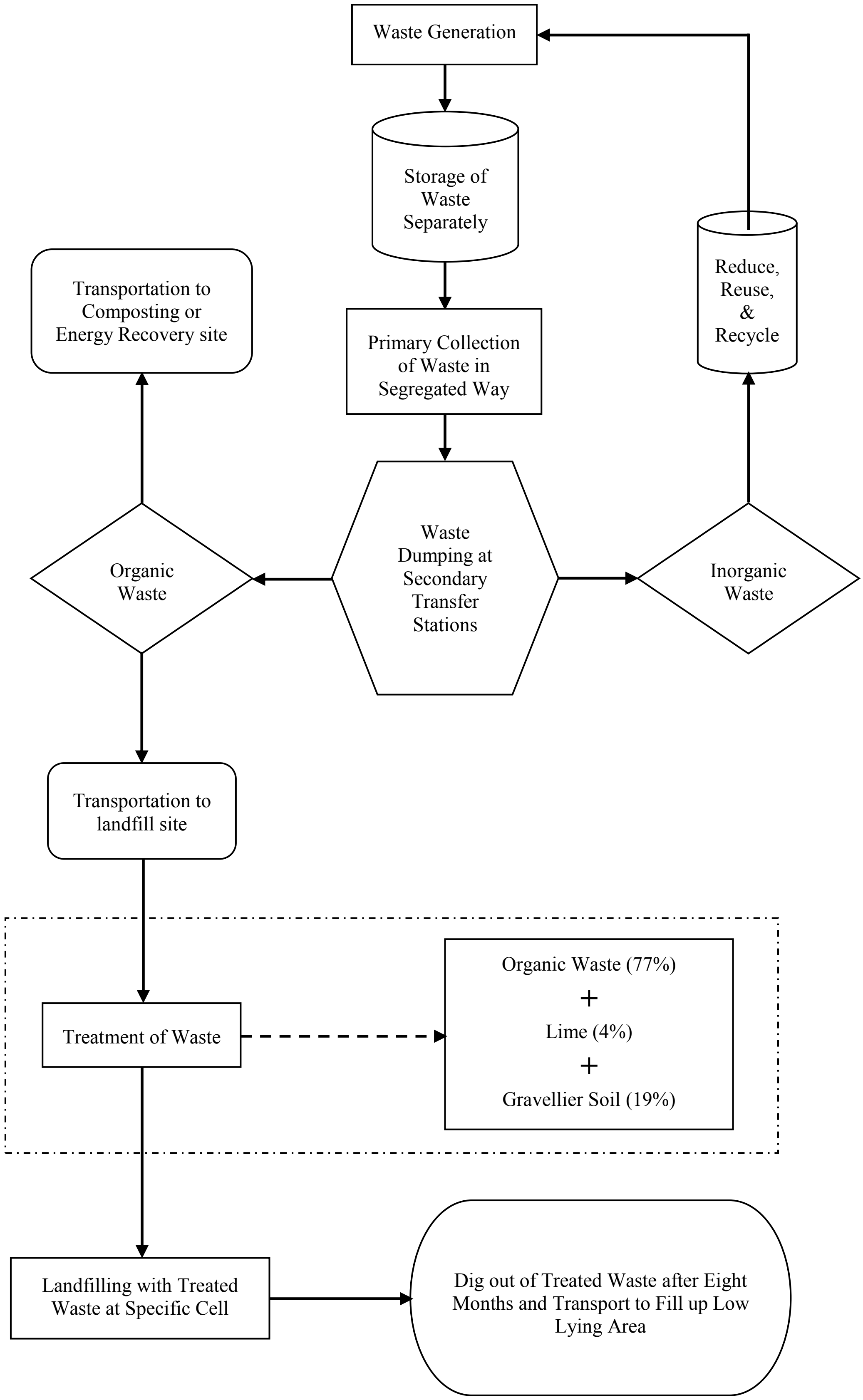


Figure-7.5: Flow Diagram of Proposed Waste Management System

Particle size of organic wastes and evenly distribution of the additives are important for the treatment of waste according to the developed technique. Bulldozer and Excavator are the common equipment used in the landfill site for conveying landfill operation. The primary shredder is suggested additionally to chop out the organic waste into smaller size which ultimately makes easier to mix the waste with stabilizers. The primary shredder is a slow running single-shaft shredder, which is used mostly for the pre-shredding of non-treated domestic waste, commercial or industrial waste, bulky waste, waste wood, mixed building construction waste, etc. The primary shredder has a throughput capacity of 50 t/h for domestic waste (output granulate approx. 100 – 300 mm) [102]. **Photograph-7.1** illustrate the picture of a Primary Shredder.

Photograph-7.1: Primary Shredder Proposed for Size Reduction of Organic Waste, adapted from [102]

Trommel drum screens are also suggested for physical size separation of organic waste and for mixing the organic waste with stabilizer additives. A trommel screen, also known as rotary screen, is an essential unit which is used mainly in the mineral and solid-waste processing industries. It consists of a perforated cylindrical drum which is normally elevated at an angle at the feed end. Physical size separation is achieved as the feed material spirals down the rotating drum, where the undersized material smaller than the screen apertures passes through the screen, while the oversized material exits at the other end of the drum [103]. **Photograph-7.2** presents the picture of a Trommel drum screen.

Photograph-7.2: Trommel Drum Screen Proposed for Physical Separations and Mixing Organic Waste with Stabilizers, adapted from [104]

7.6 Layout Plan of a Landfill Site Suitable for the Developed Technique

According to the BMDF, the draft final solid waste management handling rules, 2010 has already been approved by Ministry of Environment and Forest prepared under the ECA and sent to Ministry of Law, Justice and Parliamentary Affairs for final approval. The rule focused on necessary detailing from collection of waste to its final disposal [53]. The BMDF [53] identified several provisions included in the Draft Final Solid Waste Handling Rules, 2010 regarding facilities at landfill site:

- Landfill sites must be fenced or hedged and must be provided with a proper gate to monitor incoming vehicles or other modes of transport.
- Landfill sites must be well protected to prevent entry of unauthorized persons and stray animals.
- Approach and other internal roads for free movement of vehicles and other machinery must exist at the landfill site.

- Landfill sites must have a waste inspection facility to monitor waste brought to the landfill, an office facility for recordkeeping, and a shelter for equipment and machinery, including pollution-monitoring equipment.
- A weigh bridge to measure the quantity of waste brought to the landfill, fire protection equipment, and other facilities should be provided as required.
- Utilities such as drinking water and lighting arrangements for easy landfill operations when carried out in night hours must be provided. If possible, bathing facilities for workers should be provided.
- Safety provisions, such as health inspection for landfill workers, must be periodically made.

The proposed layout plan has been designed keeping in mind the provision mentioned in the rules. In a sanitary landfill, a cell is made up with compacted waste and soil cover (daily, intermediate, and final). But the technique developed in this study need neither any sorts of soil cover nor any layer systems during the filling operation to control nuisances or to protect the environment and public health. The proposed layout plan also encompasses modern facilities of a landfill sites, which include- weigh bridge, monitoring and control room, R&D lab, vehicle wash facilities, waste water treatment facilities, vehicle/spare parts maintenance garage, office room and staff quarters. Besides these, a store room for stabilizing additives and a large space for waste treatment are also proposed in this plan. Sufficient internal road networking with proper drainage facilities are provided as well. **Figure-7.6** presents the layout of a landfill site designed for the present study.

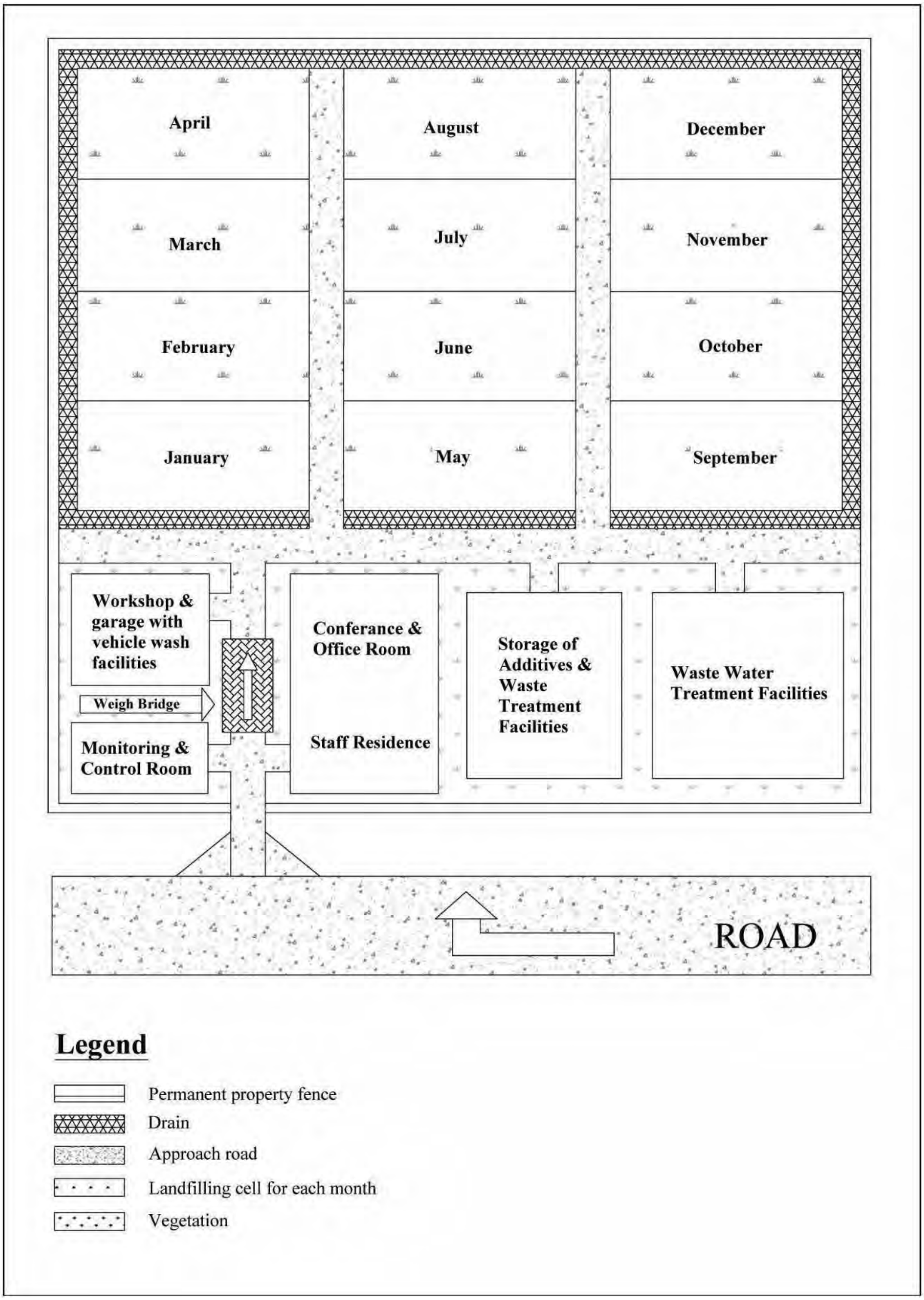


Figure-7.6: Layout of a Landfill Site compatible with Present Study

Twelve cells have been proposed in the layout plan keeping in mind the twelve month of a year. Each cell will have been filled up in each month rotationally with the treated organic waste. This technique will help to dig out the waste after eight months (32 weeks) of dumping when the treated waste will show the same results as of Smaple-2.1. The converted waste can be transferred to fill up any low land as a safe landfilling material, might be in exchange of money if demand increases. The empty cell will be used again for filling with new treated waste. This process will be found more viable in term of capital budgeting as the same landfill site can be used for years after years without increasing the demand of new land for site development. In this process the lifetime of an existing landfill site will increase which will surely decrease the average operational cost.

If DNCC & DSCC want to design a landfill site according to this proposed layout plan assuming the treated organic waste amount 1000 tonnes/day, total 30000 tonnes or 31000 tonnes organic waste have to be accommodated in a month. With the density of 0.625 gm/cm^3 measured for Sample-2.1 during Hydraulic Conductivity Tests (**Table-6.3**), total volume per month of those treated organic waste is calculated below:

$$\text{Total Volume}_{(30\ \text{days})} = \frac{\text{Total treated organic waste}}{\text{Density}} = \frac{30\times10^6\ \text{kg/month}}{625\ \text{kg/m}^3} = 48000\ \text{m}^3\text{/month}$$

Where,
Total incoming organic waste = 30000 t/month = 30×10^6 kg/month
Density = 0.625 gm/cm^3 = 625 kg/m^3

$$\text{Total Volume}_{(31\ \text{days})} = \frac{\text{Total treated organic waste}}{\text{Density}} = \frac{31\times10^6\ \text{kg/month}}{625\ \text{kg/m}^3} = 49600\ \text{m}^3\text{/month}$$

Where,
Total incoming organic waste = 31000 t/month = 31×10^6 kg/month
Density = 0.625 gm/cm^3 = 625 kg/m^3

From this calculation, the total cell area with 4 m depth can be estimated 12000 sq. meters for a month of 30 days and 12400 sq. meters for a month of 31 days. Based on this estimation, the layout plan allocate 14.72 hectares land for waste dumping cell. Another 5 hectares will be enough to provide other land filling facilities. So it can be said that about 20 hectares area is required to develop a landfill site according to the proposed layout plan which can house incoming organic waste amount 1000 tonnes/day.

7.7 Conclusions

The treated samples have been scrutinized in *Indexing Method*, and through *Cost-benefit Analysis*. Experimental parameters set previously considered as indices and in Cost-benefit analysis, cost of different developed methods has been estimated based on the current rate of lime, cement, and soil in Bangladeshi currency (Taka). The comparative analysis reveals that all the developed techniques have almost same results but the treatment costs vary a wide range. Considering the evaluation of experimental results and cost-benefit analysis, the Sample-2.1 (consisted of 77% organic waste, 4% lime and 19% gravellier soil) has been selected for converting municipal solid waste into safe land filling material. Apart from that, a waste management system has been proposed in context of the Dhaka city for the establishment of the developed technique by the city corporations. At the same time, a layout plan has been designed to accommodate the developed technique with existing landfill process.

CHAPTER-8: SUMMARY AND CONCLUSIONS

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This chapter will restate a brief of the study, including major findings and implications with concluding remarks. Some limitations of the current study and the agenda for future study are mentioned as well.

8.1 Summary

Large and rapid growing cities in the world is experiencing serious difficulties in dealing with ever increasing waste disposition burden. Increasing population, urbanization, industrialization, and changing consumption patterns are the reasons behind the generation of increasing amounts of solid waste and diversification of the type of the solid waste generated, which create an adverse effect on environment as well as social and professional life. Still now, land filling is the simplest, and most economical means of disposing of municipal waste around the world. Several studies proved that landfill gas (LFG) is a result of biodegradation of organic matter in the refuse, and since 50-70 percent of MSW is biodegradable, LFG production can be substantial. Stabilization/Solidification (S/S) is considered to be an effective technology for alternative forms of disposal, which is likely to encourage by the authority in different countries. Likewise, in many countries lime stabilization has been used for years to reduce odor and pathogens before land application. The advantages include low cost of lime and easy disposal of treated waste.

Urbanization rate stands nearly at 6% in Bangladesh, where about 13% of the total population is concentrated in six metro cities, including the capital city Dhaka. Reportedly, more than 522 urban areas in Bangladesh accumulate 13,332 tons of waste per day or 4.86 million tons annually. Generation of MSW increases proportionately with the growth of urban population, which makes difficult for most of the urban local bodies to keep pace with the demand for adequate waste management. It is projected that in Bangladesh the waste amount will grow up to 47,000 tons/day and close to 17.2 million tons per year by 2025. Several studies established that in the entire waste stream organic matters varied over a wide margin ranging from about 55% to 88% whereas, paper and plastic varied from about 1 to 11% and 1 to 7% respectively. It is reported that during the wet season the rate of waste generation increases by 46%. In Bangladesh, City Corporations and Paurashavas (municipalities) are authorized to manage MSW generated within their jurisdiction area. Dhaka, the capital of Bangladesh has two city corporations, namely Dhaka South City Corporation (DSCC) and Dhaka North City Corporation (DNCC) to govern the city. Waste management of the Dhaka city is entrusted to the DSCC and the DNCC within their jurisdiction.

Reportedly, Dhaka is most densely populated (55,500 per sq. km) city in the world with almost 15 million inhabitants. An estimation shows, jointly the DNCC and the DSCC generates approximately 1.6 million tons of municipal waste per year. Around 60-80% of the total waste was organic as reported by Waste Concern. Some studies revealed that in Bangladesh about 2.19 million tons of CO_2e is emitted per year from the total generated urban waste, where the two Dhaka city corporations collectively emit approximately 1 million tons of GHG annually. As stated in the *Clean Dhaka Development Master Plan*, appropriate solid waste management system in Dhaka would be a combination of several technologies because disposal amount in Dhaka would exceed 3,000 t/d in year 2015. Hence, it would be a practical approach to establish a base system at first consisting of landfill, and once the base system is established, other systems, for instance, composting or incineration can be introduced with less difficulty. The current study aimed to induce an effective and simple (low technology) technique for treating organic wastes as part of its waste management system with a view to minimizing the negative environmental impacts of municipal solid waste. The study emphasized on the traditional methods for stabilization of municipal solid waste in Bangladesh context so that it can be readily deployed at any site.

Like most of the cities around the world, in Dhaka waste collection consists of two parts, namely, primary collection and secondary collection. It is reported that waste Management Departments (WMD) of the two Dhaka city corporations are responsible for solid waste management and about 7961 cleaners are employed for street sweeping and collection of waste found in places other than dustbin, road side, open spaces, ditches etc. by hand trolley. Both the DNCC and the DSCC collect municipal wastes which are accumulated in corporations' bins or containers. In June 2012, total waste generation amount was estimated for the DNCC was about 2186 t/day and for the

DSCC was about 1938 t/day. DNCC was able to collect about 1100 ton of waste/day in June, 2012 whilst waste collection capacity of DSCC at that time was about 1400 t/day. For collection of accumulated waste in 180 containers, the DNCC has 115 demountable container carrier trucks, where the DSCC has 235 demountable container carrier trucks to collect accumulated waste in 270 containers. After partition of DCC, all garbage of DSCC is transported to Matuail landfill site while DNCC uses Amin Bazar landfill site. Both of these sites were developed in line with the "Clean Dhaka Development Master Plan". Major sanitary landfill components introduced under the project were the leachate collection and gas venting systems, surface drainage improvement, systematic operation of waste disposal facilities by daily covering, slope reformation, working roads, weighbridge operation, and vehicle washing facilities. Though these sites have modern waste management facilities but those cannot be classified as sanitary landfill but controlled landfill. Though the dozer, chain dozer, scraper are being used to spread the waste regularly, waste pickers salvage reusable materials from those sites.

Physical analysis of MSW collected through *Site Sampling* from different location of DNCC and DSCC, showed in the waste stream organic matters varied from about 49% to 61% whereas, paper and plastic varied from about 9.29% to 14.86% and 11% to 18.35% respectively. Over time, the share of organic wastes in the waste stream is decreasing but the percentage of paper and plastics is increasing, which indicates the growing preference for consumption of packaged food in city food habits in recent years. As stated in the *Clean Dhaka Development Master Plan*, average of apparent bulk density of solid waste in Dhaka is 0.24 t/m^3 and moisture content varies from 65% to 80%, where calorific value ranging from 2,303–3,559 kJ/kg. High moisture content and low calorific value characterize the solid waste properties in Dhaka City, which does not sustain combustion. C/N ratio in the MSW was found 16:1 which indicates that the waste needs some C/N ratio balancing before executing composting process.

Conceptual framework for this experiment was developed by reviewing literatures to collect information regarding land filling techniques. Lime is a general term for the various forms of calcium oxide or hydroxide and of less eramounts of magnesium oxide and/or hydroxide. Lime products have been used extensively in the treatment of waste for over one hundred years. Cement is a binder, a substance that sets and hardens independently, and can bind other materials together. Madhupur Tracts soils were selected for this experiment for it hardness in nature. The soils have clayey texture and contain large quantity of iron and aluminium, which are highly aggregated.

Setting various physical, chemical, and biological parameters, several experiments were conducted on four treated samples to observe the improvement at various stages of the study period. Sample-1.1 merely consisted of MSW having no additives and studied as well to compare the development under experiment. Physical parameters were set to recognize physical developments of the studied samples, and chemical parameter was fixed to understand the prospective chemical reactions of those samples at the field level. Bacteriological parameters were set to discover the scale of risks of groundwater contamination near the landfill site by the developed techniques. *Moisture Content, Temperature, Hydraulic Conductivity* with *Density* were set as physical parameters, whilst pH *value* was selected as chemical parameters for conducting this research. Bacteriological parameters included *Total Coliforms, Faecal Coliforms,* and *Escherichia coli* for conducting biological tests. More than 60 specimens were tested at predetermined intervals at *SRDI*, *Environmental Microbiology Laboratory* of ICDDR'B and *Department of Soil Environment & Water* of the University of Dhaka.

Moisture content tests results showed that moisture of all samples decreased over time at considerably rate due to the presence of lime and cement. Moisture content of Sample-2.1 dropped to 13.8% from 56.5%. Sample-2.2 also showed almost similar results- decreased to 20.1% from 52%. Likewise, Sample-3.1 and Sample-3.2 first contained 34.9% and 37.5% moisture respectively, which later decreased to 10.02% and 15.9% correspondingly. Saturated Hydraulic Conductivity with density tests indicates that the result will remain same at the highest level of water in field condition, if the land is filled with the material having density asserted in the test results. These test results revealed that Hydraulic Conductivity rate of Sample-2.1 is 8.44×10^{-3} cm/s for 0.625 gm/cm^3 density, of Sample-2.2 is 13.74×10^{-3} cm/s for 0.678 gm/cm^3 density, of Sample-3.1 is 9.81×10^{-3} cm/s for 0.716 gm/cm^3 density, and of Sample-3.2 is 9.23×10^{-3} cm/s for 0.647 gm/cm^3 density. The test results clearly demonstrate that Sample-2.1 has relatively low conductivity, where conductivity of Sample-3.1 and Sample-3.2 is little bit higher. In contrast, conductivity in Sample-2.2 is the highest in comparison to other samples. Temperature of all treated samples increased due to addition of lime. Lime caused exothermic reactions with moistures presented in the samples, which consequently increase of temperature to above 60^0 centigrade. Later, the temperature decreased and remained same as room temperature. Additionally, particle size of the treated organic waste became granular due to the presence of lime and cement (where added). Besides these, no bad smell was emitted during the study.

pH tests results showed that there was slightly shift in pH toward neutral in all treated samples. After about six months, pH values of different samples were found ranging from 7.2 to 9 and in eight months it varied in a close range of 7.0 to 7.3. All samples were found very mild alkali, which is suitable for land filling. Changes in the physical and chemical characteristics of the waste induce changes in its microorganism. It helps to decrease the microbiological elements that cause the degradable of waste and create leacheat. After about six months, tests results showed Faecal Coiforms and E. Coli. did not existed in the samples. Total Coliforms were present in the samples but the quantity decreased dramatically and became almost zero at the end of the study. After eight months, 6 CFU/gm of Total Coliforms were found in Sample-2.1, 4 CFU/gm in Sample-3.1, and 90 CFU/gm in Sample-3.2. No Coliforms were found in Sample-2.2 at the end of the study period.

Critical evaluation of the developed techniques were carried out based on the experiment results and treatment cost. Moisture Content, Hydraulic Conductivity, pH, Total Coliforms, Faecal Coliforms, and Escherichia coli were set as indices to conduct a comparative analysis among the treated samples. While Cost-benefit analysis, cost of different developed methods has been estimated based on the current rate of lime, cement, and soil in Bangladeshi currency. The entire analysis reveals that all the developed techniques have almost same results but the treatment costs vary a wide range- Tk 423 to Tk 1663 for per cubic meter volume of waste where, Sample-2.1 has the lowest and Sample-3.2 has the highest treatment cost. For Sample-2.1, additional Tk 204, for Sample-2.2 additional Tk 547, for Sample-3.1 additional Tk 1066, for Sample-3.2 additional Tk 1444 will be required for treatment of organic waste.

After technical evaluation and analysis of prospective treatment costs, the Sample-2.1 was considered the expected technique of converting municipal solid waste into safe land filling material in Bangladesh context. A waste management system has been proposed where provision of segregation of waste at source has been kept. In the proposed system, the organic waste will be treated at the landfill site and dumped instantly to avoid any further hassle. Simultaneously, a layout plan has been designed to accommodate the developed technique with existing landfill process. The key part of the design is a planned sequence of filling to achieve the expected outcome.

8.2 Conclusions

The research paper explains the fundamentals of municipal solid waste, waste composition, and waste management, examples the existing practices related to waste treatment, describes the necessity of carrying out the research, and eventually developed a conversion technique of municipal solid waste with a view to making the waste an environment-friendly product. The current study has shown if the developed technique follows, environmental and health risks associated to land filling will be decreased in a significant way. The technique balanced the moisture content rates, hydraulic conductivity rate and pH value of the treated waste such a way that it can be used as land filling materials. Moreover, the number of colony forming units of Total Coliforms bacteria in per gram were came down to almost zero which indicates the technique is safe. Additionally of present handling cost, Tk 204 will be required to treat per m^3 of waste, which is worthwhile considering the benefits will be derived from the technique. The proposed waste management system and the layout plan of landfill site will help to facilitate the developed technique within the existing mechanism. So the research findings are- environmental and health risks associated to land filling can be reduced; moisture content rates, hydraulic conductivity rate, pH value of the municipal solid waste can be controlled; an exact mixture of organic waste, lime and gravellier soil can be used as land filling material; and the conversion technique is costlier but not high-tech and can be fit in the existing waste management system.

There are still so many reasons of using municipal waste for land filling, for instance, other techniques are costlier and involve upgraded technologies, urban local bodies have low capacity of waste treatment, lack of interest of private sector in setting up waste treatment plant, and so on. Moreover, only landfill could receive and treat the whole amount of waste that generated every day. To get the optimum benefits from the techniques develop in this study, segregation of waste at source is must while at the same time, continuous R&D and training is necessary to develop technical expertise of the waste management staff of the urban local bodies.

8.3 Limitations of the Study

Though the research has been conducted dedicatedly to develop an appropriate conversion technique of municipal solid waste, the research has also some limitations. Those are:

1) The developed technology requires additional field and laboratory testing to further assess its effectiveness as a landfill barrier system.
2) Hydraulic Conductivity on different samples has been tested exclusively under laboratory conditions. Data from field conditions should have been collected to establish design values.
3) Bearing Capacity of the developed samples was required to be tested to establish the strength of those samples as land filling material. But the test has been ignored due to the high testing cost.
4) The potential impacts have been calculated without considering the seasonal effects and site-specific conditions of the exposed environment. This means that some of the potentials may not come through as real effects.

8.4 Agenda for Future Study

This study was carried out under a master's program which was cost and time bound. Considerable efforts have been placed here in establishing MSW as safe land filling materials in terms of health, environmental, and monetary aspects, however, more work needs to be done. Almost 60 tests were conducted in this study at different intervals. But to determine all the potential impacts categorically, some action researches are required to be carried out at field level in different seasons. A two or three years of observation might be sufficient to compare the consequences of laboratory experiments to the field conditions of the developed technique.

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APPENDICES

APPENDIX-A: SOME PHOTOGRAPHS OF MUNICIPAL SOLID WASTE MANAGEMENT IN DHAKA CITY

Photograph-A1: Demountable Containers full of Wastes were found during Field Survey in April, 2013 at a Permanent Secondary Waste Collection Point at Bangla Motor in Dhaka

Photograph-A2: Demountable Containers are manually being filled up with waste was observed during Field Survey in April, 2013 at a Permanent Secondary Waste Collection Point located at Banani Bazar in Dhaka

Photograph-A3: Open Secondary Waste Collection Site near Kachukhet Bazar in Dhaka was found during Field Survey in April, 2013

Photograph-A4: Open Secondary Waste Collection Site on the Road side was observed during filed survey in December, 2014 at Uttara, Sector-12 in Dhaka

Photograph-A5: Loader (Tractor) is using for Waste Loading on an Open Truck for Secondary Collection was found during Field Survey in December, 2014 at Uttara, Sector-12 in Dhaka

Photograph-A6: Spreading of Waste using Pay Loader was found during Field Survey in April 2013 at Matuail Dumping Site under DSCC

Photograph-A7: Excavator is using for Landfill Operation was observed during Field Survey in April, 2013 at Matuail Landfill Site under DSCC

Photograph-A8: Salvation of Reusable/Recyclable Materials was observed during Field Survey in April, 2013 at Matuail Landfill Site under DSCC

Photograph-A9: Drainage System at Matuail Landfill Site under DSCC was observed during Field Survey in April, 2013

Photograph-A10: Excavator is using for Landfill Operation was found during Field Survey in April, 2013 at Amin Bazar Landfill Site under DNCC

Photograph-A11: Gas vent Pipe using for Landfill Operation was found during Field Survey in April, 2013 at Amin Bazar Landfill Site under DNCC

Photograph-A12: Salvation of Reusable/Recyclable Materials was observed during Field Survey in April, 2013 at Amin Bazar Landfill Site under DNCC

a) Container Carrier

b) Open Truck

c) EGAP Vehicle (Compactor)

Photograph-A13 (a, b, c): Different types of Garbage Trucks for Secondary Collection of MSW were observed at Zonal Office (Zone-4, Mirpur) of DNCC during Field Survey in December, 2014

Photograph-A14: Picture Showing Land filling Process at Amin Bazar Landfill Site under DSCC was adapted from DNCC website (http://dncc.gov.bd/departments-with-function/department-s/solid-waste/solid-waste-2.html) on 21 March, 2015

Photograph-A15: Waste Management Workshop and Different Types of Modern Waste Transportation Vehicles used for Waste Management in Dhaka City adapted from DNCC website (http://dncc.gov.bd/departments-with-function/department-s/solid-waste/solid-waste-2.html) on 21 March, 2015

APPENDIX-B: RECORD KEEPING FORMAT

A. MSW segregation

Sample no:

Collection from:

Collection Date:

Experiment Date:

Waste Component	Weight	Percentage
Organic matter		
Paper		
Plastic		
Textile & Wood		
Leather and rubber		
Metal		
Glass		
Rubber		
Debris		
Miscellaneous		
Total		

B. pH and Moisture Content tests

Experiment Date: **Laboratory Name:**

Sample No.	Moisture Content	pH
Sample-1.1		
Sample-2.1		
Sample-2.2		
Sample-3.1		
Sample-3.2		

Method used:

C. Bacteriological tests

Experiment Date: **Laboratory Name:**

Sample No.	Total Coliforms CFU/gm	Faecal Coliforms CFU/gm	Escherichia Coli CFU/gm
Sample-1.1			
Sample-2.1			
Sample-2.2			
Sample-3.1			
Sample-3.2			

Method used:

D. Temperatures

Laboratory Name:

Date									
Sample No.	**Temperature**								
Sample-1.1									
Sample-2.1									
Sample-2.2									
Sample-3.1									
Sample-3.2									

Method used:

E. Hydraulic Conductivity tests

Experiment Date: **Laboratory Name:**

Sample No.	Hydraulic Conductivity
Sample-1.1	
Sample-2.1	
Sample-2.2	
Sample-3.1	
Sample-3.2	

Method used:

APPENDIX-C: COPIES OF TEST RESULTS

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Phone :+880-2-9840523-32/ 2405
Fax :+880-2-8812529
Web : http://www.icddrb.org

Lab. ID No.4880 | Receipt No: 22953 | Date of Reporting: 10.10.2013
Date of Sample Received: 01.10.2013

Particular of Sample: IAT SAMPLE-1.1

Client Address: MOHAMMAD RASEL KABIR, Institute of Appropriate Technology (IAT), BUET, Dhaka-1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Water Quality Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	1520	Spread Plate
2	Faecal coliforms	CFU /gm	0	Spread Plate
3	*Escherichia coli*	CFU /gm	0	Spread Plate

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Dr. Zahid Hayat Mahmud
Associate Scientist and Acting Head
Environmental Microbiology Lab, CFWD, ICDDR,B

Tested By (Code No.): 7, 8

Checked By (Code No.): 2

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Lab. ID No.4881 Receipt No: 22953 Date of Reporting: 10.10.2013
Date of Sample Received: 01.10.2013

Particular of Sample: IAT SAMPLE-2.1

Client Address: MOHAMMAD RASEL KABIR, Institute of Appropriate Technology (IAT), BUET, Dhaka-1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Water Quality Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	2090	Spread Plate
2	Faecal coliforms	CFU /gm	0	Spread Plate
3	*Escherichia coli*	CFU /gm	0	Spread Plate

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 7, 8

Checked By (Code No.): 2

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Lab. ID No.4882

Receipt No: 22953

Date of Reporting: 10.10.2013
Date of Sample Received: 01.10.2013

Particular of Sample: IAT SAMPLE-2.2

Client Address: MOHAMMAD RASEL KABIR, Institute of Appropriate Technology (IAT), BUET, Dhaka-1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Water Quality Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	900	Spread Plate
2	Faecal coliforms	CFU /gm	0	Spread Plate
3	*Escherichia coli*	CFU /gm	0	Spread Plate

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 7, 8

Checked By (Code No.): 2

ZH-Mahmud

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Web : http://www.icddrb.org

Lab. ID No.4883 Receipt No: 22953 Date of Reporting: 10.10.2013
Date of Sample Received: 01.10.2013

Particular of Sample: IAT SAMPLE-3.1

Client Address: MOHAMMAD RASEL KABIR, Institute of Appropriate Technology (IAT), BUET, Dhaka-1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Water Quality Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	2850	Spread Plate
2	Faecal coliforms	CFU /gm	0	Spread Plate
3	*Escherichia coli*	CFU /gm	0	Spread Plate

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

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Tested By (Code No.): 7, 8 Checked By (Code No.): 2

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Lab. ID No.4884

Receipt No: 22953

Date of Reporting: 10.10.2013
Date of Sample Received: 01.10.2013

Particular of Sample: IAT SAMPLE-3.2

Client Address: MOHAMMAD RASEL KABIR, Institute of Appropriate Technology (IAT), BUET, Dhaka-1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Water Quality Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	1330	Spread Plate
2	Faecal coliforms	CFU /gm	0	Spread Plate
3	*Escherichia coli*	CFU /gm	0	Spread Plate

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 7, 8

Checked By (Code No.): 2

Dr. Zahid Hayat Mahmud
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গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
মৃত্তিকা সম্পদ উন্নয়ন ইনস্টিটিউট
গবেষণগার শাখা
মৃত্তিকা ভবন, কৃষি খামার সড়ক, ঢাকা-১২১৫।

নং-কগ/৪৪(২)/০৩/ 829

তারিখ : 08/00/16

বরাবর

মোহাম্মদ রাসেল কবির
ছাত্র (এমএসসি)
আইএটি, বুয়েট।

বিষয় ঃ **Municipal Solid Waste নমুনার রাসায়নিক বিশ্লেষণের ফলাফল প্রেরণ প্রসংগে।**

উপর্যুক্ত বিষয়ের প্রেক্ষিতে আপনার প্রেরিত ০৫টি Municipal Solid Waste নমুনার রাসায়নিক বিশ্লেষণের ফলাফল নিম্নে উপস্থাপন করা হলো।

ল্যাব নং/ নমুনা নং	নমুনার নাম	পরীক্ষায় প্রাপ্ত ফলাফল	মন্তব্য
এস- ৯০৩৬ পত্রের নমুনা নং-১.১	Municipal Solid Waste	1.Moisture = 85.9 % 2.pH= 9.0	-
এস- ৯০৩৭ পত্রের নমুনা নং-২.১	Municipal Solid Waste	1.Moisture = 56.5 % 2.pH= 7.3	-
এস- ৯০৩৮ পত্রের নমুনা নং-২.২	Municipal Solid Waste	1.Moisture = 52.0 % 2.pH= 7.3	-
এস- ৯০৩৯ পত্রের নমুনা নং-৩.১	Municipal Solid Waste	1.Moisture = 34.9 % 2.pH= 7.5	-
এস- ৯০৪০ পত্রের নমুনা নং-৩.২	Municipal Solid Waste	1.Moisture = 37.5 % 2.pH= 7.2	-

বিশেস্নষণ পদ্ধতি ঃ
১। আর্দ্রতা= Gravimetric method

৪/০১/১৭

(মোঃ নাজমুল হাসান)
প্রধান বৈজ্ঞানিক কর্মকর্তা
ফোন ঃ ৯১১০৫০৭।

অনুলিপি ঃ
১। নথি।

icddr,b

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Environmental Microbiology Laboratory

Lab. ID No.6182

Receipt No: DEC1306626

Date of Reporting: 24.12.2013
Date of Sample Received: 23.12.2013

Particular of Sample: Solid Waste (Sample-1.1)

Client Address: Mohammad Rasel Kabir, IAT BUET, Dhaka 1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	4	Membrane Filtration
2	Faecal coliforms	CFU /gm	0	Membrane Filtration
3	*Escherichia coli*	CFU /gm	0	Membrane Filtration

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Dr. Md. Sirajul Islam
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Environmental Microbiology Lab, CFWD, ICDDR,B

Tested By (Code No.): 12, 13

Checked By (Code No.): 2

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Environmental Microbiology Laboratory

Lab. ID No.6183

Receipt No: DEC1306624

Date of Reporting: 24.12.2013
Date of Sample Received: 23.12.2013

Particular of Sample: Solid Waste (Sample-2.1)

Client Address: Mohammad Rasel Kabir, IAT BUET, Dhaka 1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	6	Membrane Filtration
2	Faecal coliforms	CFU /gm	0	Membrane Filtration
3	*Escherichia coli*	CFU /gm	0	Membrane Filtration

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 12, 13

Checked By (Code No.): 2

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Environmental Microbiology Laboratory

Lab. ID No.6184

Receipt No: DEC1306622

Date of Reporting: 24.12.2013
Date of Sample Received: 23.12.2013

Particular of Sample: Solid Waste (Sample-2.2)

Client Address: Mohammad Rasel Kabir, IAT BUET, Dhaka 1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	0	Membrane Filtration
2	Faecal coliforms	CFU /gm	0	Membrane Filtration
3	*Escherichia coli*	CFU /gm	0	Membrane Filtration

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Dr. Md. Sirajul Islam
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Environmental Microbiology Laboratory

Lab. ID No.6185

Receipt No: DEC1306628

Date of Reporting: 24.12.2013
Date of Sample Received: 23.12.2013

Particular of Sample: Solid Waste (Sample-3.1)

Client Address: Mohammad Rasel Kabir, IAT BUET, Dhaka 1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	4	Membrane Filtration
2	Faecal coliforms	CFU /gm	0	Membrane Filtration
3	*Escherichia coli*	CFU /gm	0	Membrane Filtration

Comment: The supplied sample is contaminated with total coliforms.

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 12, 13

Checked By (Code No.): 2

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Environmental Microbiology Laboratory

Lab. ID No.6186

Receipt No: DEC1306630

Date of Reporting: 24.12.2013
Date of Sample Received: 23.12.2013

Particular of Sample: Solid Waste (Sample-3.2)

Client Address: Mohammad Rasel Kabir, IAT BUET, Dhaka 1000.

Examination Requested: Bacteriological/ Chemical Test

Sl. No.	Parameters	Unit	Results	Method
1	Total coliforms	CFU /gm	90	Membrane Filtration
2	Faecal coliforms	CFU /gm	0	Membrane Filtration
3	*Escherichia coli*	CFU /gm	0	Membrane Filtration

N.B: This report is valid only for particular sample tested and cannot be used for publicity.

Tested By (Code No.): 12, 13

Checked By (Code No.): 2

Dr. Md. Sirajul Islam
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The Peoples Republic of Bangladesh
Soil Resource Development Institute
Central Laboratory
Krishi khamar Sarak, Dhaka.

No-Lab/44(2)/03/06

Date : 16. 01.14.

To

Professor Dr. M. Kamal Uddin
Director
Institute of Appropriate Technology (IAT)
Bangladesh University of Engineering and Technology
Dhaka-1000.

Subject: **The result of 05 Municipal Solid Waste (MSW) samples.**

The result of 05 Municipal Solid Waste (MSW) samples supplied by you are given below.

Lab No.	Name of Sample	Analytical result	Remarks
S- 9331 Sample No- MSW-1	Municipal Solid Waste	1.Moisture = 13.0 % 2.pH= 7.2	-
S- 9332 Sample No- MSW-2	Municipal Solid Waste	1.Moisture = 13.8 % 2.pH= 7.1	-
S- 9333 Sample No- MSW-3	Municipal Solid Waste	1.Moisture = 20.1 % 2.pH= 7.0	-
S- 9334 Sample No- MSW-4	Municipal Solid Waste	1.Moisture = 10.02 % 2.pH= 7.3	-
S- 9335 Sample No- MSW-5	Municipal Solid Waste	1.Moisture = 15.9 % 2.pH= 7.2	-

Analytical Method:

Mositure = Gravimetric method

16/1/14
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Bangladesh

Date: 12.02.2014

Hydraulic Conductivity of Municipal Solid Waste (MSW)

Sample	Hydraulic Conductivity (cm/s)	Density ($g\ cm^{-3}$)
IAT 2.1	8.44×10^{-3}	0.625
IAT 2.2	13.74×10^{-3}	0.678
IAT 3.1	9.81×10^{-3}	0.716
IAT 3.2	9.23×10^{-3}	0.647

12.2.14

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