ISLAMIC UNIVERSITY OF TECHNOLOGY

Sustainable Solid Waste Management through 3R Strategy in Gazipur City Corporation

by

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A thesis submitted to the Department of Civil and Environmental Engineering (CEE) in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering

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Recommendation of the Board of Examiners

The thesis titled "Sustainable Solid Waste Management through 3R Strategy in Gazipur City Corporation" submitted by Ijaj Mahmud Chowdhury, Student ID 135604 of Academic Year 2013-2014 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering.

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Dedication

I dedicate this thesis to my parents, my grandparents, my wife and my teachers.

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Glory and praise be to Allah the Almighty for giving me the strength and courage to successfully complete my M.Sc. thesis. Verily there is no strength except with Allah.

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Abstract

With rapid urbanization and population growth, developing countries like Bangladesh are experiencing challenges in municipal solid waste (MSW) management. While developed countries are giving highest priorities in resource recovery from MSW, developing countries are still facing challenges and obstacles to establish proper collection and disposal system. Gazipur City Corporation (GCC) is recently formed city corporation in Bangladesh and this city is widely known as one of the major industrial zones of the country. As the city urbanizes, the city corporation is over burdened with the solid waste management. There has been very limited study on this city and reliable data are required to plan and design appropriate management system. To obtain reliable data on solid waste in GCC area a study was carried out and main objective of the study was to determine household solid waste generation, composition, potential for resource recovery, economic benefit and landfill area saving. A questionnaire survey was also conducted to find the waste management behaviors, and their attitudes and willingness to participate in household solid waste management.

In order to achieve the proposed objectives, total 206 and 30 waste samples were collected from households and secondary dumping sites (SDS) respectively. Waste was collected both in dry and wet season. The waste was separated mainly in two categories like organic (food waste, garden waste) and inorganic (paper, plastic, metal, glass, leather etc.) contents. The study reveals that the solid waste generation rate at household level is 0.36 kg/capita per day accumulating 717.5 tons of solid waste daily in GCC area. Seasonal variation of waste generation was also computed for dry season (0.352kg/capita/day) and wet season (0.364 kg/capita/day). The waste in household mostly comprised of organic contents (83.4%) followed by plastic (6.34%), paper (5.75%), glass (0.91%), leather & rubber (0.66%), metal (0.62%) and others (2.27%). Whereas in secondary sites it was found that organic content (77.04%) was less than the weight percentage found in households. This study emphasizes on the 3R based solid waste management system which promote waste reuse and recycle through recovery of resources from the waste stream. It has been found that a significant portion of waste can be recovered as recyclable materials which accounts

for 38000 ton annually having a market value of 154.35 million BDT. Potential recoverable waste have a14.5% volumetric reduction rate which will reduce the required number of trips for collection vehicle from 254 to 216 per day saving fuel cost equivalent to 8 million BDT. Furthermore, with 3R approach land filling area requirement can also be reduced over the time and it is estimated that almost 7 acres of land area can be saved by 2036 with 100% resource recovery rate. With existing management practices, GCC require 407 BDT/ton for collection, transportation and disposal purposes. Recovering potential recoverable materials will allow to generate a revenue over 163 million BDT annually (624 BDT/ton).

The major drawback of the current solid waste management system is that there is no practice of waste segregation both at household level and secondary dumping sites. Also the existing system is only limited to waste collection from SDS and dumping at the final disposal site. No further treatment of waste is carried out formally. This study proposes an approach for integrated solid waste management (ISWM) system to minimize the current shortcomings of the management system based on 3R strategy. The proposed approach allows waste to segregate at source based on color code and suggests modification in the primary collection vehicle. The recommended method for treatment of organic waste is composting/anaerobic digestion. However, this study does not encompasses the waste generated from commercial, industrial and other sources. Further study can be carried out to determine overall MSW generation and composition. Also adequate awareness campaign shall be designed for spontaneous involvement of public in practicing 3R based waste management.

CHAPTER:1 INTRODUCTION

1.1 General

Bangladeshis one of those countries which are emerging with significant growth in GDP in last few years. This indicates Bangladesh is becoming a hub for investment resulting in rapid economic growth and urban development. Developments induce people to migrate to the urban areas and as a consequence of increase in the current development scenario the urban population has increased more than 7% in last 10 years in Bangladesh (UN, 2019). Other reasons behind the increasing rate of urban population is availability of improved lifestyle and facilities such as housing, electricity, water supply, sanitation, etc in urban areas. The matter of concern is that, solid waste the by-product of an urban lifestyle is actually growing even faster than the rate of urbanization. On a report of World Bank titled as 'A Global Review of Solid Waste Management' (Hoornweg & Bhada-Tata, 2012)mentioned that waste managed poorly or in an inappropriate way has an impact on health and environment as well as results in higher downstream costs (collection, transportation and treatment) than what it would have cost to manage the waste at first place.

Solid Waste Management is one of the major services that a city authority provides to its dwellers and it is usually one of the major services that directly fall within the city corporation's purview. The City Corporation Act 2009 of Bangladesh states that, it is the duty of city corporation to ensure collection and disposal of waste from buildings, roads, public toilets and drains under its jurisdiction (Amin, 2017). City authorities of developing countries are facing major challenges in solid waste management due to three reasons(Guerrero et al., 2013). The reasons are: (i) increasing rate of solid waste generation; (ii) budget constraints with high management cost and (iii) lack of understanding of several factors affecting different levels of waste management. Estimation of early 2000 indicated that, urban areas are producing 16015 tons/day of solid waste which adds up to 58.4 million tons per year (Bahauddin & Uddin, 2012). The projection is that, it will increase to 47000 tons per day accumulating 17.2 million tons annually by 2025 (Bahauddin & Uddin, 2012) due to population growth and increasing per capita generation rate. Considering the population of six major city corporations (Dhaka, Chittagong, Khulna, Sylhet, Rajshahi and Barishal) of Bangladesh, average per capita waste generation is found at 0.41 kg/capita/day (Ahsan et al., 2014). In another study, it was found that 52,00,919 tons of Municipal Solid Waste (MSW) was generated annually by 36.9 million urban inhabitants in 2013 with per capita rate of 0.35 Kg/day (Ashikuzzaman & Howlader, 2019).

Environmental regulatory framework has been evolving since 1992 in Bangladesh with National Environment Policy 1992. Afterwards the Environmental Conservation Act 1995 incorporated a definition of waste. The Environmental Court Act of 2000 was a pioneering act for taking action on violations of environmental laws and regulations but waste-related offenses were not specified. A major change however took place in 2013 when the National Environmental Policy recognized the 3R strategy, adopted by the government in 2010, as an appropriate strategy for waste management. USEPA recommended that a sound environmental management can be achieved by implementing the 3R concept according to its order(Julianne et al., 2008).The concept refers to Reduce, Reuse and Recycle. This concept highlights on the reduction of waste at source and increased usage of recyclable materials. The main features of the national strategy for promoting 3Rs are:

i. Prioritizing waste avoidance/reduction over recycling, and recycling over all other forms of environmentally-unsound disposal;
ii. Reusing non-avoidable waste as far as possible;
iii. Reducing hazardous content in the waste at the lowest possible level;
iv. Guaranteeing an environmentally sound residual waste treatment and disposal as basic prerequisite for environmental protection.

Gazipur City Corporation (GCC) is currently the largest among 11 other city corporations of Bangladesh in terms of area and its population is about 2.5 million (GCC, 2018). Gazipur city has been experiencing rapid urbanization due to the outward urban expansion of Dhaka and rising as a suitable investment destination because of the road network which connects both airport and sea port of the country (Rahman et al., 2018). The recent progress in urbanization has burdened GCC with increased responsibilities to deliver municipal services like water supply, solid waste management etc. GCC generates huge amount of solid waste every day. It has been found from a study that the average waste generation rate (household and healthcare) of Gazipur city is 0.25 kg/capita/day which is about 4% (Guerrero et al., 2013) of country's total solid waste generation.

City authorities are usually responsible for management of solid waste and they often face challenges and difficulties to ensure an effective and efficient system which is sometimes beyond their ability to tackle (Sujauddin et al., 2008; Zohoori & Ghani, 2017) due to lack of organization, financial resources, and absence of multi-disciplinary thought process (Burnley, 2007). Being the largest and newest city corporation GCC also needs investigation on overall solid waste management practices, problems and its solutions.

The existing solid waste management practice done by the city corporation is only limited to collection and disposal of waste. There are several secondary dumping sites in different zones of GCC from where the conservancy department of GCC collects the waste and dumps it to the final dumping site. No segregation of waste has been done for separating reusable/recyclable items in between primary and secondary dumping of solid wastes that eventually make this process less efficient and costly. There are not available data in previous literature that reflects the opportunity for resource recovery options in this city. Without this type of study it is very much challenging to propose an appropriate management system that will consider a sustainable solution. As in GCC, there is no existence of structured waste management system which can ensure sustainability in the waste stream; this study will fill the gaps in current system incorporating 3R policy in line with the 3R strategy. This study identified the per capita waste generation and composition at household level along with the possibility of resource recovery potential.

1.2 Problem Statement and Objectives of the Study

Increasing quantity of solid waste with the growing population is becoming a major concern for the city authority. With the traditional method of waste management which is only limited to collection and dumping is not helping the city authorities both in management and environmental perspective. Failing to address the waste as a potential resource, GCC is missing out an opportunity to generate significant revenue. The core problems which exist in GCC in regard to solid waste are unavailability of solid waste generation and composition data which are required to determine the resource recovery potential and absence of an integrated solid waste management system. This study intends to address is to solid waste generation and composition in GCC, resource recovery potential and approaches to introduce 3R based solid waste management system. The following objectives have been pursued in order to accomplish the overall goal of the research:

1. To investigate solid waste generation rate (seasonal) in the households, composition of waste at different dumping stages (household level, secondary dumping sites).
2. To find the current management practices, limitations and drawbacks of the present SWM practices in Gazipur City Corporation.
3. To perform waste reduction analysis at different dumping stages and estimate cost saving/earning through source reduction, reuse and recycle of waste materials.
4. Propose an optimized and integrated solid waste management system incorporating 3R strategy.

1.3 Scopes and Limitations of the Study

Several data are available on waste management of major cities of Bangladesh except the study area of this research. Gazipur is an important city irrespective of its size and business value. Primary data has been collected and analyzed on waste generation, composition and its seasonal variation both at household level and secondary dumping sites. Data obtained from this study will be compared with the data collected from several secondary sources. Existing waste management practices and problems, options for resource recovery are analyzed through this study for economically and environmentally feasible sustainable waste management. The study of 3R practices and its viability is also analyzed with reliable information collected from primary and secondary sources. An approach toward integrated solid waste management incorporating 3R strategy is provided with this study.

The limitations faced due to the absence of reliable data as well the study does not consider commercial, office, street waste etc. of MSW. Solid waste generation from sources other than households was not considered. This study does not largely focus on the process and cost involved in resource recovery options, landfill site design parameters and other treatment options. This study is limited to the revelation of solid waste generation rate, composition of waste in GCC along with perception of people against waste management practices and proposed an integrated solid waste management system based on 3R approach and economic benefits that can be gained with that approach.

1.4 Layout of the Thesis

The thesis presents literature review, data analysis, current solid waste management system, findings of the study in total seven chapters. In addition a list of references has also been presented

Chapter 1 thoroughly discusses the background and objectives of this study.

Chapter 2 discusses the solid waste generation, composition and management scenario globally and locally. It emphasizes on different literature ranging from determination and status of waste generation to the resource recovery of waste. In this chapter the 3R strategy is also discussed.

Chapter 3 presents the overview of the study area including general information, demographics and current status of the solid waste management system practiced by GCC.

Chapter 4 presents the information pertaining to the methods and procedures followed in this study.

Chapter 5 presents the results of the analysis performed on collected waste sample. The results obtained from the analysis are further considered for the calculation of waste generation rate, waste composition, resource recovery potential, volume reduction, trip calculation and revenue generation. Limitations and the drawbacks of the present SWM practices in GCC are also presented in this chapter.

Chapter 6 presents an approach for integrated solid waste management incorporation 3R strategies

Chapter 7 presents the conclusions drawn from the results of this study and also suggests recommendations for future works.

CHAPTER:2 LITERATURE REVIEW

2.1 General

In 1989, Basel conventions defined waste as any substance or object that is supposed or intended to be disposed as per the provisions of law. Under Environmental Conservation Act (1995) of Bangladesh waste is referred as "any solid, liquid, gaseous, radioactive substance or the discharge, disposal and dumping of which may cause harmful change to the environment". A much more detail definition has been provided by The Resource Conservation and Recovery Act (RCRA) which states "solid waste means any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities"(USEPA, 2020). Municipal or household waste are generated from random human activities from variable sources and a previous study cited in Miezah et al. (2015), indicates that household waste are highest in percentage (55 – 80%) in developing countries followed by commercial or market areas (10–30%) with varying quantities from streets, industries, institutions among others (Miezah et al., 2015; Nabegu, 2010).

There has been a lot of study regarding managing waste and convert waste into resources. As managing waste comes with lots of challenges specially for developing cities, the best way to deal with this problem is actually to deal with minimum waste. In general terms, the most effective way to overcome this issue may be done by waste minimization or source reduction of waste. While talking about source reduction or sustainable management system the term "3R- Reduce, Reuse, Recycle" comes eventually. The developing countries are now in such a state that they cannot afford further delay in case of adopting 3R strategy as sooner or later there will be no space for dumping or land filling of the waste. Growth in population and economy, faster urbanization, improvement in the lifestyle of people; all of these have played a great role in accelerating the municipal solid waste generation in developing countries (Minghua et al., 2009).

In many developing countries, open dumping is the most common practice for waste disposal, which often leads to water contamination, foul odors, and other environmental, health and hygiene problems (National 3R Strategy Development, 2009). To get rid of these problems developing countries often prioritize waste collection over disposal and this impact the overall budget where only a fraction of the budget is going toward disposal mechanism whereas high-income countries are giving more emphasis on disposal system (Hoornweg & Bhada-Tata, 2012). Managing solid waste typically absorbs more than 1% of gross national product (GNP) and 20%–40% of municipal revenues in developing countries (Rodic, 2010). Also, according to Faccio et al., (2011) urban waste collection has also been proved to be one of the most visible and expensive municipal services as it involves complex operational problems in regards to investment (vehicle fleet), operational (fuel and maintenance) and environmental costs (emission, noise, traffic and odor).

In recent years, Bangladesh is trying new alternatives in technical and administrative processes to identify innovative approach to tackle waste management more efficiently. Although there are several strategies followed by the developing countries for efficient waste management but their level of performance has not been critically investigated (Aliu et al., 2014). More than 522 cities, towns and economic hubs are generating thousands of tons of solid waste coming from several sources such as domestic, industrial, commercial, health care facilities etc. that needs to be managed on daily basis. Major environmental concerns relating to water, land and air pollution have been frequently raised due to low collection efficiency, unavailable transport services and lack of proper treatment, recycling and unsatisfactory disposal facilities (DoE, 2010).

For a comprehensive evaluation of waste management options it is require to have reliable data on waste management (Allesch & Brunner, 2014). Unfortunately, absence of these required statistics and data is an usual phenomenon in developing countries (Buenrostro et al., 2001) and if available, they are often inconsistent as they come from heterogeneous sources for which validation becomes difficult and these are sometimes based on assumptions but not scientifically measured (Allesch & Brunner, 2014). These ambiguous information and data often creates negative impact while it comes to the investors/business entities who want to do business in this sector (Miezah et al., 2015). Being the newest city corporation GCC is extensively facing this deficit problem and lacking of these data will result negatively in overall management system. This study will identify the basic data related to household solid waste management required for incorporating 3R strategy in GCC.

To introduce sustainable solution it is important to realize the factors that influence the dwellers to dispose household waste. In a study of developing city, Tadesse et al., (2008) analyzed and revealed that one of the important factors in onsite storage is directly linked with the supply of adequate waste containers and its location. Insufficient supply of waste containers and longer distance to these containers affects the disposal choice and leads to open and roadside dumping.

2.2 Global Scenario

The waste generation rate is increasing globally, particularly in developing countries where the waste is poorly managed, partially collected; disposal sites are insufficient and contaminated with hazardous contents (Hyman et al., 2013).

From the statistics of 2012 it is estimated that presently there are over 3 billion residents in the urban areas which is more than one-third of current world populations. More surprising news is that in two last decades the Municipal Solid Waste (MSW) generation rate increased over 87.5% from 0.64 kg/capita/day to 1.2 kg/capita/day. World's urban population will rise to 4.3 billion by 2025 generating 2.2 billion tons of waste per year (1.42 kg/capita/day) (Hoornweg & Bhada-Tata, 2012). However global estimates cannot dictates the local generation rate as there are several factors which influence the generation rate locally such as economic development, degree of industrialization, public lifestyle, local climate etc. But it is a common finding that higher economic and urbanization growth rate are highly connected with the increase of generation rate as with these living standard, consumption of goods and services correspondingly increases. Urban residents produce about twice as much waste as their rural counterparts (Hoornweg & Bhada-Tata, 2012). This scenario can easily be understood if the per capita waste generation rate of developed and developing countries is observed. In 2009 and 2010 the solid waste generation rate was around 0.6 kg/capita/day (Babayemi & Dauda, 2010) and at the same year the solid waste generation rate of United States was about 2 kg/capita/day (US EPA, 2014) which is more than seven times than of Nigeria. Compare to Bangladesh (0.41 kg/capita/day) (DoE, 2010) in the mentioned year United State generated almost 10 times of MSW.

2.2.1 Waste Generation

The statistics are such that almost half of the world's population (3.5 billion) are lacking access of proper waste management facilities and thus open dumping has become the major waste disposal method in many most low- and lower middle-income countries (Hoornweg & Bhada-Tata, 2012). As mentioned in the above article, the world is going to produce more than 2.2 billion tons of solid waste annually by 2025 will make the situation more challenging and worsening in regards to the increasing rate of waste generation. This generation of waste varies from country to country and country's income status as well. The other factors contributions to the waste generation are urbanization, industrialization, increasing population and economic development.

Waste generation by region

To understand the global scenario of waste generation and management it is really important to learn the current state of different countries. The countries over the world are divided into several regions as follow:

Classification According to Region						
Africa (AFR)	East Asia & Pacific (EAP)	Eastern & Central Asia (ECA)	Latin America & the Caribbean (LAC)	Middle East & North Africa (MENA)	Organization for Economic Co-operation & Development (OECD)	South Asia (SAR)

Source: What a waste, World Bank Urban Development Series, 2012

Bangladesh falls under SAR region which also includes Bhutan, India, Maldives, Nepal, Pakistan and Srilanka. Table 2.1 provides a summary of waste generation scenario of different regions mentioned above.

Per capita waste generation in Sub-Saharan Africa region ranges from 0.09 to 3.0 kg per day with an average per capita generation rate of 0.65 kg/day accumulating 62 million tons annually. Islands of these regions are found to be the places with highest generation rate, likely due to the tourism industry.

Asia and the Pacific Region produces almost 270 million tons per year out of which alone China is responsible for 70% of the regional total. Generation rate varies from 0.44 to 4.3 kg/capita/day with an average of 0.95 kg/capita/day.

On the other hand several countries in Eastern and Central Asia region do not have sufficient waste data. This region is accounted for at least 93 million tons of solid waste per annum with an average generation of 1.1 kg/capita/day.

Latin America and the Caribbean has the most comprehensive and consistent data (Martínez Arce et al., 2009). This region generates 160 million tons/year with an average rate of 1.1 kg/capita/day.

Countries from Middle East and North Africa region generate 63 million tons per year where per capita generation ranges from 0.16 to 5.7 kg per person per day, and has an average of 1.1 kg/capita/day.

South Asian countries accumulate about 70 million tons of solid waste per year ranging from 1.1 to 3.7 kg/capita/day with an average of 2.2 kg/capita/day. It is estimated that, by 2025 this region will produce over 200 million tons of solid waste annually.

OECD countries are responsible for the most quantity of solid waste generation. Countries under this region are responsible for producing 572 tons of solid waste annually with an average of 2.2 kg/capita/day.

Table 2:1 Current and predicted urban solid waste generation per capita by region

Region	Current Available Data			Projections for 2025			
	Total Urban Population (millions)	Urban Waste Generation		Projected Population		Projected Urban Waste	
		Per Capita (kg/capita/day)	Total (tons/day)	Total Population (millions)	Urban Population (millions)	Per Capita (kg/capita/day)	Total (tons/day)
AFR	260	0.65	169119	1152	518	0.85	441840
EAP	777	0.95	738958	2124	1229	1.5	1865379
ECA	227	1.1	254389	339	239	1.5	354
LCR	399	1.1	437545	681	466	1.6	728392
MENA	162	1.1	173545	379	257	1.43	369320
OECD	729	2.2	1566286	1031	842	2.1	1742417
SAR	426	0.45	192410	1938	734	0.77	567545
Total	2980	1.2	3532252	7644	4285	1.4	6069703

Source: (Hoornweg & Bhada-Tata, 2012)

Waste generation by country income level

High-income countries are responsible for generating maximum amount of waste per capita, while least quantity of solid waste is produced by the low-income countries. Due to China's inclusion in the middle-income countries, the result is somewhat skewed and lower middle income countries have a higher waste generation rate than upper middle income countries. The average per capita waste generation amounts for the various income groups reflect the income level of the countries (Figure 2.1). It is also estimated that the generation rate will be almost double by 2025 and lower and lower middle-income countries will make the larger contribution to this.

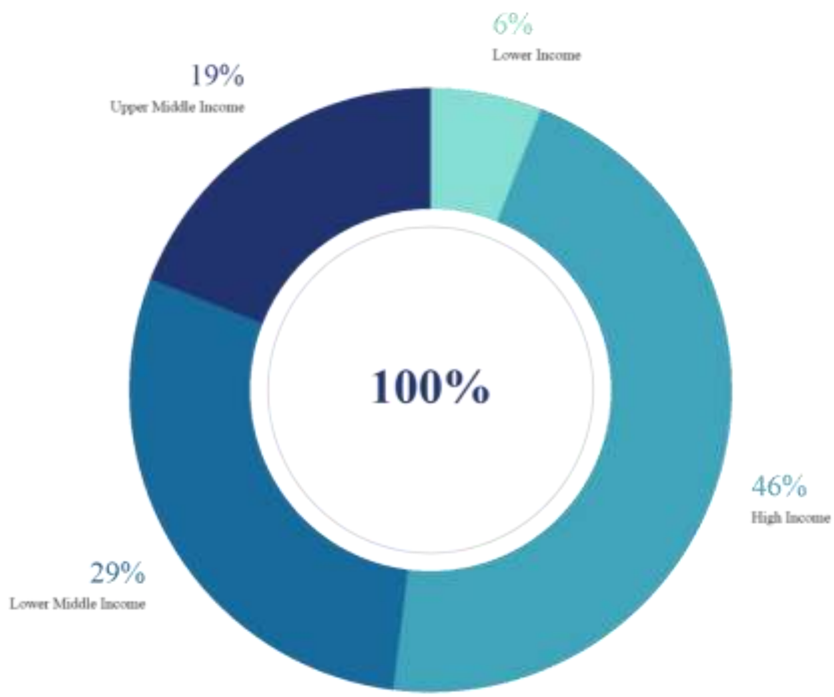

Figure 2:1 Waste generation by country income level (Hoornweg & Bhada-Tata, 2012)

2.2.2 Waste Collection

Waste collection is the collection of solid waste from point of generation to the point of secondary transfer sites or final disposal or treatment site. In overall waste management system waste collection is the most visible step and is considered as a urban service (Scheinberg et al., 2011). The usual practices to collect municipal solid waste is mentioned below (Hoornweg & Bhada-Tata, 2012):

1. House-to-House: This is widely practiced in developed countries. Waste collectors collect waste from individual house. In countries like Bangladesh, several NGOs and community-based organizations are providing this service to urban residents. The user usually pays a monthly fee for this service.

2. Community Bins: Waste generator bring their waste to the nearby community bins placed in a neighborhood. MSW is then collected up by the city authority according to a set frequency.

3. Curbside Pick-Up: This is a secondary version house-to-house collection system. Waste producers/householders usually place the waste bag or container on the curbside or in the alley on a set schedule which is usually set by the local authorities.

4. Self-Delivered: Waste producer directly deliver the waste to disposal sites or transfer stations, or hire third-party operators (or the municipality).

The overall waste collection efficiency mainly affected by two important factors namely (i.) collection coverage (% of household served) and (ii) availability of collection vehicles (Scheinberg et al., 2011). Scheinberg et al., (2011) also mentioned that the cities in high income countries usually have higher coverage than cities in low income countries. The MSW collection rates by income level and by region are shown in Figure 2.2 and 2.3. In low- and middle-income countries collection coverage can be found as low as around 40%, compared to the 98% for high-income countries. Some middle-income countries still dispose of waste at poorly operated landfills. The lower collection efficiency along with the reality of poor institutional capacity, financial constraints and lack of political will, the developing countries are facing major challenges in waste management (Hyman et al., 2013). Regions with low-income countries tend to have low collection rates. South Asia and Africa are the lowest with 65% and 46% respectively. Not surprisingly, OECD countries tend to have the highest collection efficiency at 98%.

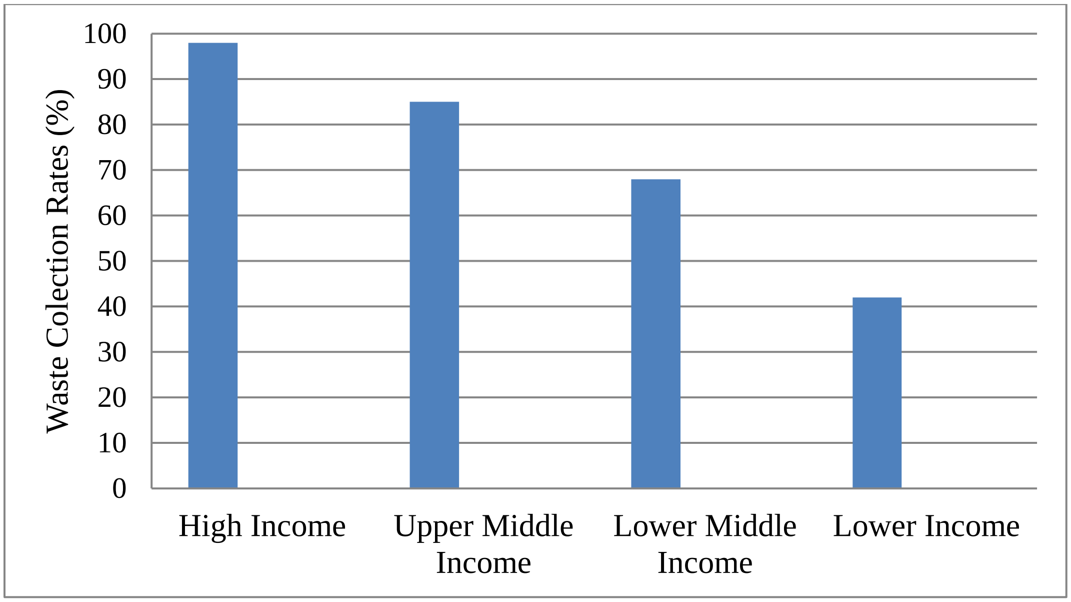

Figure 2:2 Global Waste Collection Rates by Country Income Level(Hoornweg & Bhada-Tata, 2012)

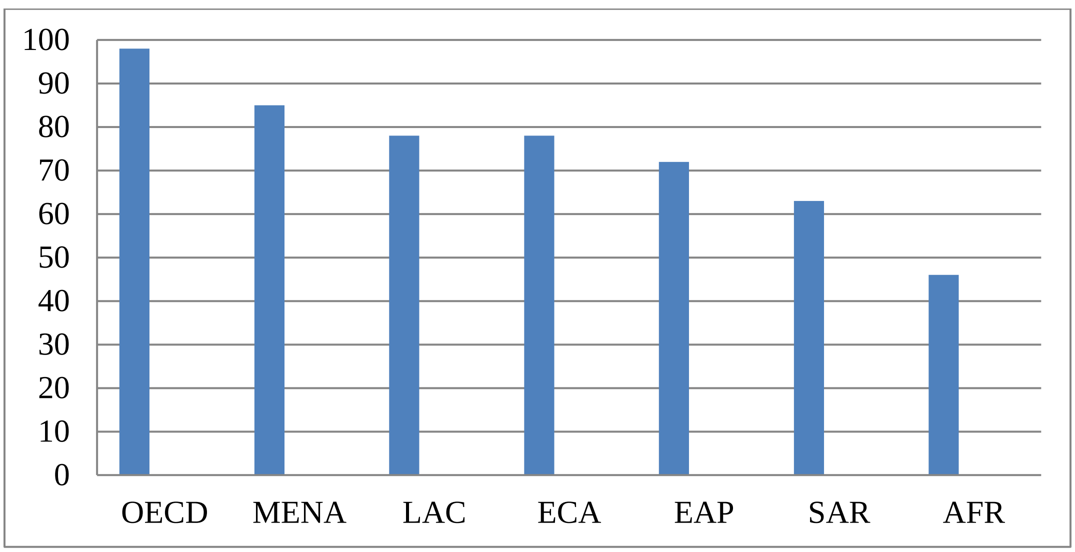

Figure 2:3 Global Waste Collection Rates (%) by Region(Hoornweg & Bhada-Tata, 2012)

2.2.3 Waste Composition

Composition may be defined as the term used to describe the individual components that make up a solid waste stream and their relative distribution (Alabdraba & Al-Qaraghully, 2013). It provides a description of the constituents of waste and composition of solid waste varies widely from place to place. Data on composition is very important because these will eventually provide indications on recyclable waste, transport requirements and overall management systems. Developed nations having high income, paper is the major contributor in the waste stream followed by organic content, plastic and others. On the contrary organic content dominates the waste stream in low and middle income countries in the range of 40%-85% (Hoornweg & Bhada-Tata, 2012) of total waste. With rapid urbanization and economic development, consumption of inorganic materials (such as plastics, paper, and aluminum) increases, while the relative organic fraction decreases (Nabegu, 2010). The total MSW from a community are composed of the waste materials identified in Table 2.3. Figure 2.4 shows the MSW composition for the entire world in 2009. Organic waste comprises the majority of MSW, followed by paper, metal, other wastes, plastic, and glass.

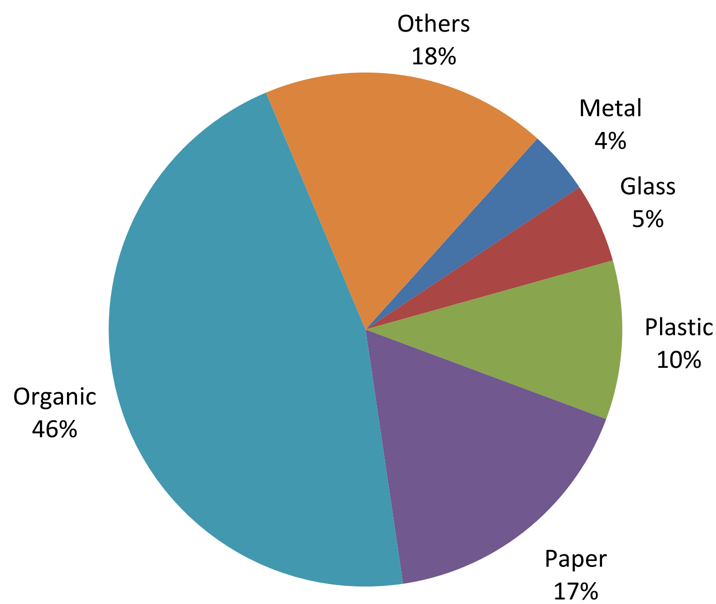

Figure 2:4 Waste compositions by types of waste (Hoornweg & Bhada-Tata, 2012)

Table 2.2 illustrates the waste composition of different waste item based on country income level. The organic fractions make up 64% of the waste stream for low-income countries and paper only makes 5%, whereas in high-income countries the situation is completely opposite for organic and paper contents contributing 28% and 31% respectively.

Table 2:2 Current and forecasted generation of waste by different types

Recent Estimates						
Income Level	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Low Income	64	5	8	3	3	17
Lower Middle Income	59	9	12	3	2	15
Upper Middle Income	54	14	11	5	3	13
High Income	28	31	11	7	6	17
2025 Estimates						
Low Income	62	6	9	3	3	17
Lower Middle Income	55	10	13	4	2	15
Upper Middle Income	50	15	12	4	3	13
High Income	28	30	11	7	6	17

Source: (Hoornweg & Bhada-Tata, 2012)

2.3 Solid Waste and its Management Practices

The overall waste stream of a city consists of hundreds of separate waste items. Although waste composition is typically provided by weight, as a country prosper, waste volumes tend to be more important with regard to collection because it becomes more important to collect waste in a sustainable manner. To realize the waste stream and proper management the waste are classified according to their sources, producers and types of solid waste is shown in Table 2.3 and Table 2.4 (adopted from D. Hoornweg & Thomas., 1999).

Table 2:3 Sources, Producers and Types of Solid Waste

Source	Typical waste producing units	Types of solid wastes
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes).
Industrial	Light and heavy manufacturing, fabrication, construction sites, power and chemical plants.	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes.
Commercial/Institutional	Stores, hotels, restaurants, markets, office buildings, etc./Schools, hospitals, prisons, government centers.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes.
Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.

Municipal services	Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants.	Street sweepings; landscape and tree trimmings; general wastes from parks, beaches, and other recreational areas; sludge.
Process (manufacturing, etc.)	Heavy and light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing.	Industrial process wastes, scrap materials, off-specification products, slay, tailings.
Agriculture	Crops, orchards, vineyards, dairies, feedlots, farms.	Spoiled food wastes, agricultural wastes, hazardous wastes (e.g., pesticides).

Table 2:4 Types of Waste and Their Source

Type	Sources
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Strictly speaking paper is organic but unless it is contaminated by food residue, paper is not classified as organic.
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Other	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

Any discussion of waste management will involve the use of various concepts. These concepts are the foundations of waste management policy across the globe. Whether any country can follow or not, work based on a common waste management hierarchy shown in Figure 2.5. Due to economic deficiency many country cannot allocate required budget for waste management (Hoornweg & Bhada-Tata, 2012). It is often found in developing country that majority portion of the allocated fund is spent on waste collection instead of a standard disposal system. This brings the difference among the different income level countries. Comparison of SWM practices in different counties based on their economies is given in Table 2.5.

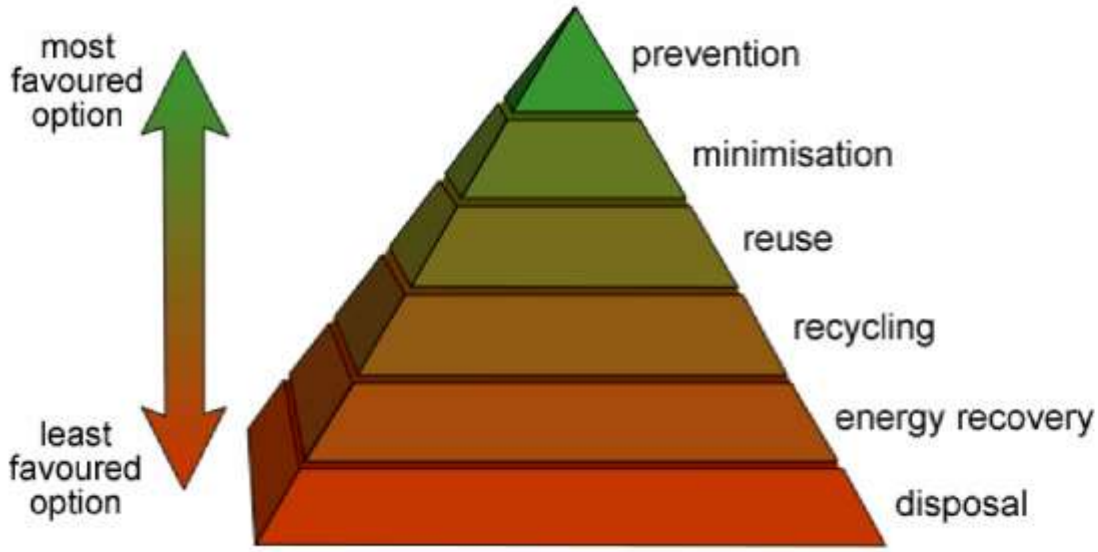

Figure 2:5 Waste Management Hierarchy (DoE, 2010)

Table 2:5 Comparison of Solid Waste Management Practices by Income Level

Activity	Low Income	Middle Income	High Income
Source Reduction	No organized programs, but reuse and low per capita waste generation rates are common.	Some discussion of source reduction, but rarely incorporated into an organized program.	Organized education programs emphasize the three 'R's' — reduce, reuse, and recycle. More producer responsibility & focus on product design.
Collection	Periodic and inefficient. Service is limited to high visibility areas, the wealthy, and businesses willing to pay. Overall collection below 50%.	Improved service and increased collection from residential areas. Larger vehicle fleet and more mechanization. Collection rate varies between 50 to 80%. Transfer stations are slowly incorporated into the SWM system.	Collection rate greater than 90%. Compactor trucks and highly mechanized vehicles and transfer stations are common. Waste volume a key consideration. Aging collection workers often a consideration in system design.
Recycling	Although most recycling is through the informal sector and waste picking, recycling rates tend to be high both for local markets and for international markets and imports of materials for recycling, including hazardous goods such as e-waste and ship-breaking. Recycling markets are unregulated and include a number of 'middlemen'. Large price fluctuations.	Informal sector still involved; some high technology sorting and processing facilities. Recycling rates are still relatively high. Materials are often imported for recycling. Recycling markets are somewhat more regulated. Material prices fluctuate considerably.	Recyclable material collection services and high technology sorting and processing facilities are common and regulated. Increasing attention towards long term markets. Overall recycling rates higher than low and middle income. Informal recycling still exists (e.g. aluminum can collection.) Extended product responsibility common.
Composting	Rarely undertaken formally even though the waste stream has a high percentage of organic material. Markets for, and awareness of, compost lacking.	Large composting plants are often unsuccessful due to contamination and operating costs (little waste separation); some small-scale composting projects at the community/ neighborhood level are more sustainable. Composting eligible for CDM projects but is not widespread. Increasing use of anaerobic digestion.	Becoming more popular at both backyard and large-scale facilities. Waste stream has a smaller portion of compostables than low- and middle-income countries. More source segregation makes composting easier. Anaerobic digestion increasing in popularity. Odor control critical.

Landfilling/ Dumping	Low-technology sites usually open dumping of wastes. High polluting to nearby aquifers, water bodies, settlements. Often receive medical waste. Waste regularly burned. Significant health impacts on local residents and workers.	Some controlled and sanitary landfills with some environmental controls. Open dumping is still common. CDM projects for landfill gas are more common.	Sanitary landfills with a combination of liners, leak detection, leachate collection systems, and gas collection and treatment systems. Often problematic to open new landfills due to concerns of neighboring residents. Post closure use of sites increasingly important, e.g. golf courses and parks.
Costs	Collection costs represent 80 to 90% of the municipal solid waste management budget. Waste fees are regulated by some local governments, but the fee collection system is inefficient. Only a small proportion of budget is allocated toward disposal.	Collection costs represent 50% to 80% of the municipal solid waste management budget. Waste fees are regulated by some local and national governments, more innovation in fee collection, e.g. included in electricity or water bills. Expenditures on more mechanized collection fleets and disposal are higher than in low-income countries.	Collection costs can represent less than 10% of the budget. Large budget allocations to intermediate waste treatment facilities. Up front community participation reduces costs and increases options available to waste planners (e.g., recycling and composting).

Source: (Hoornweg & Bhada-Tata, 2012)

2.4 Waste Management Practices in Developing Nations

Solid waste management in developing countries is not limited to formal system only. Informal sectors also play a significant role in urban SWM. The formal system consists of two parts: (i) the municipal authority which is responsible for waste collection, transport and disposal; (ii) private organizations interested in converting waste to marketable products. The informal sector consists of many actors such as waste-pickers, small scrap dealers and wholesaler, who together recycle about 20% of waste (Karagiannidis & Kontogianni, 2012). Contribution of informal recycling in SWM is significant in developing countries as large quantities of waste is handled by the informal sectors saving up to 20% of municipal budget otherwise that waste need to be dealt by the city authority (Scheinberg et al., 2011).

Daily management of solid waste produced by the citizens is one of the fast growing problems in developing countries. Current management strategies are inefficient, because of their complexity, financial and technological gap also exist which affect the overall management system. Improper management of wastes led to public health hazards, pollution of water bodies, etc. Many researchers have indicated factors influencing the components of the waste management system. According to Sujauddin et al., (2008) the generation of waste is influenced by family size, their education level and the monthly income. Households attitudes related to separation of waste are affected by the active support and investment of a real estate company, community residential committees' involvement for public participation (Zhuang et al., 2007) and fee for collection service based on the waste volume or weight (Scheinberg et al., 2011). Gender, peer influence, land size, location of household and membership of environmental organization explain household waste utilization and separation behavior (Ekere et al., 2009). It has been reported that collection, transfer and transport practices are affected by improper bin collection systems, poor route planning, lack of information about collection schedule (Hazra & Goel, 2008) insufficient infrastructure, poor roads and number of vehicles for waste collection. Organizing the informal sector and promoting micro-enterprises were mentioned by (Sharholy et al., 2008) as effective ways of extending affordable waste collection services.

2.4.1 Problems and Constraints in Developing Countries

A typical waste management system in developing country displays variety of problems such as low collection coverage, irregular collection services, open dumping and burning without proper pollution control. These problems are caused due to some technical, financial and social constraints.

Technical constraints

A good solid waste management system requires technical expertise, advanced knowledge and use of appropriate technologies which are not visibly present in most developing countries(Di Bella & Vaccari, 2014). Absence of skilled manpower with necessary expertise for solid waste management planning and operation is prevalent at both local and national level (Igbinomwanhia & Ideho, 2014). Person responsible for managing waste at local level often found with limited or no prior technical background (Hisashi Ogawa, 1996).The collection vehicles used to collect and transfer solid waste in not adequate and lack required specifications in most cases. Moreover, most vehicles were kept open while collecting waste resulting waste littering on the roads (Igbinomwanhia & Ideho, 2014). Absence of sufficient engineered land fill site is also responsible for environmental pollution and reflects poor, inadequate and inefficient waste management system (Igbinomwanhia & Ideho, 2014).

Institutional and financial constraints

SWM is not only an environmental issue rather it involves a wide range of stakeholders to properly manage this sector. Increased generation of MSW has put much burden on the management authority especially in developing countries where institutional and financial structure is not adequately organized (Karak et al., 2012; Ngoc & Schnitzer, 2009). Further financial constraints, including absence of required land area for safe disposal, material recovery facility and modern treatment technologies lead to inefficient waste management system. Absence of effective cost recovery mechanism also prevents the mobilization of financial resources in developing countries like Bangladesh (DoE, 2010). Lack of coordination among agencies involved as national counterpart as support agencies for several SWM projects often remain unaware of what other national agencies are doing.

This leads to duplication of tasks, wasting of resources, and hampering the overall progress in SWM (Hisashi Ogawa, 1996).

Social constraints

Developed countries have been successful in implementing integrated approach in SWM by focusing not only in technical, institutional and environmental elements but also the social factors in waste management (Rada et al., 2010). In lesser developed countries, issues related to social concerns often left with minimum budget which results negatively in gaining long term commitment from public while addressing waste management problem (Mmereki et al., 2016). Mindset of people plays a key role in adapting with the prescribed waste management practices and policies. Failing to people's behavior towards a problem may not bring desired results whereas success of any program depends on the active participation of public at different levels of waste management.

2.5 Factors Influencing Waste Management

Factors influencing waste management are discussed below:

Waste amount and composition

Reliable and up to date data on waste quantity and composition is one of the important factors in designing overall solid waste management system. These data usually provide the basis planning and implementing waste management activities (Karak et al., 2012; Shekdar, 2009). Domestic waste from developed countries usually consist of high amount of packaging materials made of paper, plastic, glass and metal having a low waste density. On the contrary, waste from developing or low income countries contain high amount of organic content with higher density and moisture content because of the high usage of fruits and vegetables (Zurbrügg, 2003). As a result vehicles used in industrialized countries transporting low density waste is not suitable or appropriate always to operate similar vehicles for waste with a higher density. Also waste stored and collected in mixed condition with rich organic and moisture content can reduce the resource recovery potential (Mmereki et al., 2016).

Access to waste for collection

Successful waste management system shall ensure accessibility of waste collection/dumping points by the users/collectors. In many instances waste might not be able to be transferred/reached through roads or alleys which may be inaccessible to certain methods of transport because of the road geometry or congestion (Zurbrügg, 2003). This happens mostly in unplanned settlements such as slums or low-income areas and thus largely affects the selection of equipment.

Awareness and attitudes

Disseminating the right information and creating awareness are considered as best practices to engage public. This can be done through media such as radio, TV, social media campaigns etc. (Mmereki et al., 2016). When people are informed about the benefits of waste management programs, how to sort waste and engage actively in waste management planning they are more likely to participate actively in the campaign and this can affect the overall waste management system (Mmereki et al., 2016; Zurbrugg, 2002). Awareness and changed attitudes of public towards waste management will promote waste minimization, household waste segregation, willingness to pay for waste management services.

Institutions and legislation

Institutional deficiencies and inadequate legislation is a common problem persist in the nations of South Asian region (Visvanathan & Glawe, 2006). In order to improve the accountability of the entire management system it is important to have an effective institution with defined administrative procedures and planning. This can ensure clarity of roles and co-ordination and jurisdictional boundaries (Mmereki et al., 2016). The relevant policy shall not only focus on how to manage waste better rather the policy must be directed towards optimizing the usage of resources by reducing the generation of waste and hence where the waste is generated, by converting the waste into a resource (Hyman et al., 2013).

2.6 ‘3R’ Strategy for Solid Waste Management

The principle of reducing, reusing and recycling of waste resources and products is often called the "3Rs".

- Reducing means choosing to use items with care to reduce the amount of waste generated.
- Reusing involves the repeated use of items or parts of items which still have usable aspects.
- Recycling means the use of waste itself as resources.

Waste minimization can be achieved in an efficient way by focusing primarily on the first of the 3Rs, "reduce," followed by "reuse" and then "recycle." The waste hierarchy (Figure 2.5) refers to the "3Rs" i.e., reduce, reuse and recycle, which classify waste management strategies according to their desirability (DoE, 2010).

Waste reduction and source separation

The first R (reduce) involves prevention and reduction of waste. To elaborate, waste reduction seek to reduce the generation of waste at source which can be done through redesigning of products or changing patterns of production and consumption in such a way that the product can become long lasting and reusable (Hoornweg & Bhada-Tata, 2012). To make these changes it requires initiating dialogues for sound waste management policy. Successful waste reduction is only possible when policies restrict the manufacturers to design products in certain way and consumers or users also need to play a key role by refusing to choose or use products that carry waste implications. According to Hyman et al., (2013), recent study revealed that in developed countries, 30-40% of food is wasted, which becomes a burden for the city authority can be easily minimized or reduced with better decision-making by consumers and producers.

The second R (reuse) involves secondary and subsequent uses of waste materials either in part or whole. ‘Reuse’ can be achieved through segregation of waste at source rather than disposal site (Peprah et al., 2015). Source separation means sorting of waste material having a potential for further use, composting, anaerobic digestion, and recycling. Separation at source has mainly two main benefits such as (i.) it enables the value of re-usable goods and recyclable materials; and (ii.) sorted waste minimizes the requirement of waste sorting in downstream which is more difficult and often expensive. These non- non-infrastructural elements (reduction and source separation), are often neglected and disregarded, are nevertheless key to successful waste management(Hyman et al., 2013).

2.6.1 Current practices of 3Rs in Asia

Growing consumption statistics (Visvanathan et al., 2007) from the developing Asian countries has acquired an alarming dimension in regards to solid waste management (Khajuria et al., 2008). Waste management in majority of the Asian countries usually has been limited to transporting the waste to the final disposal site. Moreover, due to available space constraints and technological deficiency sustainability of landfills has become a challenge in Asia (Visvanathan & Glawe, 2006). To tackle the waste management challenges in this region 3R strategy was adapted by several states as this can be a sustainable option for reducing waste at minimum level (Chowdhury et al., 2014).

The "3R Initiative" was officially launched at the 3R ministerial conference hosted by the Government of Japan in April 2005, with an aim to promote global action on 3R. In March 2006, a Senior Officials Meeting on 3R was organized in Japan resulting in strong commitment of governments and other stakeholders to implement 3R at local, national, and regional level. Regional 3R Forum in Asia was established through the joint effort of Ministry of the Environment of Government of Japan and United Nations Centre for Regional Development (UNCRD). The Inaugural Regional 3R (reduce, reuse, and recycle) Forum in Asia, which was held in Tokyo from 11 to 12 November 2009 and was participated by Bangladesh, resulted in the Tokyo 3R Statement that aims to provide an important basis and framework for the promotion of 3Rs in Asia.

Addressing solid waste challenges in developing countries is really a difficult and complicated task. The challenges start from the very first step of waste generation where no source segregation is done and public participation is minimum, resulting all the waste items ends up in one common container. In most Asian countries, resource recovery and recycling usually dominated by the informal sector. Collection and sorting of waste followed by trading and recycling of disposed materials provide income to hundreds of informal workers or waste pickers who works under labor-intensive and unhygienic ways irrespective of the toxicity. Recovered and recyclable products then enter a chain of dealers or processing before they are finally sold to manufacturing enterprises. However, the services of rag pickers often go unnoticed and issues concerning their livelihood are unaddressed. It has been estimated that about 20 to 30% of the waste generated in the cities of Asia Pacific region, are recycled by the informal sector (Visvanathan et al., 2007). For example, in Bangladesh the informal sector is responsible for recycling about 4 to 15% of the total solid waste generated (Enayetulla et al., 2005). According to Rodic (2010) the informal sector in Dhaka, Bangladesh recovers roughly 18% of materials. This situation in industrialized country is completely opposite where recovery is governed by the formal sector, driven by law and a general public concern.

Lately, the significance of recycling activities by informal sectors in reducing waste quantity, recovering recyclable materials and associated financial benefits is being acknowledged. Many NGOs and CBOs (Community based Organizations) are actively working on 3R related issues, often in a decentralized manner failing to fit in the bigger picture due to lack of communication, networking and other factors. Currently, a long-standing practice and a complex networking of informal source separation and recycling of materials exists (Chowdhury et al., 2014). Prioritizing the 3Rs among themselves may not make a significant change within a short time, but it can become beneficial in the long run.

2.6.1.1 Status and Technology Gaps in 3R Implementation

The composition of MSW differs for different countries and regions and plays a significant role in determining and designing an appropriate technology for treatment and allocating the space needed for treatment facilities. The MSW generated in most developing Asian countries is dominated by biodegradable organic fractions (above 40%) with the moisture content more than 50% (Visvanathan & Glawe, 2006). Figure 2.6 presents the waste composition in the municipal solid waste of some Asian countries. The waste components are, in most cases, discarded or dumped without any treatment or recycling.

Most of the developing Asian countries are in a budding stage when it comes to implementing 3R technologies. Such practices have been prompted by some private sector and NGOs to initiate recycling and proper waste management strategies. Waste Concern, an NGO in Dhaka, Bangladesh, for instance, has been actively involved in promoting 3R initiatives. Waste Concern initiated 700-tons per day capacity composting project for Dhaka City Corporation area. This project is expected to produce compost 50,000 tons every year, creating job for 800 urban poor, saving municipal waste management cost, improve the environment and reduce 89,259 tons of CO_2emission/ Year (DoE, 2010).

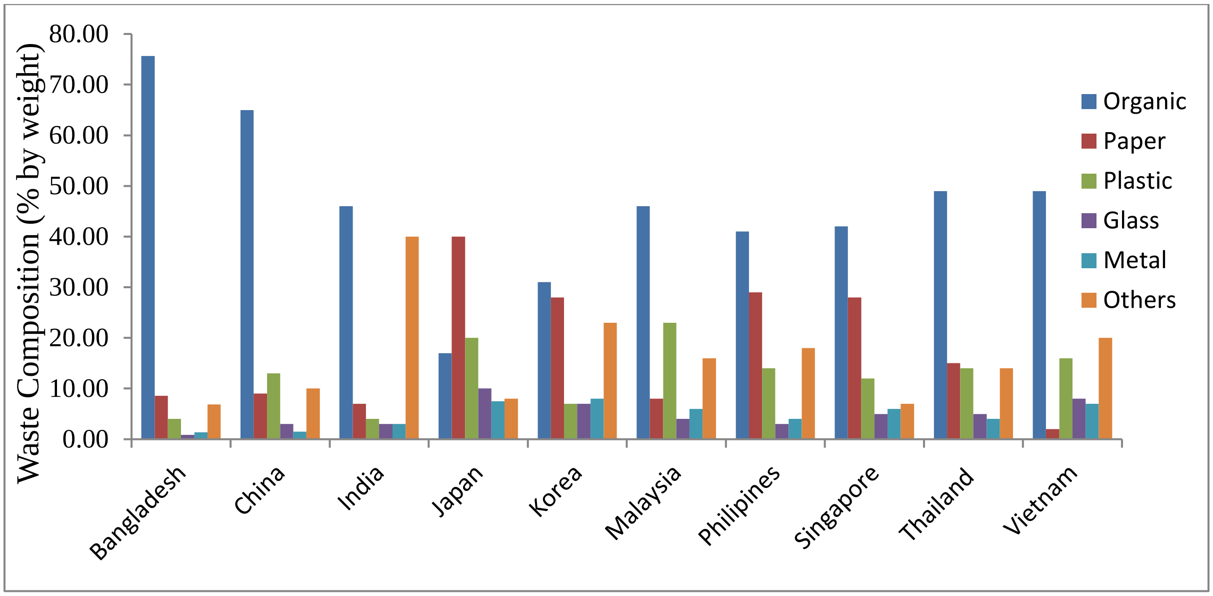

Figure 2:6 Composition of municipal solid waste in some Asian countries(Dhokhikah & Trihadiningrum, 2012)

Material recovery and sorting in MSW remains largely unexplored in many Asian countries. Although some pilot models have proved successful in developed countries, many details are yet to be determined in terms of implementation necessitating further research. Table 2.6 presents the status and technology gap in 3R implementation in some developing and developed Asian countries. In developing countries, a chain of informal recyclers, from waste scavengers to the waste dealers, perform the task of material recovery and sorting. It is justifiable to state that their livelihood could be at stake provided such technologies are operational and commercially successful, which practically is not likely to happen at least in the coming years. Nevertheless, pondering upon the health risks and the resource conservation, these providing technologies or at least some formal registration and support from the governments is vital. It is undeniable that major focus should be paid to the 3R technologies associated with MSW sorting, pulverization and composting (Visvanathan et al., 2007).

Given the recent status of Bangladesh, there are scopes for the city authorities to adopt waste management strategies already experienced by several countries. The 3R approach shall be understood in a broader context rather than strictly focusing on waste management only. Many countries have developed policies on 3R approach which are basically founded upon the promotion of sustainable production and consumption patterns, with the greater aim of achieving a sound material-cycle society or circular economy. Bangladesh can update the policy and learn through several initiatives taken by other countries. For instance, with growing concern of e-wastes, China introduces various specific recycling laws, such as the Rules on the Administration of the Recovery and Disposal of Discarded Electronic and Electrical Products (Amin, 2017). They have also developed indicators to monitor the progress of the circular economy at the national, local and industrial levels. Countries like Philippines took several initiatives to promote waste management and recycling in the country such as eco-waste management, recycling collection events, waste markets and organizing the informal sector to improve the efficiency of recovering recyclable wastes among others.

According to Amin, (2017) Thailand has modified their earlier solid waste management regulations with the inclusion of - unlock, promote and support waste utilization based on 3Rs waste segregation at sources, besides decentralized role of operator to local organization. In Viet Nam, targets for waste management are set under the National Strategy on Integrated Solid Waste Management (2009) for the year 2025, including midterm strategic targets by 2015 and 2020. In drafting this strategy, an exceptionally high target of 90% recycling rate and 100% collection rate for large urban areas by 2025 was indicated; this target was later deemed to be impossible to achieve within the designated time frame. Thus, proper data management and planning are essential considerations in the course of developing an implementable 3R strategy.

Various activities related to the 3Rs, such as waste segregation, introduction and operation of appropriate technologies, and collection of waste management fees, cannot be implemented without proper understanding of the public and specifically, partnership with local communities. Collaboration between central and local governments thus represents a vital aspect of recycling policy governance. In the context of increasing urban population trend in Bangladesh, a shift from a centrally-led, command and control type system to a consensus-building approach of policy implementation is crucial for the effective promotion of the 3Rs, including collaboration with stakeholders, information sharing and exchange, and incentive provision, among others.

Table 2:6 Status and Technology gaps in 3R implementation in developing countries

Country	Separation at source	Collection		Intermediate treatment process										Final disposal methodologies		
				Recycling				Biological		Incineration						
		Regular truck	Compator truck	Mechanical sorting (MBT / MRF)	RDF	Gasification	Informal Recycl-ing	Composting	Anaerobic diges-tion	Open burning	Small scale	Incineration with pollution control	Waste to energy (thermal energy conversion)	Open dumping	Controlled dumping	Sanitary Landfill
Bangla-desh		✓ 55% (G)					✓ 15% (G)	✓	✓	✓	✓			✓		
China	Pilot cities	✓ Rural	✓ Urban	✓ Pilot cities			✓	✓ 2% (C)	✓		✓	✓ 16% (C)	✓	✓ Rural	✓ Small-city	✓
India	Pilot cities	✓ Rural	✓ Urban	✓ 200 manual MRF	✓ 12 RDF plants	✓	✓ 15% (C)	✓ 8542 units	✓ 645 units		✓	✓ 6% (C)	✓	✓ Rural	✓ 1380 nos.	✓ 4515 ton/d
Indonesia		✓	✓	✓ 200 manual MRF	Planned in 2018	Agricultural waste only	✓	✓	✓	✓	✓ 4.79 % (C)	✓ 6.59% (C)		✓	✓	✓
Japan	✓		✓		✓	✓		✓	✓			✓	✓ 306 units			✓
Malaysia		✓			✓ 1 integrated power plant		✓ <15% (G)	✓ 1% (G)			✓	✓ 5 units				✓

Country	Separation at source	Collection		Intermediate treatment process									Final disposal methodologies			
				Recycling				Biological		Incineration						
		Regular truck	Compator truck	Mechanical sorting (MBT / MRF)	RDF	Gasification	Informal Recycl-ing	Composting	Anaerobic diges-tion	Open burning	Small scale	Incineration with pollution control	Waste to energy (thermal energy conversion)	Open dumping	Controlled dumping	Sanitary Landfill
Philipp-ines	✓	✓	✓	✓ Few	✓ Few	✓	✓	✓	✓ Few	✓			✓ Few	✓ 341 units	✓ 215	✓ 114 without gas recovery, few with gas recovery
Singapore	✓		✓		✓		✓	✓ Horticultural waste								
Thailand	✓	✓	✓	✓ 3 units	✓		✓	✓	✓	✓	✓ 8 units	✓ 2 units	✓ 1 unit	✓	✓ 367 units	✓ 73 without gas recovery, 1 with gas recovery

Note: G = of generation; C = of collection
Source: (Amin, 2017)

2.6.1.2 Benefits of 3R

Waste or source reduction initiatives (including prevention, minimization, and reuse) seek to reduce the quantity of waste at generation points by redesigning products or changing patterns of production and consumption. A reduction in waste generation has a two-fold benefit in terms of greenhouse gas emission reductions. First, the emissions associated with material and product manufacture are avoided. The second benefit is eliminating the emissions associated with the avoided waste management activities.

Reducing, reusing, recovering, and recycling municipal waste are effective and high-impact means of reducing greenhouse gas (GHG) emissions(EPA, 2006). When discarded materials (waste) are recycled, they provide industry with an alternate source of raw materials. This results in lower demand for virgin materials whose extraction, transport, and processing are a major source of GHG emissions. Recycling thus reduces emissions in virtually all extractive industries: mining, forestry, agriculture and petroleum extraction.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that "waste minimization, recycling and re-use represent an important and increasing potential for indirect reduction of GHG emissions through the conservation of raw materials, improved energy and resource efficiency and fossil fuel avoidance" (Bogner et al., 2007).

There are also other potential benefits (Hyman et al., 2013):

- Land can be put to more productive purposes if not used for open dumping or allocation as landfill.
- Land values will be higher when it is possible to control or avoid the odor and unsightliness associated with poorly managed wastes.
- Recovery of raw materials from waste reduces the need for use of newly extracted materials.
- Waste management provides employment for large numbers of people (both low and high value jobs) and opportunities for enterprise development.
- Energy can be extracted from combustion processes, anaerobic digestion or methane recovery from landfill.
- Composting and anaerobic digestion provide nutrients for agriculture or energy.

- Some industrial wastes can be sold as soil conditioners.
- Greenhouse gas reductions (and lower energy costs) may result from processing choices.

2.6.1.3 Current 3R Status of Bangladesh

The national 3R goal for waste management was to achieve complete elimination of waste disposal on open dumps, rivers, flood plains by 2015 and promote recycling of waste through mandatory segregation of waste at source as well as create a market for recycled products and provide incentives for recycling of waste. However, there has been little physical development in regard to the accomplishment of the goal.

The main objective of this 3R strategy is to delineate ways and means of achieving national 3R goals through providing a uniform guideline for all stakeholders. Specific objectives of this strategy are to (DoE, 2010):

- address the key issues and challenges of waste management acting as a barrier for promotion of 3R in the country;
- define the roles of various actors to promote 3R in the country; and
- guide the creation of enabling conditions for success regarding implementation of 3R in the country. Recent activity and status of Bangladesh against 3R strategy in Table 2.7

Table 2:7 Recent activity and status of Bangladesh against 3R strategy

Activity	Status in Bangladesh
Source Reduction	Reuse and recycling is done by the informal sector Segregation of recyclable/reusable waste item with economic value is mostly done at source by the users
Collection	No provision for collection of waste in segregated manner Collected via door-to-door service, community bin Demountable containers Designated open space
Transportation	Conventional open truck, demountable containers, tractors and trailers in some areas No provision for transfer stations Waste mixed with medical/hazardous waste Transportation does not synchronize with capacity of collection points
Recycling	Mostly done through informal sector/NGO Not accountable

	Presently some local government bodies are doing community based composting Recently using Clean Development Mechanism (CDM) under the Kyoto protocol Waste Concern with a Dutch company took an initiative for a 700 tons/day capacity composting plant and landfill gas recovery project at Matuail Landfill Site at Dhaka city.
Incineration	Not common or successful due to high capital and operation costs Not all types of waste are viable for incineration Few incinerators are used to manage health care related waste
Land filling	Usually open dumping is adopted Causing problem to health and environment All types of wastes including hospital waste are being disposed of at the landfill site.
Cost	5-20% of the annual municipal budget is used for solid waste management.

2.7 Current Status of Solid Waste Management of Bangladesh

The MSW generation rate in urban areas of Bangladesh was 0.41 kg/capita/day (Bahauddin & Uddin, 2012) estimated in 2012 which is lower than the average generation rate of South Asian Region countries estimated as 0.45 kg/capita/day (Hoornweg & Bhada-Tata, 2012). This is expected to increase up to 0.75 kg/capita/day by 2025 whereas generation of SAR countries is expected to rise by 0.77 kg/capita/day and urban population will be doubled from 3,81,03,596 to 7,69,57,000 (Hoornweg & Bhada-Tata, 2012). Another study revealed solid waste generation rate as 0.56 kg/capita/day (*Bangladesh Waste Database*, 2014) of urban areas of Bangladesh back in 2014. The global generation rate will increase by 18.3% from 1.2 to 1.42 kg/capita/day in the period of 2012 to 2025 (Hoornweg & Bhada-Tata, 2012). Another source published that the MSW in urban areas was found as 0.32 kg/capita/day adding up to 0.51 million ton annually (Ashikuzzaman & Howlader, 2019; Shams et al., 2017).

Department of Environment (DoE), Waste Concern, ITN-BUET together stated in a report that with this increasing rate most of the urban local bodies will find it difficult to keep pace with the demand for adequate solid waste management and conservancy services provided by the urban local bodies (DoE, 2004). Consequently, a backlog between demand and supply for solid waste management in most of the urban local bodies is created. Lack of financial resources, institutional weakness improper choice of technology and lack of public awareness about solid waste management has rendered solid waste management services far from satisfactory. Existing pattern of waste management is given in Figure 2.7

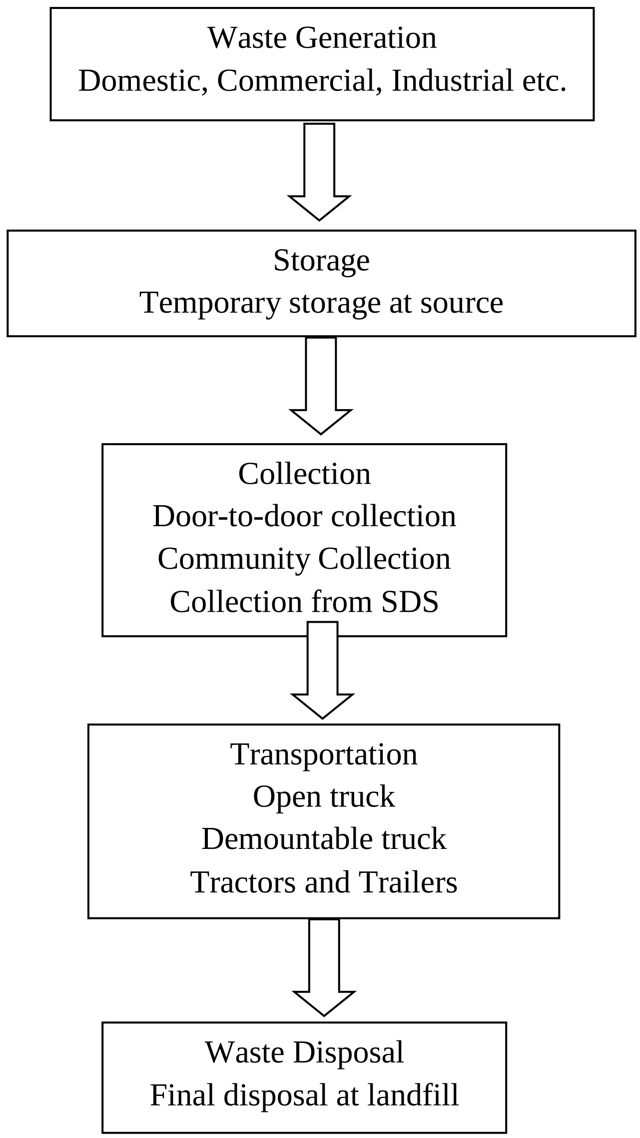

Figure 2:7 Typical methods for waste management system in Bangladesh (Ashikuzzaman & Howlader, 2019; DoE, 2004)

2.7.1 Waste Generation, its Composition and Characteristics (city & population wise):

The entire sum of waste produced each day in Bangladesh has been expanding every year since 1991. While in 1991 the urban ranges of Bangladesh were creating around 6,493 tons per day of metropolitan strong squander, by 2005 that figure had more than multiplied to reach 13,330 tons per day. In 2014, it is assessed that Bangladesh created 23,688 tons per day in its urban ranges (*Bangladesh Waste Database*, 2014). At the same time the full urban populace of Bangladesh has been expanding, from 20.8 million in 1991 to 32.76 million in 2005 to 41.94 million in 2014 due to quick urbanization. The full urban populace is evaluated to be as high as 78.44 million by 2025, and the whole waste generation is anticipated to reach 47,000 tons per day. There is an obvious link between amounts of waste generated and a higher urban population. Interestingly, since 2005 the rate of change of total waste generated daily has exceeded the rate of change of the population growth, due to an increased average daily per capita waste generation rate (*Bangladesh Waste Database*, 2014). The following table shows waste generated in different urban cities/towns of Bangladesh.

Table 2:8 Solid waste generation in major cities of Bangladesh

City/Town	Waste Generation Rate (2005)	No. of City/ Town	Total Population	Total Waste Generation (Ton/day)		Average TWG (Ton/day)
				Dry Season	Wet Season	
Dhaka	0.56	1	7,227,891	4,047.62	5,909.52	4,978.57
Chattogram	0.48	1	2,656,472	1,275.11	1,861.66	1,568.38
Rajshahi	0.44	1	456,277	200.76	293.11	246.94
Khulna	0.27	1	673,093	181.74	265.33	223.53
Barishal	0.25	1	345,972	86.49	126.28	106.39
Sylhet	0.3	1	509,107	152.73	222.99	187.86
Pourashavas	0.25	308	19,363,662	4,840.92	7,067.74	5,954.33
Other Urban Center	0.15	208	5,754,294	863.14	1,260.19	1,061.67
Total		522	36,986,768	11,584.63	16,913.56	14,249.09

Source: Adopted from (Ahsan et al., 2014; Shams et al., 2017)

As per Table 2.8, an average of 7311 ton of waste generated daily in the six major cities of Bangladesh, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet. The Dhaka city contributed the major portion (68%) to the total waste stream, which amounted about 5000 ton. The Dhaka and Chittagong city contributed approximately 89% (6547 ton) of the overall waste stream. The overall socio economic condition of the country is also very much responsible for the very high percentage of organic matter. The generation rate in major cities was ranged from 0.25 to 0.48 kg/cap/day, while highest generation rate was

0.48 kg/cap/day in Dhaka city, lowest generation rate was 0.25 kg/cap/day in Barisal city and the weighted average was 0.387 kg/capita/day for six major cities.

When comparing the percentages of the urban population with the percentages of waste generation as shown in Figure 2.8, interesting patterns emerge in the case of the two largest cities in Bangladesh; Dhaka and Chittagong. Although Dhaka is inhabited by 16.77% of Bangladesh's urban population, being the most populous city in Bangladesh, the capital city generates 25.44% of the country's urban waste. Similarly, as the second largest city in Bangladesh, Chittagong is populated by 6.18% of the country's urban population, but in fact generates 7.67% of its urban waste. Alternatively, other much smaller urban areas, those not categorized as cities or pouroshovas, collectively make up 37.53% of the urban population of Bangladesh, but only generate 23.65% of its urban waste.

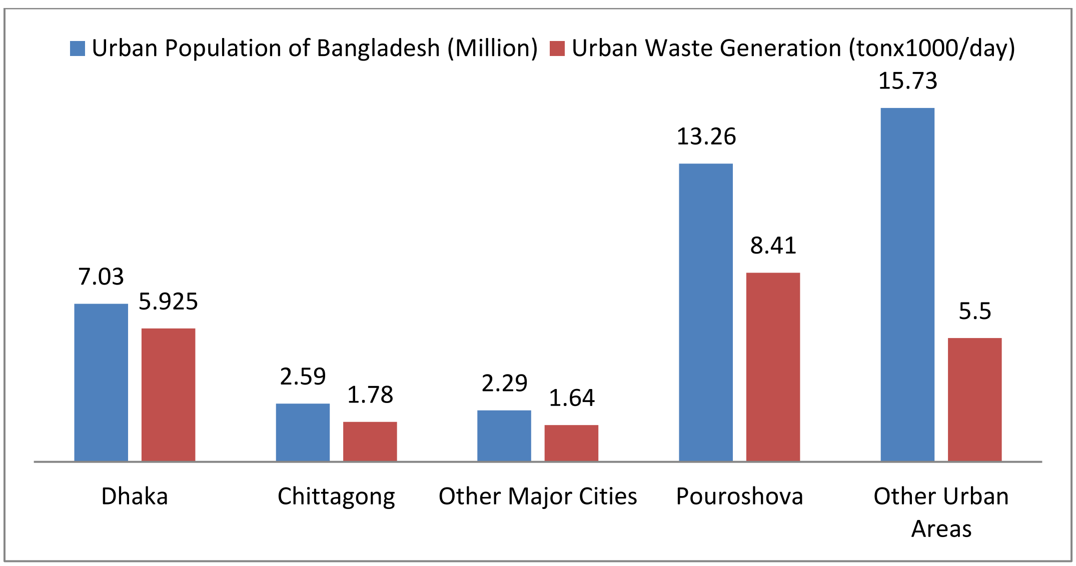

Figure 2:8 Solid Waste Generation in Urban Zones of Bangladesh (Bangladesh Waste Database, 2014)

JICA has conducted several studies on solid waste management of Bangladesh, especially for Dhaka city. One of the studies of JICA revealed the average per capita generation of waste in DCC is 0.56 kg/day accumulating 3200 ton/day out of which domestic generation is 0.34 kg/capita/day resulting daily generation of 1950 ton/day (JICA, 2005). Solid waste generation can also be found in many other literatures for other city corporations or municipalities as well. Alamgir & Ahsan, 2007 conducted a study on waste generation based on socio-economic status of residents of major city corporations as stated in Table 2.9.

Table 2:9 Per capita generation at residential areas in six major cities of Bangladesh

Income Level*	Per capita waste generation (kg/day)						
	DCC**	CCC**	KCC**	RCC**	BCC**	SCC**	Average
A	0.504	0.378	0.368	0.343	0.327	0.429	0.392
B	0.389	0.343	0.333	0.320	0.278	0.395	0.343
C	0.371	0.350	0.319	0.242	0.247	0.340	0.312
D	0.305	0.253	0.264	0.309	0.269	0.248	0.275
E	0.270	0.189	0.203	0.239	0.172	0.260	0.222
Average	0.368	0.30	0.297	0.291	0.259	0.334	0.309

Source: (M Alamgir & Ahsan, 2007)

* High socio-economic (A), Middle upper socio- economic (B), Middle socio- economic (C), Middle lower socio- economic (D), Low socio- economic (E)

** DCC-Dhaka City Corporation. CCC-Chittagong City Corporation. KCC-Khulna City Corporation. RCC-Rajshahi City Corporation. BCC-Barisal City Corporation. SCC-Sylhet City Corporation.

Table 2.10 and Figure 2.9 provide the information on composition of MSW in Bangladesh and how the generation of waste types changed a lot between 2005 and 2014 respectively.

Table 2:10 Solid waste composition in major city corporations of Bangladesh

Waste Category	MSW generation (ton/day)						All Waste Stream
	DCC	CCC	KCC	RCC	BCC	SCC	
Organic matter	3647	968	410	121	105	158	5409
Paper	571	130	49	15	9	18	792
Plastic	230	37	16	7	5	8	303
Textile & Wood	118	28	7	3	2	5	163
Leather & Rubber	75	13	3	2	1	1	95
Metal	107	29	6	2	2	2	148
Glass	37	13	3	2	1	2	58
Other	555	97	26	18	5	21	722
Total	5340	1315	520	170	130	215	7690
Population (Million)	11.00	3.65	1.50	0.45	0.40	0.50	17.5
Per capita (kg/day)	0.485	0.360	0.347	0.378	0.325	0.430	0.387

Source: (M Alamgir & Ahsan, 2007)

On average in urban zones of Bangladesh, food waste still makes up the larger part of waste finishing at the landfill at 77.70%. This was an increment of +9.01% from the 2005 urban average of 68.69%. Similarly, the rate of food waste in cities expanded +6.32% from 69.32% in 2005 to 75.64% in 2014. Overall in urban ranges of Bangladesh, the rate of plastics finishing up at the landfill has gone up by 2.60% from 4.75% to 7.35% between 2005 and 2014. In cities of Bangladesh the sum of plastic waste has expanded by +3.30% from 5.15% to 8.45% over the same time period. A comparative diminishment in paper waste is seen within the cities, with a reduction of 1.77% from 8.99% to 7.22%.

The increment in plastic and diminish in paper waste is mostly due to the changes in selection of packaging materials in Bangladesh, with plastic packaging getting to be favored over paper packaging. Electric and Electronic waste, referred as e-waste, was not recorded in its claim as a particular category in 2005. The most recent category of electric and electronic waste claim making up 0.64% of the urban and 0.35% of city waste generated in 2014. Whereas in cities the rate of wood waste created has diminished from 3.52% to as it were 0.96%, meaning a diminish of -2.57% from 2005 to 2014, on average in urban ranges the rate of wood has diminished by -1.06% from 3.78% to 2.72% over the same time period. This may be translated to be a sign of urban tenants in Bangladesh having moved forward.

In urban regions in common, the rate of fabrics and textiles waste produced has gone down. From 2005 to 2014, the rate of fabrics went down from 3.06% to 2.55% in urban zones, meaning a reduction of 0.50%. At the same time, in any case, the rate of waste created in cities expanded by +0.06% from 3.39% to 3.45%.

Notably, the increments in food waste and plastics, as well as the rise of different e-wastes, are symptomatic of an increment within the GDP of Bangladesh. With more purchasing power and an progressively consumerist society, the appearance of plastic bundling materials, and more prominent electric and electronic products, the composition of metropolitan strong squander in Bangladesh is changing.

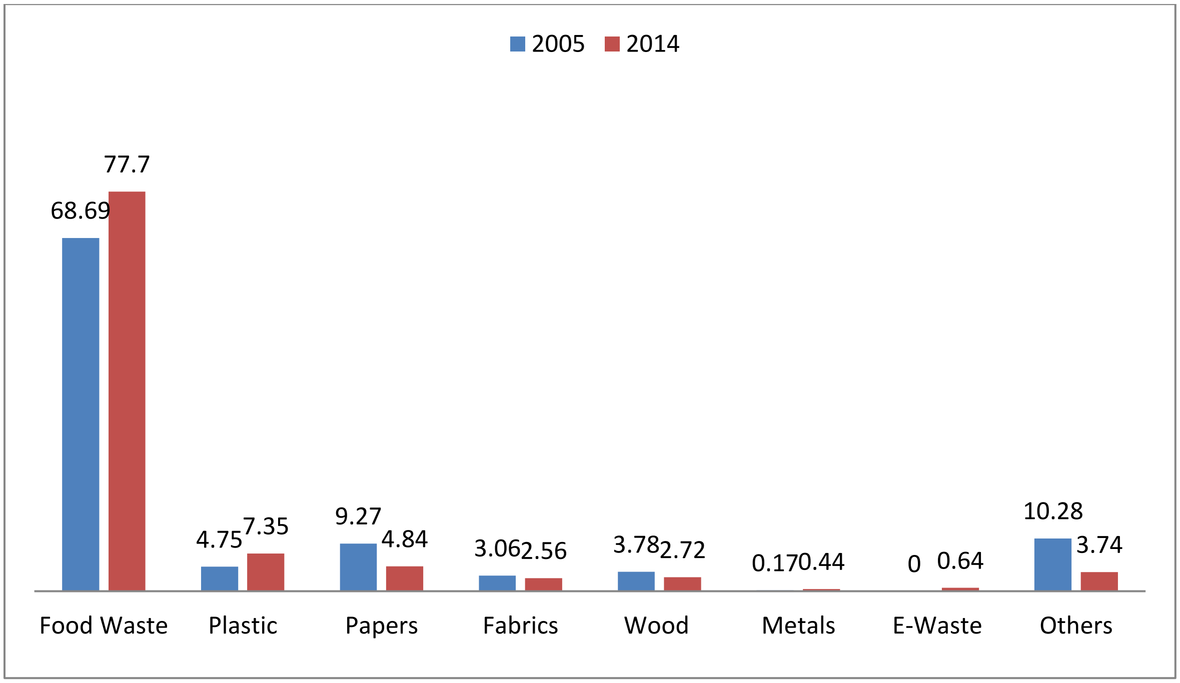

Figure 2:9 Average Composition of Waste (%)
Source: (*Bangladesh Waste Database*, 2014)

2.7.2 Collection of Waste

In majority of the urban areas, community bin system of waste collection is being practiced in Bangladesh. Recently, in some areas NGOs have introduced door-to-door collection of solid waste. But the coverage of neither communal dustbin system nor house-to-house waste collection system is sufficient yet. Moreover, no specific rule and criterion is followed while placing dustbins. The practice of widely spaced communal bins is usually a failure because the demand placed on the households goes beyond willingness of the residents to co-operate. Table 2.11 shows the waste collection rate in different cities and urban centers. It also shows the number of cleaners, trucks and the cost for per ton of solid waste management based on per day collection of solid waste and the annual conservancy budget.

Table 2:11 Collection rates of waste by different city authorities of Bangladesh

City/Town	Total Waste Generation Ton/day	Waste Collection Rate %	No. of Cleaners per 1000 population	No. of Trucks per 15000 population	Cost per ton Tk.

Dhaka	4634.52	37	1.2	0.5	669.98
Chattogram	1548.09	70	0.77	0.6	411.59
Rajshahi	172.83	56.67	0.8	0.5	235.56
Khulna	321.26	47.70	0.62	0.48	986.00
Barishal	134.38	44.30	1.24	0.23	1932.00
Sylhet	142.76	76.47	0.85	0.72	1562.00
Pourashavas	4678.40	54.42	1.05	0.54	447.85
Other Urban Center	1700.65	52	0.55	0.42	312.00
Total	13332.89	Avg. 55	-	-	-

Source:(Enayetulla et al., 2005)

2.7.3 Waste Separation and Resource Recovery by the Informal Sector

Separation of waste and recycling in Bangladesh is still largely an informal phenomenon. As a labor-abundant and capital & material resource-scarce economy, reuse, separation and recycling practices are widespread in the country but not organized and accounted.

One macro level estimate on the extent of recycling by the informal sector is available in Waste Concern's work (Enayetulla et al., 2005), which reports that the informal sector is responsible for recycling from 4% to 15% of the total solid waste generated in different cities and urban centers. This recycled amount saves about Tk 10,705.5 million (15.29 million US $) annually, the study reports (Enayetulla et al., 2005). Waste separation for reuse, selling and recycling currently take place at the following level or sources of waste separation:

- Household/at source of waste generation
- Neighborhood/community/primary collection point
- During the process of waste collection
- During transportation of wastes by municipal workers to dumping sites
- Finally from the dumping sites.

At source, the waste generators separate waste which has higher market value such as newspapers, bottles and plastic containers and sell them to street hawkers. Waste pickers look for recyclable wastes in and around waste bins at primary collection points for collecting materials with low market value such as broken glass, cans, and polythene which are discarded by households. The final phase of the collection of recyclable materials by the waste pickers is from the waste vehicles immediately after unloading at dump sites that continues until nothing appears of worth to be recovered.

Alamgir & Ahsan, 2007 estimated potential recovery and reduction in one of their studies. They estimated the total weight of recyclable and compostable materials was 2,488,185 ton (6817 ton/d) in the six major cities of Bangladesh in 2005. The average recovery rate is 70%, experienced of national associated recycler. Then the recovered materials are 4772 ton/d (= 6817 × 70%) and the revenue is 213,097 $/ d or 77,780,430 $/yr as shown in Table 2.12

Table 2:12 Recoverable materials in MSW of Bangladesh

Item	Weight (ton)	Recovered Weight (ton)	Market Value (US$)
Paper	288900	202230	13468700
Plastic	110400	77280	4017300
Metal	53900	37730	3309600
Leather & Rubber	34600	24220	1,315,300
Glass	21100	14770	249,550
Bone	5000	3500	140,000
Organic Matter (Compostable)	1974285	1382000	55,279,980
Total	2488185	1741730	77,780,430

2.8 Treatment Options

Selecting an appropriate MSW treatment options depends on the waste quantity and composition. Several treatment options are discussed below in regard to management of the organic portion of the collected solid waste in GCC.

2.8.1 Composting

Composting is a widely practiced solid waste treatment method to recover organic waste through controlled biological decomposition which converts degradable organic matters into soil like stable products known as compost. The result found in this study shows a higher percentage of organic content (>80% in both seasons) in the waste stream of GCC. Also the average moisture content of solid waste in GCC varies in between 59% and 74% (Rahman et al., 2018). It has been recommended in several studies that high organic and moisture content is suitable for composting (Ahsan et al., 2014; Bari et al., 2007; BMDF, 2012).

The basic technology which can be used for composting is consist of three phases (Jovicic et al., 2009) namely (i.) pre-processing, (ii.) composting process and (iii.) post processing. Pre-processing involves segregation of unwanted materials and size reduction (shredding) of organic content. In the next phase, the organic content is piled in the composting bed and several additives (saw dust, cow dung etc.) are used to optimize the process. Volume of the compost pile is reduced in this phase as microorganisms decompose the raw feedstock. In the last stage, the compost product is cured and the compost can be said matured. The process flow for a typical composting plant is shown in Figure 2.10.

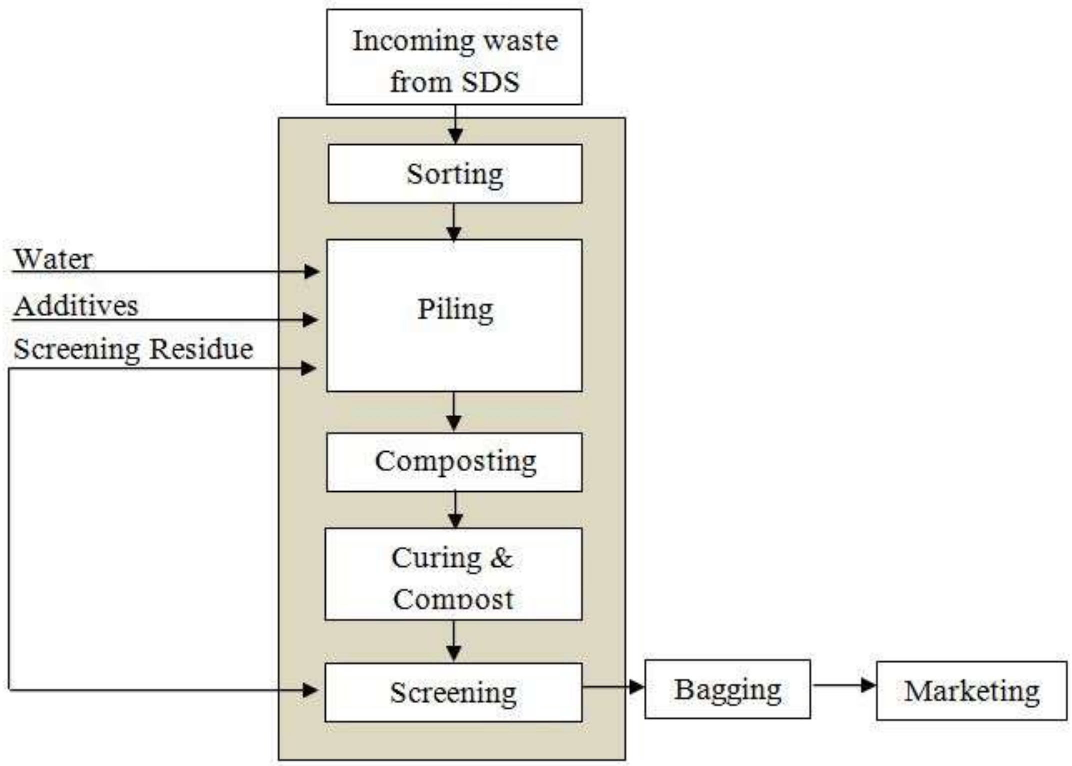

Figure 2:10 Different steps of a composting process

2.8.2 Anaerobic Digestion

Anaerobic digestion is the process through which methane enriched gas (biogas) can be produced via microbiological digestion of the organic fractions in anaerobic condition. The low calorific value (Yousuf & Rahman, 2007) present in the waste of Bangladesh makes it suitable for anaerobic digestion rather than incineration. Similar to potential for composting, the waste type found in GCC, a considerable quantity of organic waste can be recovered into biogas through anaerobic (Bhattacharjee et al., 2013) digestion and then to electricity. By exploring biogas as a treatment option, it is possible to produce $0.21m^3$ of methane for every kg of organic waste. According to the findings of this study, if this treatment option is adapted by GCC, it can produce up to 125.5m3 of methane gas daily against the generated organic waste (598 ton per day).Expected electricity generation can be estimated as 1.2 KW per m3 methane gas (Waste Concern, 2016).

One of the significant features of this option is that this technology ensures better hygienic and sanitary condition. Determining the capacity of the anaerobic digester depends upon the amount of organic fractions is desired to be treated. The capacity of digester(s) in required to treat the organic waste in GCC can be estimated based on the following parameters:

- Maximum organic waste feedstock
- Density of waste
- Hydraulic retention time
- Available area to construct biogas plant

2.8.3 Refuse Derived Fuel (RDF)

Refuse-derived fuel (RDF) is a fuel produced by shredding and dehydrating solid waste (MSW) with a waste converter technology (BMDF, 2012). RDF consists of segregated combustible MSW fractions (plastic, paper) with high calorific value which is too contaminated to be recycled. One of the less expensive and well-established technologies to produce RDF from MSW is mechanical biological pre-treatment (MBT). An MBT plant separates out metals and inert materials, screens out organic fractions (for stabilization using composting processes, either with or without a digestion phase), and separates out high-calorific fractions for RDF. RDF can also result from a 'dry stabilization process' in which residual waste (after separating out metals and inert materials) is dried through a composting process leaving the residual mass with a higher calorific value (Gendebien et al., 2003).The final product is suitable to be used as fuel in coal based power plant, cement plant. Refuse derived fuel (RDF) can be produced from municipal solid waste (MSW) through a number of processes as shown in Figure 2.11.

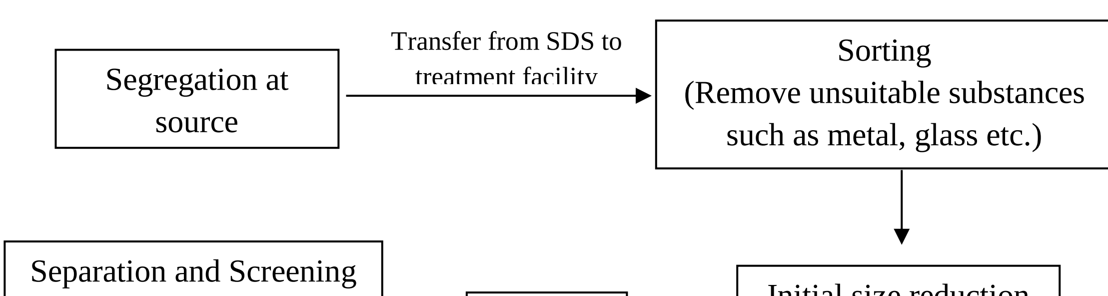

Figure 2:11 Refuse Derived Fuel (RDF) process flow

2.9 Overview of the Study Area

The Gazipur City Corporation was established in January 2013 and is composed of 57 wards drawn from most of the previous Gazipur Sadar Unions and the entire former Tongi Municipality. The Mayor and 76 elected Councilors administer the City Corporation. GCC is the largest city corporation of Bangladesh having an area of 329.53 square kilometer. The current population of Gazipur city is about 2.5 million. This article describes the general information such as location, city layout, and population, socio-economic and environmental condition of the study area. Overviews of the existing solid waste management system like on-site storage, primary collection, secondary collection, transportation and disposal methods are discussed here.

2.9.1 Location, Layout and Population Distribution

Gazipur City Corporation is located in the center of the country. Connectivity of the capital city Dhaka with northern regions is through Gazipur City. It lies between 23052’45" and 2406’12"north latitudes and between 90015’2"and 90029’50" east longitudes.

To identify the waste generation rate and waste characteristics of the whole city was divided into five zones. Corresponding zonal area and projected population can be obtained from Table 2.13 (Hifab, 2016). To propose an implementable waste management system it is very important to have a concrete data on population. Increasing population has a causal relationship with waste management in urban areas, because it has the potential to produce a large amount of solid waste, which is one of the challenges facing any urban area in the world (Zerbock, 2003). Figure 2.12 shows the location of each zone under GCC.

Table 2:13 Zonal area and respective projected populations

Zone	Area sq.km.	Projected Population			
		2016	2021	2026	2036
Zone-1 (TONGI)	32.60	650,598	805,998	959,819	1,207,106
Zone-2 (GACCHA & PUBAIL)	75.93	448,945	556,178	662,323	832,963
Zone-3 (GAZIPUR)	47.78	244,528	302,936	360,750	453,693
Zone-4 (BASAN & KOYALTIA)	104.20	347,146	430,063	512,139	644,086
Zone-5 (KONABARI & KASHIMPUR)	61.28	326343	572,750	682,057	857,782
Total	321.79	2,017,560	2,667,925	3,177,087	3,995,629

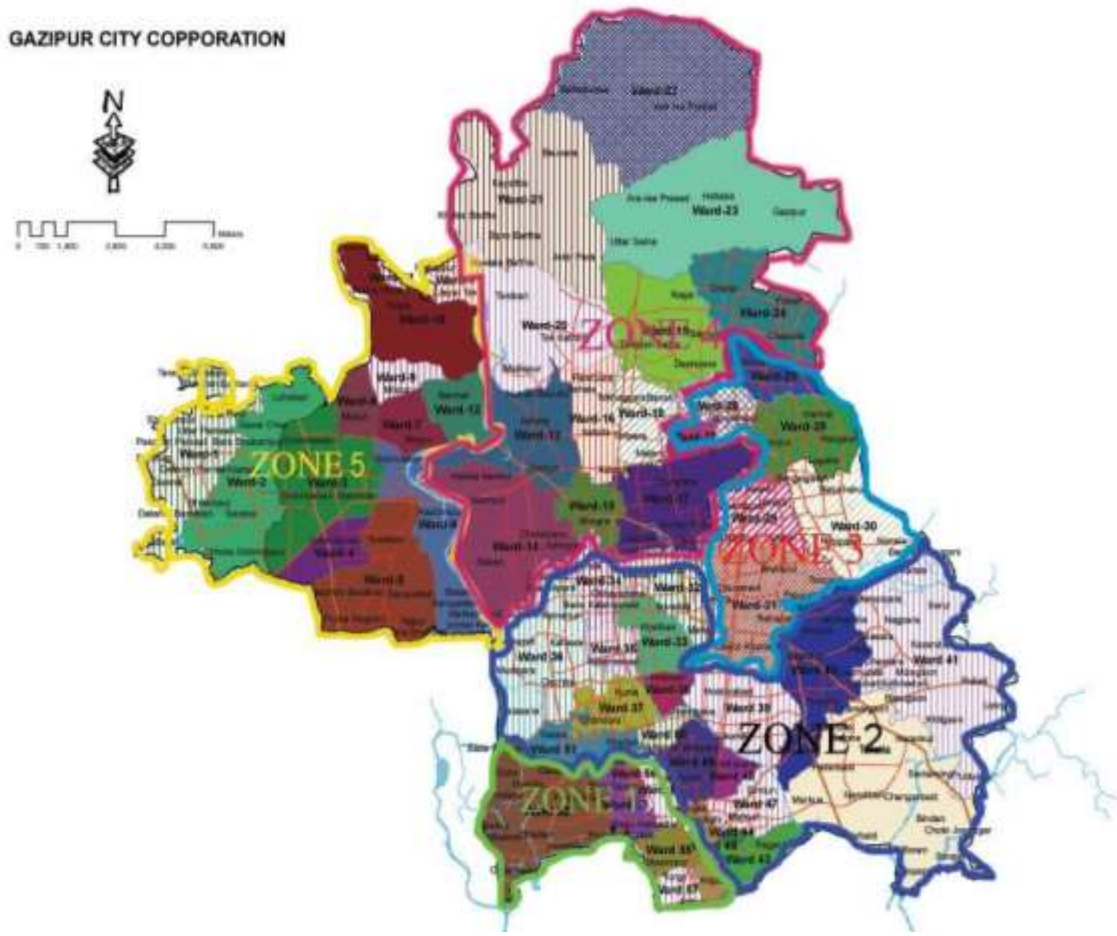

Figure 2:12 Map of five different zones in GCC

2.9.2 Socio-Economic Condition

The Bangladesh Bureau of Statistics estimates that within the City Corporation there are approximately 750,000 poor (CARE Bangladesh, 2014) residents, of which 700,000 are living in one of 1,410 slums or informal settlements. (It is important to note that prior to January 2013, sections of the new Gazipur City Corporation operated as a separate district and many of the available statistics are from this time). Currently, no one is able to provide a complete profile of the communities now considered part of the new boundaries (CARE Bangladesh, 2014). In 2013, the Urban Partnership for Poverty Reduction Program that covers some but not all slums within Gazipur estimated 56% of Dhaka residents are renting housing. Only 30% have access to water and 10% to sanitation services. Most unplanned settlements in the City Corporation catchment area are located either on freehold or leasehold land (Konabari slum) or squatting on government land

(Tongi slum). It is estimated that Dhaka needs 55,000-83,000 new housing units per year to cope with an annual 5% increase in migration into the city. Presently, 25,000 units per year are being built by either government or private citizens. Currently, Gazipur has weak legislation and no formal land use plans to designate areas as residential or for industrial purpose (CARE Bangladesh, 2014).The area also lacks a waste disposal site to cope with the hundreds of tones of rubbish produced daily.

According to (BBS, 2013))The Literacy Rate of Gazipur district (before its formation as City Corporation) is about 62.60% (Male- 66.00% and Female- 58.90%), School attendance rate is 42.50% for 5 to 24 years age group. There are 5 universities, 2 technical institutions, 3 agricultural institutions, 3 Government colleges and many other institutions in Gazipur. Gazipur is also known as the one of the important industrial hubs of the country. There are Garment and textile industries, steel and engineering factories, jute mill, sugar mills etc. Most of the residents are directly or indirectly related to the readymade garment or textile industry. For instance, within Konabari, 70% of the working tenants work in the garment sector, both in primary and secondary factories. The remaining 30% of Konabari residents work in informal spinning and knitting factories, cosmetic factories, banks, commercial institutions, different manufacturing plants, brick kilns, or as day laborers.

2.9.3 Environmental Condition

In Gazipur city, environmental pollution is increasing day by day. The city is suffering with its expanding population bringing four major issues of environmental concern: air pollution, noise pollution, water pollution and municipal solid wastes. The city also suffers from unexpected local flooding due to drainage congestion during heavy rainfall. Gazipur City Corporation does not have storm drains to let out the waters after heavy rains, which leads to water logging, traffic jam and public suffering. The city also suffers from unhygienic sanitation conditions and high incidence of diseases. Annual average temperature of this Gazipur district varies from maximum 36°C to minimum 12.7°C. and annual rainfall is 2376 mm.

2.9.4 Present situation of SWM in GCC

Gazipur city generates a huge quantity of wastes everyday from different sources. A significant portion of municipal solid waste comes from residential waste. The other important sources are industries, medical/hospitals and commercial institutions. According to the City Corporation Act 2009, Gazipur City Corporation (GCC) is responsible for collection, transportation, treatment and disposal of solid wastes in Gazipur City. Due to several limitations especially lacking in disposal area, GCC has not been able to properly manage the solid waste disposal. However, a number of non-governmental Organizations (NGOs), Community Based Organizations (CBOs) and social groups are also involved in MSW management in Gazipur city. Recently the city corporation has revised the categories of zones and divided the GCC into 8 zones and extended waste collection capacity. As per 2020 data provided by GCC (field study, 2020), the recent estimated municipal waste generation rate is 3000-4000 ton/day. Out of this GCC collect 2400-2500 tons of waste daily maintaining a collection efficiency of 60-70%. However, this estimation has been made based on the vehicle capacity and number of trips made. But in this case, no utilization factor has been considered to evaluate the actual weight that is being carried to the final dumping site.

2.9.5 Onsite storage and separation

In GCC, Householders usually store wastes in different sizes of plastic/metal boxes, buckets etc. They store their waste at their own responsibility and waste bucket is mostly used for kitchen waste. Although some NGOs are even supplying waste bins to motivate people for cooperating waste management system. From the questionnaire survey conducted in this study it has been found that 78% of household uses at least a bin/basket for the storage of wastes at source and only 15% of people store the waste in segregated condition at household level which include reusable plastic items/containers are being like PET bottle.

2.9.6 Primary Collection

As mentioned earlier the SWM system of GCC is not well organized, the overall primary collection system is not maintained and operated by the conservancy department. Several NGOs and local communities play the key role to collect the solid waste from households or community bins to secondary dumping sites.

Wastes are also dumped into community/block dustbin by households from where wastes are also being collected and transferred to secondary dumping sites as mentioned in Table

3.2.According to field study about 500-600 community vans are operated throughout the GCC area operated by several NGOs or community based organizations. No. of primary collection vehicles can also be found in Table 2.15.

2.9.7 Secondary Disposal Site

Secondary dumping/disposal site (SDS), is the point which receives wastes from several sources such as domestic, industrial, commercial etc. SDS is considered as the facilities where large amount of wastes are accumulated and finally transferred to the disposal site by large vehicles.

There are 15 designated secondary disposal sites in different zones of GCC among 6 are in permanently located and rests are temporarily located. Apart from these 15 designated SDSs there are about 200non-designated SDSs scattered throughout the GCC where residents/waste collector dump waste. The details are shown in Table 2.14.Though in MSW management, SDS plays an important role, the condition of SDSs in GCC are very unpleasant, alarming and no nuisance control is present.

Table 2:14 Details of Secondary Dumping Sites (SDS)

Type of SDS	Quantity	Location	Ward	Zone
Permanent	01	Soilargoti	46	1
Permanent	01	Adjacent to 80MW power supply centre	44	1
Permanent	01	Shilmun	47	1
Temporary	01	East Arichpur, Bou Bazar Road	45	1
Temporary	01	Station Road, Thelagari Stand	56	1
Temporary	01	Tongi Bazar	57	1
Permanent	01	Gacha	35	2
Permanent	01	Adjacent to Titas Gas Office	26	3
Temporary	01	Shibbari Circle	26	3
Temporary	01	Shardi	27	3
Temporary	01	Doshtola T&T	18	4
Temporary	02	Shalna Bazar	19	4
Temporary	02	Bangla Bazar	22	4
Temporary	200	Located in all different zones, referred as community bins		

Source: Conservancy Department (GCC), Field Study (2020)

2.9.8 Secondary Collection and Transportation

Usually, motorized vehicles are used to transfer wastes from SDSs to final dumping site or ultimate disposal site and non-motorized vehicles are used for transferring wastes from community bins or households to SDS. Recently in few zone small motorized vehicles are also been used for this purposes as well.

Conservancy department of the city corporation setup the time-schedule and types of vehicle for collection and transportation. Generally collection vehicles such as covered drum truck, waste truck with compactor, are used for waste collection and transportation. Usually collection and transportation are done at evening and night times Figure 2.13 to 2.15 shows the typical waste collection and transportation in GCC in regards to secondary sites. In GCC, there are more than 200 secondary dumping sites and community bins as mentioned earlier. For regular operation, city authority collect and transport waste only from major SDSs from different zones, whereas the remaining SDSs are covered in lower frequency. Current resources of the GCC for waste management are summarized in Table 2.15.

Table 2:15 Existing resources for waste management of GCC

Item	Quantity	Capacity (ton)	Vehicle Type
Tri-Cycle Van	500-600	0.3-0.5	Non-motorized
Motorized Truck	18	3	Hydraulic
	10	15	Hydraulic
	4	5	Hydraulic
Compactor Truck	2		Hydraulic
Manual Truck	4	3	--
Payloader Trailer	6	--	Hydraulic
Excavator	4	--	Hydraulic
Backhoe loader	01	--	Hydraulic
Skid Steer Loader	04	--	Hydraulic
Wheel Loader	01	--	Hydraulic
Chain Dozer	02	--	Hydraulic

Source: Conservancy Department (GCC), Field Study (2020)

In total there are 56 different types of vehicles to carry and manage waste from secondary points to final dumping station. For transportation 36 numbers of trucks of different sizes (3 ton, 5 ton, and 15 ton) are used. All the vehicles listed in Table 2.15 except primary collection vehicles (tri-cycle van) are stationed in zone 1 and zone 3. To transfer waste from SDSs to final dumping site, the vehicles are dispatched from zone 1 and zone 3 average roundtrip distances are 30 and 15 km respectively (Field study, 2020). In general, the trucks carry waste in day and night shift but the night shift is preferred because 3-5 trips can be made at night whereas only 1-3 trips is made in day shift. In excess of these GCC use rented vehicles for waste transportation as per need (during religious festivals, bishwa ijtema and other national occasions).

Figure 2:13 Dumping of waste at SDS after primary collection

Figure 2:14 Waste transporting to ultimate disposal site from SDS

Figure 2:15 Open and unprotected secondary dumping site

2.9.9 Ultimate Disposal Site

Currently GCC uses only one landfill site of 5 Acres for final disposal of waste which is owned by Roads and Highway Department, another organization of government. Existing site has no sorting and recovery facilities and absence of composting or any other treatment options is worsening the environmental condition. The exposed and uncontrolled open dumping of waste are responsible for severe environmental pollution which includes air pollution, water and soil contamination, odor and dust problems etc. Figure 2.16 and 2.17 are showing the current condition of final disposal site.

Figure 2:16 Final disposal site at Kadda Baimail

Figure 2:17 Collection vehicles are waiting in line to dump the waste

2.9.10 '3R' Activities in GCC

Typically, an MSW industry spreads over four major components namely 3R, composting, waste to energy and land filling. Unfortunately in case of GCC no formal waste to energy project and composting facilities are present.

3R promotes reduce, reuse and recycling activities related to generation and management of solid waste. The concept of minimizing waste impacts in terms of quantity or ill-effects, by reducing quantity of wastes, reusing the waste products with simple treatments and recycling the wastes by using it as resources to produce same or modified products is usually referred to as "3R".

Output monitoring report of city corporations also revealed that till the financial year of 2017-18 no 3R plotting was done for GCC (LGED, 2018).At present, in GCC there is no practice on reduction of wastes at source. Reduction at source requires intervention in both large and micro level. In GCC, informal sectors by various groups of different community are playing the major role in recycling of solid waste. All the buyers of the reusable/recyclable items belong to the informal sector and only a few formal manufacturers are involved in recycling. Some cases householder sale these types of items to local vendors/hawkers. Moreover, various types of reusable/recyclable items are reclaimed / collected by the scavengers or street children. In most cases, the reclaimed items are paper, magazine, newspaper, paper cartoon, book, PET bottle, plastic container, oil container, tin can, wood, leather, shoes, rubbers etc.

The MSW of Bangladesh is suitable for composting due to its high moisture and organic contents. In Bangladesh, mainly NGOs are involved in composting. Besides the city corporation areas, composting plants are also set-up in some municipalities with technical assistants from experienced NGOs, financial support from donor agencies with the collaboration of local city authorities. In case of our study area, there is no single composting plant operated by City Corporation. But there are several NGOs who are operating composting plant are small scale.

2.10 Summary

In this chapter, several literatures have been reviewed focusing on the global and local solid waste characteristics including solid waste generation, composition and waste management practices. As this study focuses on the 3R strategy for waste management several, definition, principle and activities of 3R have also been discussed widely followed by country status and technology gap in terms of 3R implementation. The waste management scenario and several relevant waste treatment options like composting, anaerobic digestion, RDF etc. have been mentioned based on the treatment and recovery of waste type available in Bangladesh. Afterwards, a detailed review was done on the Gazipur City Corporation. The overview on the study area (GCC) indicated the current practices and drawbacks of solid waste management in GCC, waste collection resources available in GCC, disposal techniques and 3R status in the study area.

To summarize, the gap in the literature observed focuses on the solid waste characteristics in GCC, resource recovery potential and 3R based solid waste management system in GCC.

CHAPTER:3 METHODOLOGY

3.1 General

Waste stream analysis can be defined as any program which involves a logical and systematic approach for obtaining and analyzing data on one or more waste streams or sub streams. The analysis also provides an estimate of solid waste quantity and composition, referred to as waste characterization. There is currently no agreed international standard for waste stream analysis or waste characterization(EPA, 1996). This chapter presents methods that were used during this research study. The chapter describes the research design, the research approaches, the sample and sampling procedure, the sources of information, data collection and analysis.

The methodology employed in this study was the combination of following four tasks:

l. Data collection from sources

2. Direct field investigation

3. Data analysis

4. Questionnaire survey

5. Approach to integrated solid waste management promoting 3R strategy

3.2 Data Collection

Both primary and secondary sources of data collection were collected during this study. The use of the two types of data collection was meant to complement one another during the research. Data from previous study on waste scenario of Bangladesh were also collected to compare the findings of the study

3.2.1 Primary Sources of Data Collection

This involves the extraction of information from the field investigation in order to get first-hand information. For this source, questionnaires and field study were used. Solid waste generation rate and composition data are ascertained from primary sources such as residential and secondary dumping stations.

3.2.2 Secondary Sources of Data Collection

Secondary data is obtained from text books, journals, news papers, reports as well as internet sources. Key personnel related to conservative department of GCC were also interviewed and they had provided information of the data sources. Several sources of secondary data are given below (not limited to)

- Gazipur City Corporation (GCC)
- Bangladesh Bureau of Statistics (BBS)
- Waste Concern
- World Bank
- JICA

3.3 Direct Field Investigation and Analysis:

Direct field investigation includes MSW generation, composition analysis in field. Data revealed from field were also used for comparison with other major city corporations of Bangladesh. Based on the collected and computed data, finally an economic analysis has been done based on the resource recovery potentials.

3.3.1 Sampling Period

Waste generation is affected greatly by seasonal variation; therefore, ideally waste analysis should be carried out at three month intervals. Periodic variations in MSW composition can be influenced by either seasonal variations or changes occasioned by special events such as holidays and tourism (Roberts et al., 2010). Identifying seasonal variation is important because it will enable the authority to design the management system efficiently. People's spending nature and consuming pattern are different in different seasons. Thus it may influence the overall solid waste characteristics and may require different management techniques especially in waste collection frequency and allocating optimum trip for waste collection. In this study the waste has been collected twice a year for consecutive two years (2016 and 2017) in dry and wet season of respective year.

Solid waste from households and secondary dumping sites has been collected in dry and wet seasons. November to February and May to July was considered as dry and wet season respectively as per the climatic condition of Bangladesh. Samples were collected in two cycles from the households from different zones in consecutive two years for both the seasons as given following Table 3.1:

Table 3:1 Season and cycle of sample collection

Year	Season	Cycle	Month
2015-16	Dry	1	November, December
2016	Wet	1	June, July
2016-17	Dry	2	December, January
2017	Wet	2	June, July

3.3.2 Selection of Households and Secondary Dumping Sites

Household waste means waste produced within the area of a building or self-contained part of a building used for the purposes of living accommodation. A secondary dumping site is the point where all the waste within a locality is accumulated to collect and transport to the final dumping site. As the study area was divided into 5 zones, waste samples were collected in total two cycles and two seasons in each cycle as mentioned in Table 4.2. Using Slovin's equation a sample size for GCC can be estimated as follows

$$n = N / (1 + Ne^2)$$

Where,
n = Sample size
N = Population size = 25,00,000
e = margin of error = 5% = 0.05
Therefore, the sample size for GCC is, $n = 2500000 / (1 + 2500000 * 0.05^2) = 400$

However, the total numbers of households cover in all the cycles are 206. Reduced numbers of samples have been collected due to several shortcomings such as non-cooperation of the householders, willingness to participate in waste survey, resource constraints (limited manpower and transport provisions), etc. The households were selected randomly from each zone as shown in Table 3.2. Corresponding households were given a waste bag to store their domestic waste for one day (24 hrs) and collected accordingly for further analysis. Waste sample was also collected from several secondary dumping sites selected randomly from each zone in each cycle of dry and wet season. Waste has been collected in a 30 kg bag from secondary stations and then analyzed.

Table 3:2 Number of sample collected from each zone

	No. of samples from household				No. of samples from secondary dumping sites			
Sources	Cycle 1		Cycle 2		Cycle 1		Cycle 2	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Zone 1	16	13	10	10	2	2	1	1
Zone 2	12	13	8	8	2	2	1	1
Zone 3	11	12	10	8	2	2	1	1
Zone 4	12	9	8	8	2	2	1	1
Zone 5	12	10	8	8	2	2	1	1
Total	63	57	44	42	10	10	5	5

3.3.3 Sample collection and transportation

To collect the waste sample from respective household, containers (bags) were supplied for storing waste generated in a day and the waste was collected on the following day. Afterwards the collected waste bags were transported to a temporary sorting place at IUT or nearby available location for sorting and weighing after 24 hours air drying of waste. Similarly waste was collected and transported to sorting place from selected SDSs.

3.3.4 Sample Analysis

Generation: The collected waste was transported to a sorting facility and kept for 24 hours for sun-dry. 24 hours sun-dry condition created a favorable condition for waste sorting. Then initial weight of the raw waste has been taken. The weighted waste from different households was analyzed to determine the generation rate and volume of waste generated was calculated as follows:

Generation rate = (Weight of waste in 24 hours) / (No. of family members); Kg per capita per day

Volume = Weight / Typical Density

Typical density used in this study is shown in Table 3.3.

Table 3:3 Typical density and moisture content of different types of waste

Waste Type	Density (kg/m^3)	Typical Moisture Content (%)
Food waste	290	70
Gardens	105	60
Paper	85	6
Plastic/Polythene	65	2
Dirt, Ashes, Brick Chips	800	12
Glass/Bottle	195	2
Metal/Tin	90	3
Rubber	130	2
Leather	160	10
Wood	240	20
Battery	900	3
Aerosol Can	400	3

After getting the representative generation rate of each zone the zonal average has been calculated and then the overall generation rate and composition of domestic waste for GCC was computed against the available population data.

Composition: After taking the initial weight collected from households and SDSs, wastes were sorted into three categories such as organic, inorganic and hazardous waste as stated in Table 3.4.Then the weight of each component was measured. The dry weight of different waste type has been calculated using the typical moisture content found in the literature. The waste collected from secondary dumping sites also analyzed in similar way. The typical formula for the determination of moisture content is as follows:

Moisture Content = (Total weight of waste – Dry weight of waste)/100 % (Baba et al., 2014)

Table 3:4 Categories and types of waste analyzed

Waste Category	Types
Organic Waste	Food waste
	Gardens
Inorganic Waste	Paper
	Plastic/Polythene
	Dirt, Ashes, Brick Chips

	Glass/Bottle
	Metal/Tin
	Rubber
	Leather
	Wood
Hazardous Waste	Battery
	Aerosol Can

The composition of solid waste was then compared against organic and inorganic contents. Volume reduction analysis and resource recovery potential is also analyzed using the composition obtained from this study.

3.3.5 Questionnaire Survey

During waste collection from households, a questionnaire survey has been conducted with a view to explore their knowledge and practice about solid waste management. The 13 questions (Annex II) were set out to illustrate a general idea on the behavioral pattern of the inhabitants of GCC in terms of solid waste management. The questions were selected based on the following three concerns:

- Onsite segregation and storage practices/behavior
- Primary disposal practices
- Overall waste management concepts

Altogether there were 113 respondents from different households from the overall study area.

3.4 Revenue and Land Requirement through 3R Approach

Based on the resource recovery potential, an economic analysis has been done to identify the compare between the revenue earned by applying 3R techniques and operation cost required per ton of solid waste.

Revenue through 3R techniques (BDT/ton) = (Annual revenue from resource recovery + Annual earnings through fuel cost saving from volumetric reduction) / Annual waste generated (ton)

Annual Operation Cost (BDT/ton) = (Salary + Fuel Cost + Repair & Maintenance Cost + Others) / Annual waste generated (ton)

An estimation of potential of landfill space saving by incorporating 3R approach in SWM is also evaluated by estimating the volume required for land filling and the associated area required as follows:

$$\text{Volume of MSW required for disposal } (m^3/year) = \frac{\text{Projected waste generation (ton/year)* Collection efficiency}}{\text{Compacted waste density } (ton/m^3)}$$

Area required for land filling (m^2/year) = Volume of MSW for disposal/dumping height

The required area for disposal site is calculated by assuming a 6m dumping height and a compaction factor of 1.1 ton per cubic meter (Zurbrügg et al., 2005).

3.5 Projection on Solid Waste Generation

Future solid waste generation for GCC is projected based on the following two approaches:

i. Population trend: The forecasting for growth in waste generation can be made by population trend using annual growth rate of population and per capita waste generation of baseline year.

ii. Compound annual growth rate (CAGR), gross annual product (GAP) and income spending approach: Bangladesh Center for Advanced Studies uses a procedure for predicting future waste generation(Islam, 2016). By estimating the compound annual growth rate of population, GAP and considering that 70% of the additional income going into consumption, waste generation growth factor is calculated in percent (GAP *0.70). Projected waste generation for GCC was calculated as following

$$PWG = [\{PBY * (1 + CAGR)^N\} * (PCWB + PCWB * WGG)]/1000$$

PWG =Projected waste generation (ton/day)
PBY= Population in baseline year
CAGR= Compound annual growth rate of population
PCWB= Per capita waste generation in Baseline year (kg/capita/day)

WGG = Waste generation growth factor = GAP * 70% = 5.6%; considering recent GAP as 8% (*World Bank*, 2020)

N = Number of years

3.6 Identifying SWM Drawbacks and Incorporating 3R Concept

This study also emphasizes on the limitations and drawbacks of the solid waste management system in GCC to achieve the objective II. These were identified through interviews with key personnel from conservancy department of GCC. Also several remarks are made based on the literature review and field study. For objective IV, an integrated approach for SWM is proposed incorporating 3R concept. Several literatures mentioned 3R based SWM system in many studies which directed this study to propose an integrated SWM approach.

CHAPTER:4 RESULTS & DISCUSSIONS

4.1 General

This chapter describes the results of this study which include estimation of per capita waste generation rate, total amount of waste generated, composition, trips required to manage the generated waste. An analysis was done to find out the benefits of applying 3R policy at both household level and secondary dumping sites which involve the potential of resource recovery, monetary saving and saving of land space required for final disposal. The results obtained from this study were compared with other published data and reports. This chapter also contains an analysis of the drawbacks and shortcomings of the current practice of MSW management.

4.2 Solid Waste Generation Rate

4.2.1 Household Level

Reliable estimate of the quantity of solid waste generated in the city is very important in the planning for proper solid waste management. The data obtained through the waste collection and analysis as mentioned the tables of Annex-I were analyzed for zonal and seasonal variation in terms of total waste generation rate for respective zones and season were also determined.

Solid waste generation rate at household level rate is calculated and stated below in the following tables (Table 4.1 – 4.5) for different zones. As solid waste was collected in two seasons in two cycles, a seasonal variation in each cycle is also shown here.

Table 4:1 Waste Generation Rate (WGR) in zone 1

	Cycle 1		Cycle 2		Seasonal Average WGR (kg/capita/day)		Overall WGR (kg/capita/day)
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
No. of Households	16	13	10	10	0.34	0.33	0.335
Total Family Members	82	54	78	61			
Waste collected (kg)	24.70	17.68	28.87	20.20			
WGR(kg/capita/day)	0.30	0.33	0.37	0.33			

Table 4:2 Waste Generation Rate (WGR) in zone 2

	Cycle 1		Cycle 2		Seasonal Average WGR (kg/capita/day)		Overall WGR (kg/capita/day)
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
No. of Households	12	13	8	8	0.38	0.40	0.39
Total Family Members	66	54	74	69			
Waste collected (kg)	25.64	21.94	27.86	26.79			
WGR(kg/capita/day)	0.39	0.41	0.38	0.39			

Table 4:3 Waste Generation Rate (WGR) in zone 3

	Cycle 1		Cycle 2		Seasonal Average WGR (kg/capita/day)		Overall WGR (kg/capita/day)
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
No. of Households	11	12	10	8	0.37	0.38	0.375
Total Family Members	57	71	64	71			
Waste collected (kg)	25.72	27.84	18.75	26.64			
WGR(kg/capita/day)	0.45	0.39	0.29	0.38			

Table 4:4 Waste Generation Rate (WGR) in zone 4

	Cycle 1		Cycle 2		Seasonal Average WGR (kg/capita/day)		Overall WGR (kg/capita/day)
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
No. of Households	12	9	8	8	0.33	0.33	0.33
Total Family Members	82	68	66	47			
Waste collected (kg)	23.41	21.69	24.36	16.09			
WGR(kg/capita/day)	0.29	0.32	0.37	0.34			

Table 4:5 Waste Generation Rate (WGR) in zone 5

	Cycle 1		Cycle 2		Seasonal Average WGR (kg/capita/day)		Overall WGR (kg/capita/day)
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
No. of Households	12	10	8	8	0.34	0.38	0.36
Total Family Members	64	41	47	41			
Waste collected (kg)	17.53	14.18	19.46	16.61			
WGR(kg/capita/day)	0.27	0.35	0.41	0.41			

Overall average generation rate of solid waste in GCC is 0.36 kg/capita/day as shown in Table 4.6 using the obtained waste generation rate from Table 4.1 to 4.5 for different seasons. From the Table 4.6 and 4.7 a comparison is made about the per capita generation and daily generation in all the zones at different seasons. The highest generation rate was found in zone 2 in the wet season at 0.40 kg/capita/day and lowest rate was found in zone 4 at 0.33 kg/capita/day in both dry and wet seasons. Altogether 107 and 99 samples were collected to determine the waste generation rate in dry and wet season respectively. To identify any significant different is present or not a t-test was conducted assuming a confidence level of 0.05 (95%), a value of < 0.05 would indicate a high probability that any variation is not by chance. Conversely any value > 0.05 indicates either that there is no variation or that variation is not statistically significant. The results showed a p-value > 0.05 indicating that there is no significant difference in waste generation in dry and wet seasons. The seasonal and zonal variation in per capita waste generation is shown in Figure 4.1 for comparison.

Table 4:6 Estimated per capita solid waste generation rate in GCC

Zone	Seasonal WGR (kg/capita/day)				Zonal Average WGR (kg/capita/day)	Overall Average WGR (kg/capita/day)
	Dry Season	Average	Wet Season	Average		
1	0.34	0.352	0.33	0.364	0.335	0.358≈0.36
2	0.38		0.40		0.39	
3	0.37		0.38		0.375	
4	0.33		0.33		0.33	
5	0.34		0.38		0.36	

Table 4.7 shows the daily generation of solid waste in different seasons. In both seasons zone 1 generates highest quantity of solid waste because of higher population.

Table 4:7 Seasonal solid waste generation at household level in GCC area

Zone	Population at study period	Seasonal Generation (ton/day)		Zonal Average Generation (ton/day)
		Dry Season	Wet Season	
1	650,598	221	215	218
2	448,945	171	180	175.5
3	244,528	90	93	91.5

4	347,146	115	115	115
5	326,343	111	124	117.5
Total	2,017,560	708	727	717.5

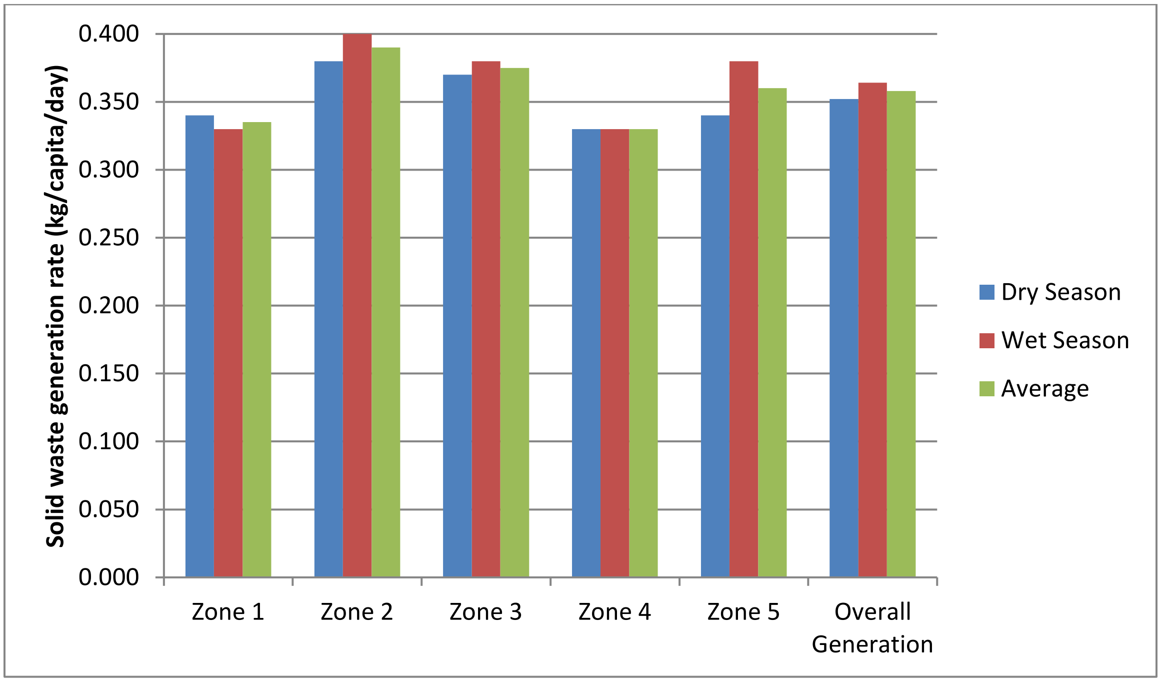

Figure 4:1 Composition of solid waste generation rates in different zones of GCC area

4.2.2 Comparison with other Studies

Although GCC is the largest city corporation in terms of area, Dhaka city remains on the top for generating largest amount of solid waste in Bangladesh. Ahsan et al., 2014, has estimated the solid waste generation rate in six city corporation areas in Bangladesh. As per their study waste generation rate in the six major cities of Bangladesh is ranging from 0.25 to 0.56 kg/capita/day for Dhaka and Barishal city respectively. Whereas in the municipal areas of Bangladesh, the daily solid waste generation rate is projected to be 0.6 kg per capita per day by 2025 (Bhuiyan, 2010). According to Shams et al., 2017, the waste generation has increased from 1.1 million tonnes in 1970 to 5.2 million tonnes in 2015. The trends of waste generation per year is growing at a rate of 0.1343 million tonnes per year (368 t per day). About 78% of solid waste is generated from housing sector and 20% from business sector, 1% from the institutional sector and the rest from other sectors (Ahsan et al., 2014).

Table 4.8 provides a comparison on the solid waste generation status of GCC with other cities of Bangladesh. Being a relatively new city corporation it actually produced way more waste than most of the old city corporations even considering a growth factor in those city corporations. Hence it is high time to rethink about the waste management system of GCC.

However, the comparison that has been made is not from the same timeline. Due to the unavailability of data of same year, comparisons were drawn from available literature.

Table 4:8 Component weight of waste generated in different city corporations in Bangladesh

Waste Category	MSW generation (ton/day)							All Waste Stream
	GCC[1]	DCC[2]	CCC[2]	KCC[2]	RCC[2]	BCC[2]	SCC[2]	
Organic matter	594.06	3647	968	410	121	105	158	6001
Paper	42.76	571	130	49	15	9	18	834.56
Plastic	43.3	230	37	16	7	5	8	346.38
Textile & Wood	12.25	118	28	7	3	2	5	175.25
Leather & Rubber	5.3	75	13	3	2	1	1	100.26
Metal	3.97	107	29	6	2	2	2	150.60
Glass	8.60	37	13	3	2	1	2	66.58
Other	7.2	555	97	26	18	5	21	729.17
Total	717.5	5340	1315	520	170	130	215	8405.37
Populatio	2.17	11	3.65	1.5	0.45	0.4	0.5	19.52
Per capita	0.36	0.485	0.36	0.347	0.378	0.325	0.43	0.38

Source: [1]Field Study (2017); [2]Alamgir & Ahsan, 2007

There are several other published data and reports present from where a comparison can be done on solid waste generation rate of GCC and other major city corporations of Bangladesh. Table 4.9 also presents a comparative study between this study and MSW generation rate of major cities. From Table 4.9 it has been noted that Guerrero et al., 2013 conducted a study on Gazipur city which differs largely with the waste generation rate obtained from this study. This is mainly due to the difference in the year of study. That study was conducted in the year of 2007 to 2009 whereas current study focuses on the data collected in 2016 to 2018. Back then, the city was not declared as a city corporation and over the time population and lifestyle of people changed a lot which can influence the changes in generation rate.

Table 4:9 Solid waste generation rate in major cities of Bangladesh

City	Per capita generation (Kg/day)	Solid Waste Generation (ton/day)	Data Source
Domestic Solid Waste			
DCC	0.34	1945	(JICA, 2005)
CCC	0.257	877	(BMDF, 2012)
RCC	0.203	179	
Rangpur Municipality	0.226	100	
Patuakhali Municipality	0.145	14	
Dhaka	0.37	4070	(Alamgir & Ahsan, 2007)
Chittagong	0.30	1100	
Rajshahi	0.29	130.5	
Sylhet	0.34	170	
Khulna	0.30	450	
Barisal	0.26	104	
GCC	0.36	717.5	This study
Municipal Solid Waste			
DCC	0.485	5340	(Muhammed Alamgir & Ahsan, 2007)
DCC (Domestic, business & street)	0.56	3200	(JICA, 2005)
DCC	0.56	4634.52	(Enayetulla et al., 2005)
CCC	0.360	1315	(Muhammed Alamgir & Ahsan, 2007)
CCC	0.340	--	(BMDF, 2012)
KCC	0.346	520	(Muhammed Alamgir & Ahsan, 2007)
RCC	0.378	170	(BMDF, 2012)
RCC	0.289	--	
BCC	0.325	130	
SCC	0.430	215	
GCC	0.25	--	(Guerrero et al., 2013)

Considering the above comparisons of GCC data with the other cities based on domestic waste generation, it can be concluded that GCC produces second highest quantity of solid waste (717.5 ton/day) after Dhaka (4070 ton/day) and Chittagong (1100 ton/day).

There exists a wide variation in per capita solid waste generation in the cities of Asian countries. The Table 4.10 shows the waste generation in major cities of some Asian countries (Rodic, 2010) for comparison. It can be concluded that GCC is still on the lower side in terms of daily solid waste production per capita. The cities having higher generation rate is mainly known for world famous tourist spot.

Table 4:10 Comparison among major cities in Asia against waste generation

City, Country	Waste Generation		Respective Country's Urban Generation Rate (Kg/capita/day)
	Ton/day	Kg/capita/day	
Dhaka[1] , Bangladesh	5340	0.485	0.43[3]
Gazipur City Corporation, Bangladesh*	717.5	0.36	
Jakarta[2], Indonesia	6000	0.65	0.52[3]
Jakarta[3], Indonesia	7896	0.88	
Kathmandu[2], Nepal	523.8	0.66	0.12[3]
Bangkok[2], Thailand	8778	1.54	1.76[3]
Kuala Lumpur[2], Malaysia	3798.9	1.62	1.52[3]
Allahabad[2], India	500	0.4	0.34[3]
Delhi[3], India	5875	0.57	
Kolkata[3], India	2652	0.58	
Beijing[3], China	861	0.9	1.02[3]

[1](Alamgir & Ahsan, 2007b); [2](Dhokhikah & Trihadiningrum, 2012); [3](Hoornweg & Bhada-Tata, 2012); *This study

4.3 Compositions of Solid Waste in GCC

To prepare an integrated waste management system, it is necessary to identify the quantity of waste generated as well as different categories of the waste especially with respect to the implementation of disposal and resource and energy recovery options. Characterization of waste is also important to determine its possible environmental impacts. In general, the waste components vary with the location and season of the year, include food wastes, paper, plastic, cloths, metal, glass and others.

4.3.1 Composition of Household Waste

The organic and inorganic fraction in solid waste varies somewhat from city to city based on the economic status of the people, food processing, educational background and overall lifestyle. Table 4.11 provides the composition of waste items observed in 5 zones in GCC. From the Table it is seen that the solid waste is mostly dominated by the organic waste. On the other hand, non bio-degradable waste is mostly comprised of paper and plastic. Although glass, metal, tin, rubber, wood and leather were found in many cases. Paper waste includes paper cartons, paper carrier-bags, newspapers, magazines, and advertising material etc. Plastic waste refers to plastic packaging bags, PET bottles, plastic utensils, and plastic toys etc. Metal means aluminum beverage such as containers for soft drinks, metal food cans etc. Glass mainly includes the different glass bottles for sauce, jam, pickles and broken drinking water glass.

Table 4:11 Solid waste composition indifferent zones of GCC area

	Composition (% by weight)								
Zone	Food Waste	Gardens	Paper	Plastic/ Polythene	Glass/ Bottle	Metal/ Tin	Leather& Rubber	Others	Total
Average in Dry Season									
1	84.40	0.43	6.45	3.77	1.94	0.71	--	2.28	100
2	84.78	0.00	5.70	4.22	3.42	0.00	--	1.88	100
3	84.48	4.00	3.85	7.68	0.00	0.00	--	0.00	100
4	75.32	5.87	7.76	6.65	0.00	2.64	--	1.75	100
5	82.76	0.00	6.44	10.80	0.00	0.00	--	0.00	100
Avg.	82.35	2.06	6.04	6.624	1.072	0.67	0	1.182	100
Average in Wet Season									
1	76.89	--	4.85	5.90	1.15	0.00	2.51	8.70	100
2	74.41	4.56	9.77	6.56	2.32	0.23	0.56	1.59	100
3	87.47	--	4.70	4.95	--	0.77	--	2.10	100
4	80.90	--	3.62	6.21	0.35	1.90	2.57	4.45	100
5	84.34	3.52	4.38	6.21	0.00	0.00	1.00	0.00	100
Avg.	80.80	1.61	5.46	6.07	0.76	0.58	1.33	3.36	100
Overall Composition in GCC									
	81.65	1.86	5.75	6.34	0.91	0.62	0.66	2.27	100

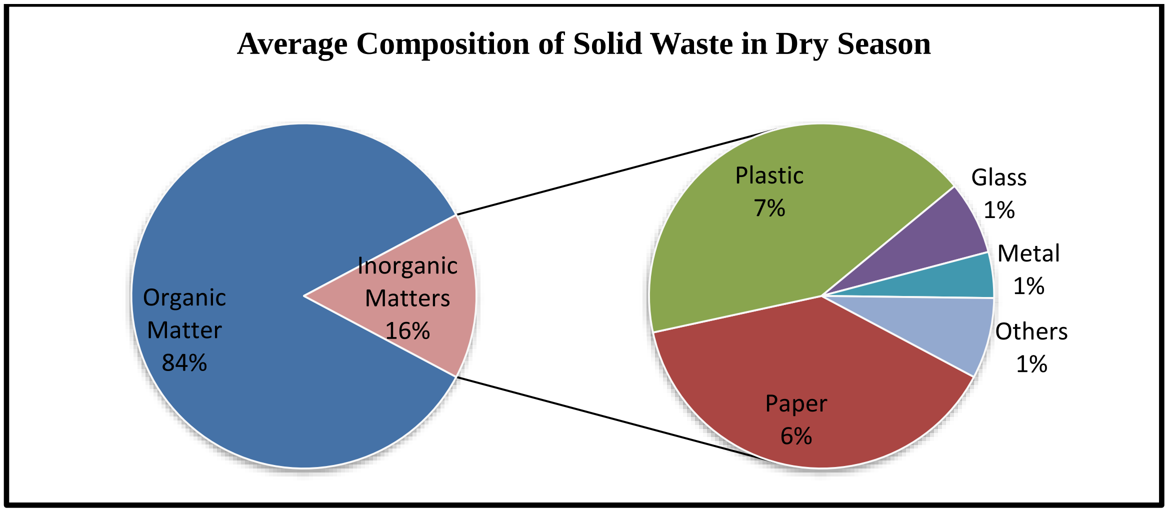

Figure 4:2 Average composition of household solid waste (dry season)

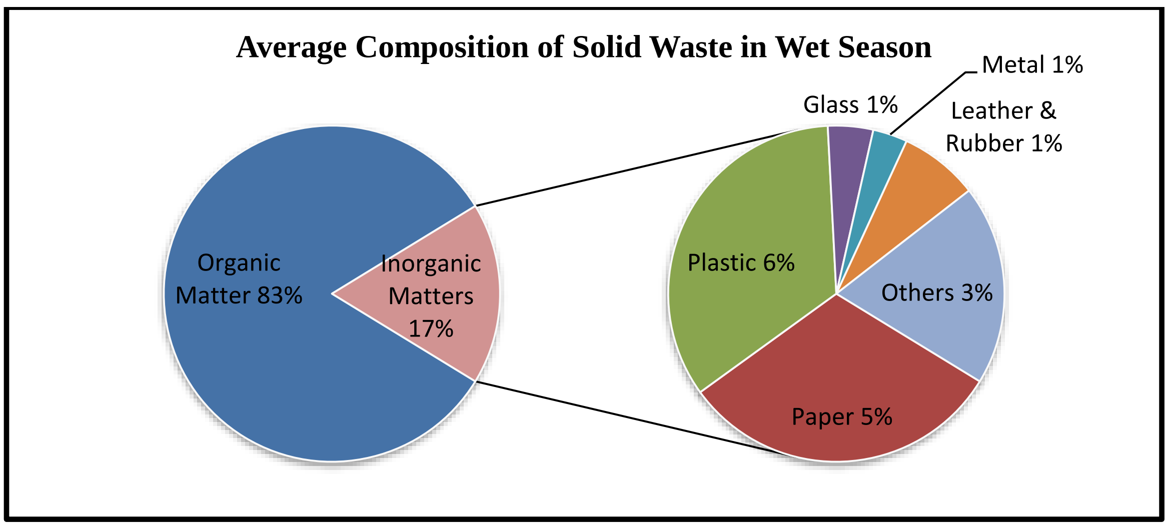

Figure 4:3 Average composition of household solid waste (wet season)

Figure 4.2 and 4.3 show the average seasonal data of waste composition collected from all zones in wet and dry season respectively. In both seasons, paper and plastic waste items were found in highest quantity but no significant seasonal variation was observed. Glass, metal, leather and rubber accounted for total 3% (1% each) of the recyclable waste.

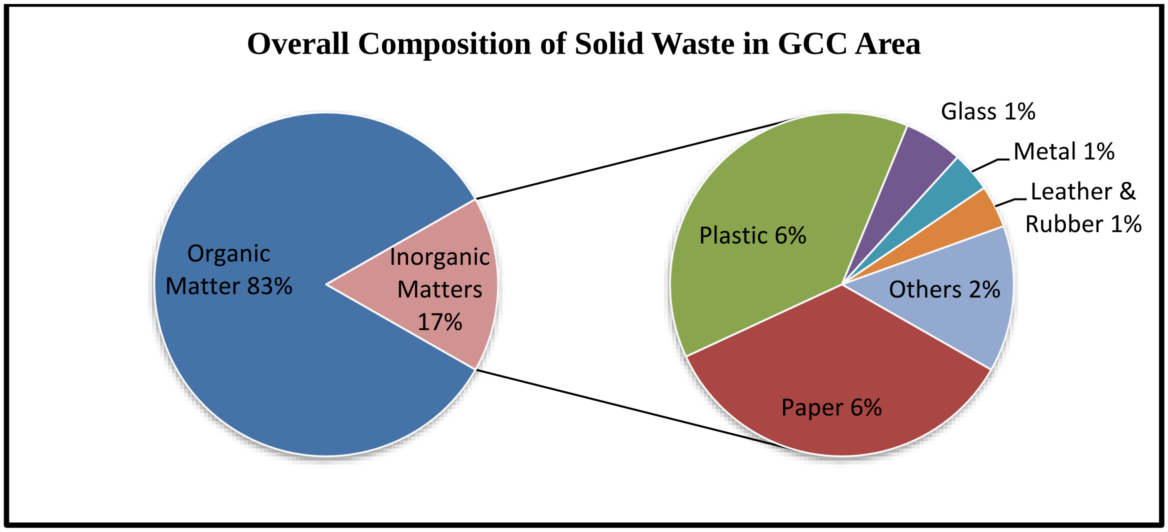

Figure 4:4 Overall composition of household solid waste in GCC area at household level

4.3.2 Composition of Waste from Secondary Dumping Sites

Waste composition was also determined from the waste collected from secondary dumping sites. In total 30 samples were collected from SDSs of GCC which consist of 6 samples from each zone. Among these 6 samples similar quantity of samples (3 nos.) were collected for dry and wet season. Table 4.12shows the amount of waste collected from SDS to check the composition of MSW at SDS. Table 4.13 provides the percentage in weight of the waste items found from secondary sources in different seasons. In all cases food waste contributes maximum contents of total waste followed by paper and plastic.

Table 4:12 Average weight of waste collected from SDS

Zone	Average weight in Kg	
	Dry Season	Wet Season
1	43.00	54.51
2	33.14	40.02
3	28.16	34.17
4	47.12	49.08
5	32.92	30.74

Table 4:13 Composition (%) of solid waste at secondary sites in GCC area

Composition (% by weight)										
Zone	Food Waste	Gardens	Paper	Plastic/ Poly-thene	Glass/ Bottle	Metal/ Tin	Leather & Rubber	Textile	Others*	Total
Dry Season										
1	71.11	3.23	5.69	4.20	4.40	0.78	1.12	1.52	7.94	100
2	62.87	7.56	8.27	6.24	1.62	2.12	0.29	0.00	11.03	100
3	72.25	0.00	5.23	7.37	4.43	0.15	0.16	5.29	5.11	100
4	81.30	0.00	4.89	2.57	2.16	0.00	0.00	5.16	3.91	100
5	63.32	0.00	9.44	10.26	4.57	6.84	3.59	0.00	1.98	100
Avg.	70.17	2.16	6.70	6.13	3.44	1.98	1.03	2.40	6.00	100
Wet Season										
1	74.03	9.18	5.67	6.17	3.06	0.58	0.00	0.00	1.31	100
2	61.27	7.49	9.15	13.55	7.83	0.00	0.71	0.00	0.00	100
3	83.02	7.70	3.34	2.70	0.00	0.00	0.00	3.23	0.00	100
4	82.01	0.00	7.81	8.74	0.00	0.00	0.00	0.00	1.44	100
5	82.40	1.61	8.00	4.77	0.00	3.22	0.00	0.00	0.00	100
Avg.	76.55	5.20	6.80	7.18	2.18	0.76	0.14	0.65	0.55	100
Overall Composition at SDSs in GCC										
	73.36	3.68	6.75	6.66	2.81	1.37	0.59	1.52	3.27	100

*Includes wood, Dirt, Ashes, Brick Chips, Battery, Aerosol Can etc.

A comparison of waste comparison at household waste and waste collected from SDS is shown in Figure 4.5. It is seen that, in secondary sites the quantity of paper, plastic and other non-biodegradable items increases. This increment is due to the dumping of wastes in the secondary dumping sites from nearby institutions, commercial complexes, industries. As the inorganic content of wastes increases in the secondary stream, the overall organic content seems to have a reduced weight percentage. However, recovery of waste by informal sectors is not accounted here. But it can be concluded that a significant amount of solid waste is added to the stream from nearby commercial and industrial sources which was also revealed during the personal interview with GCC personnel.

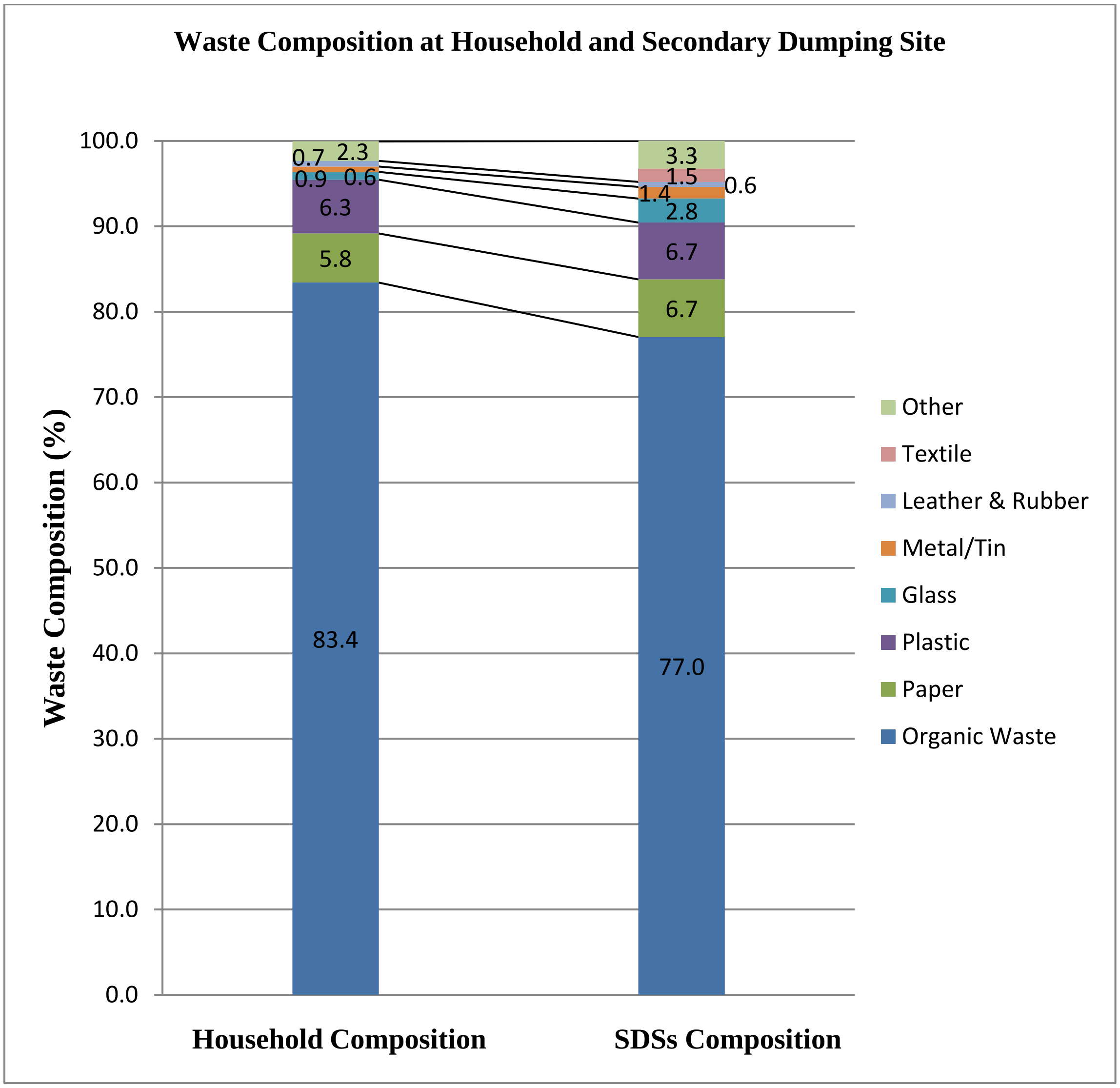

Figure 4:5 Average composition of waste at household level and secondary dumping sites

4.3.3 Comparison with Previous Studies

The composition of waste from household and SDS in GCC area obtained from this study is compared with waste composition in six major city corporations of Bangladesh. Numerous studies have been conducted on the solid waste composition in major cities and municipalities areas in Bangladesh as shown in Table 4.14 (Alamgir & Ahsan, 2007). Shams et al., 2017 also compared composition of urban areas in Bangladesh where the wastes are rich in organic contents with 74% food waste, 8% paper, 5% plastics, 2% textile and wood, 2% leather and rubber, 2% metal, 1% glass and 6% other waste. Wastes from DCC area are consists of less amount of organic waste (68%) and a higher amount of paper and plastic waste in these studies compare to other cities. It is also estimated according to Ahsan et al. 2014, households, businesses, and institutions contribute respectively 78%, 20%, and 1% of waste while the other sectors responsible for only 1%.

Table 4:14 Composition of Solid Waste in major Cities of Bangladesh

Waste Category	Solid Waste Composition (%)							
	GCC[1]		DCC[2]	CCC[2]	KCC[2]	RCC[2]	BCC[2]	SCC[2]
	Household	SDS						
Organic matter	83.50	77.04	68.30	73.61	78.85	71.18	80.77	73.49
Paper	5.7	6.75	10.69	9.89	9.42	8.82	6.92	8.37
Plastic	6.34	6.66	4.31	2.81	3.08	4.12	3.85	3.72
Textile & Wood	1.32	1.52*	2.21	2.13	1.35	1.76	1.54	2.33
Leather & Rubber	0.66	0.59	1.40	0.99	0.58	1.18	0.77	0.47
Metal	0.62	1.37	2.00	2.21	1.15	1.18	1.54	0.93
Glass	0.91	2.81	0.69	0.99	0.58	1.18	0.77	0.93
Other	0.95	3.27	10.39	7.38	5.00	10.59	3.85	9.77
Total	100	100	100	100	100	100	100	100

*only textile composition

[1]This study, [2]Alamgir & Ahsan, 2007

A recent study by Shams et al., (2017) on the solid waste composition in the cities of Bangladesh as shown in Table 4.15 also reflects the similar composition as in most of the cases as shown in previous table indicating minimum changes in consumption pattern.

Table 4:15 Composition of Solid Waste in urban areas of Bangladesh

Waste Category	Solid Waste Composition (%)							
	GCC[1]		Dhaka[2]	Chittagong[2]	Khulna[2]	Rajshahi[2]	Barishal[2]	Sylhet[2]
	Household	SDS						
Organic matter	83.50	77.04	68.30	70.5	78.9	70.0	81.1	73.5
Paper	5.7	6.75	10.79	4.63	9.5	9.0	7.2	8.6
Plastic	6.34	6.66	4.31	8.7	3.1	9.0	3.5	3.5
Textile & Wood	1.32	1.52*	2.21	2.4	1.3	6.0	1.9	2.1
Leather & Rubber	0.66	0.59	1.40	5.8	0.5	1.1	0.1	0.6
Metal	0.62	1.37	2.00	2.65	1.1	3.0	1.2	1.1
Glass	0.91	2.81	0.69	1.0	0.5	1.1	0.5	0.7
Other	0.95	3.27	10.39	7.4	5.1	0.8	4.5	9.9
Total	100	100	100	100	100	100	100	100

*only textile composition

[1]This study, [2](Shams et al., 2017)

From the above data, it is observed that GCC has the highest organic content (83.50%) compare to other city corporation areas. From several studies it has been found that in developing nations major fractions of waste is organic due to income level and living standard (Bobeck 2010; Hoornweg & Bhada-Tata, 2012), socio-economic background of residents (Karak et al., 2012). On the contrary, plastic waste was found in higher rate than Khulna, Barishal and Sylhet areas which is a resultant of rapid urbanization. This could also be seen as an indication of future waste generation as many developing countries are staring to imitate the lifestyle and attitudes of industrialized, high-income countries.

A comparison of waste composition in GCC is done with some major Asian cities and Table 5.18 shows the comparison. It appears from Table 4.16 that the organic content of the waste from GCC is higher than other Asian countries. Parrot et al., 2009 noted that due their economic development, lesser developed countries and developing countries tend to generate waste with higher organic (biodegradable) fraction. On the other hand, other cities mentioned in the comparison are mostly tourism based cities whereas in GCC most of the residents are working class people whose living standards are less than the people of the other cities.

Table 4:16 Solid Waste Composition (%) in major Cities of Some Asian Countries

Waste Category	Jakarta	Kathmandu	Bangkok	Kuala Lumpur	Beijing	Kolkata	GCC
Year	NA	2007	NA	2008	2006	2005	
Source	(Kardono, 2007)	(Dangi et al., 2011)	(Udomsri et al., 2011)	(Saeed et al., 2009)	(Zhen-shan et al., 2009)	(NEERI, 2005)	This study
Organic matter	68.12	67.8	42.68	61.5	65.2	55.9	83.50
Paper	10.11	6.5	12.09	16.5	11.1	4.6	5.73
Plastic	11.08	0.3	10.88	15.3	12.7	3.2	6.29
Textile	2.45	--	4.68	1.3	--	--	1.26
Leather & Rubber	0.55	--	2.57	0.6	--	--	0.56
Metal	1.0	4.9	3.54	0.25	0.3	0.4	0.56
Glass	1.63	1.3	6.63	1.2	1.8	1.7	0.98

Other	4.12	19.2	16.94	1.1	9	34.1	1.12
Total	100	100	100	100	100	100	100

4.4 Projection of Solid Waste Generation

Future solid waste generation for GCC is projected based on two approaches. The first approach is based on annual growth rate of population and per capita waste generation of baseline year for different zones as shown in Table 4.17. From the estimation of population trend, without considering any changes in people's lifestyle and consumption behavior the overall waste generated can be expected to increase by almost 25%, 50% and 90% in the year of 2021, 2026 and 2036 respectively. Table 4.18 shows the projected waste generation in GCC area and it depicts an increasing trend from 717.5tons per day to 1561 tons per day from year 2016 to 2036 under CAGR approach. Figure 4.6 also depicts that by year 2036 per capita generation rate will increase by 16% from 0.36 to 0.42 kg/capita/day. It has also been observed that there remains wide variation in these two approaches of prediction as the population and income spending approach considered in two estimates differs considerably.

Table 4:17 Projection of Waste Generation based on population growth trend

ZONE	YEAR							
	2016		2021		2026		2036	
	Population	Avg. WGR t/day	Population	Avg. WGR t/day	Population	Avg. WGR t/day	Population	Avg. WGR t/day
1	650,597	218	805,998	268.01	959,819	319.16	1,207,106	401.39
2	448,944	175.5	556,177	216.84	662,323	258.22	832,963	296.46
3	244,528	91.5	302,935	114.46	360,750	136.31	453,693	159.11
4	347,144	115	430,064	141.47	512,139	168.47	644,086	211.46
5	326,343	117.5	404,294	145.961	481,450	173.82	605,490	203.82
TOTAL	2,017,556	715.8	2,499,468	887	2,976,481	1,056	3,743,338	1,272

Table 4:18 Projection of Waste Generation based on CAGR approach

Zone	Daily Waste Generation Ton/day				Per Capita Waste Generation Kg/day			
	2016-17	2021	2026	2036	2016-17	2021	2026	2036
1	218	281	353	469	0.335	0.348	0.368	0.388
2	175.5	229	288	382	0.39	0.412	0.435	0.459
3	91.5	122	153	203	0.375	0.401	0.424	0.447
4	115	150	188	250	0.33	0.348	0.368	0.388
5	117.5	154	193	257	0.36	0.380	0.401	0.424
Total /Average	717.5	935	1,175	1,561	0.358	0.378	0.399	0.421

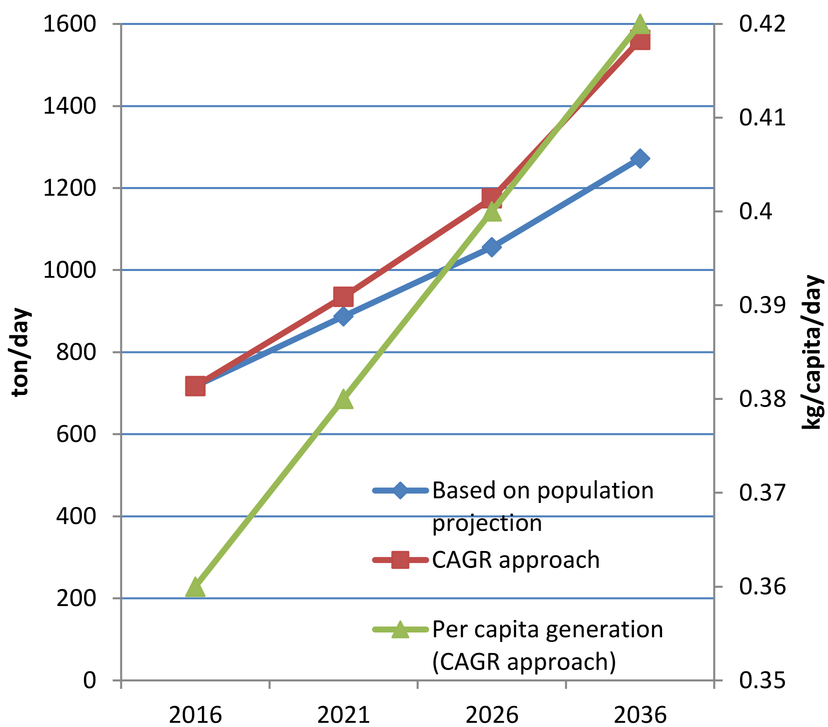

Figure 4:6 Trends of waste generation in GCC

4.5 Findings from Questionnaire Survey

A questionnaire survey was carried out to observe the householders tendency in managing the solid waste and perception on overall waste management practices. A total of 113 respondents participated in the survey. The respondents were asked whether they possessed and used waste containers in their home. This was asked to establish whether the people bother to have their solid waste collected in containers. The respondents were also asked whether they tried to do any kind of solid waste sorting, simply by way of separating some types of waste items from the rest. This was to base on their own discretion of what types of waste they felt should not be mixed with other types for whatever reason.

Table 4.19 represents the findings of the questionnaire survey which was made based on the storage, sorting and disposal method practiced at household level. These responses can guide us to plan and design an integrated waste management system since the survey quantifies onsite storage condition (96% households have onsite storage facility at any format) and contains information on waste segregation practices (15% households sort wastes at household).

Table 4:19 Survey responses about household storage, sorting and primary disposal

Topic	Options	Responses (%)
Onsite Storage	Container/Basket	78
	Polythene	18
	Open Space	04
Type of Dustbin	Plastic	40
	Metal	11
	Others	41
	Do not use	08
Possession of Basket	Yes	60
	No	40
Whether waste is sorted	Segregated	15
	Mix	85
Disposal method of PET bottle	Sell	27
	Reuse	50
	Dump with other waste	23
Primary Disposal	Door to door	46
	Practice open dumping	20
	Drop at nearby dustbin	34

To implement 3R concept, it is also necessary to understand resident's behavior and perception towards waste management system. This questionnaire also covered topics related to waste collection system. Usually, in door to door collection system, the service provider charged a service fee per month. This survey revealed that 29% and 15% people pay less than 100 taka and 200 taka per month whereas other do not pay as they do not take the services. When respondents were asked about their willingness to pay for the service; 53% responded yes and 36% did not show any interest about paid service.

When people were asked about their willingness against sorting or segregation of waste if they are provided with free multiple bins; it revealed mixed responses from the respondent. 38 persons out of 113 have shown interest to sort their waste but almost half of the people do not have any direct willingness towards segregation.

From this survey, it is observed that, a relatively big percentage of respondents do not have any prior knowledge or understanding on the consequences of the actions they make to manage their household waste.

4.6 Analysis of Trip Required and Waste Collection Efficiency

The number of trips required to carry domestic solid waste is calculated in this study. As there are truck of different capacity and many trucks were also rented on demand basis; a weighted average of $8m^3$/truck has been considered here. From literature it has been found that for MSW a compaction factor about 1.5 can be used (Ramakrishna et al., 2016) to estimate the compacted volume. Again, reported solid waste density values used in calculating waste quantity also vary widely ranging from 0.35 ton/m^3 to 0.80 ton/m^3(Hai & Ali, 2005). For Dhaka city average on-truck density is also estimated as 0.47 ton/m^3 in a study conducted by JICA (JICA, 2005). In this study a value of 0.35 ton/$m^3$is assumed. Table 4.20 shows the total no. of trips required per day to transfer all the household waste generated to the final disposal site located at Kadda, Baimail from SDSs.

Number of trips required per day is dependent on the quantity of daily waste generated. Responsible person from conservancy department of GCC informed that GCC produces approximately 3000-4000 tons of solid waste daily which includes waste from domestic, commercial, industrial, market/bazaar and hospital sources. Estimated current collection efficiency as per GCC estimation is 60-70%. Currently GCC is making about 250 trips daily to collect only a part of the generated MSW from the SDSs whereas total 256 numbers of trips are required to obtain 100% collection efficiency in regard to daily household generation only. Zone 1 needs maximum numbers of trips (78 nos.) whereas Zone 3 requires 33 numbers of trips.

Table 4:20 No. of Trips Required for 100% Collection Efficiency of domestic waste

Zone	total generated waste		Average volume of waste carried by truck	No. of trips required per day
	ton/day	m^3/day	m^3	
1	218	623	8	78
2	175	500		63
3	92	262		33
4	115	327		41
5	117	336		42
Total	716.8	2,048		256

Usually the trips are generated from two stations (zone 1 & zone 4). These two zones are the dispatch station of the collection vehicles. From these two points the collection vehicles visit the SDSs of all zones to collect and dump the waste at final disposal site and the round trip distance from zone 1 and zone 3 is about 30km and 15km respectively. The vehicle dispatch from zone 1 station covers the SDSs of zone 1 & 2 and the rest SDSs are covered by the vehicles dispatched from zone 3 station. Considering the average vehicle speed of Dhaka as 6.4 km/hour (Gallagher, 2016), the average trip time for waste collection in GCC area is 4.6 hours (zone 1,2) and 2.35 hours (zone 3,4,5).

4.7 Resource Recovery and Economic Benefit by Incorporating 3R

The supply of raw material is not infinite and the recovery of material from waste stream is essential for the conservation of natural resources. Consequently, reuse, recycling, and productive use of wastes are important activities in the integrated management of MSW; these activities are mainly aimed at reducing the volume of waste to be disposed of and, especially, increasing its economic value. By recovering these materials at source, following benefits can be achieved:

- Creating employment through cooperative groups.
- Reduction in MSW volume.
- Less collection equipment needed.

- Longer life span of sanitary landfills, decreasing the demand for land —which is increasingly scarce and expensive.
- Lower costs of the urban cleaning service.
- Conservation of natural resources and environmental protection.

4.7.1 Potential of Resource Recovery

From the waste composition data it was observed that there are several recyclables / reusable items in significant quantity in the waste stream of GCC. Table 4.21 and 4.22 present the potential recoverable materials in each zone and total resource recovery per day from the households and SDSs in GCC area respectively. It is observed that a total of 104 ton/day can be recovered from the household waste in GCC area whereas the resource recovery potential from SDSs is about 133.54 ton/day. The increased recovery potential in SDSs indicates the incoming waste from other sources has higher content of recoverable materials.

Table 4:21 Weight of recoverable materials from households in GCC

		Wt. of Recoverable Materials in Dry Season										
Zone	Total Waste Generated	Paper	Plastic	Metal / Tin	Leather & Rubber	Glass	Paper	Plastic	Metal / Tin	Leather & Rubber	Glass	Total
	Ton/day	Dry Season (%)					Dry Season (Ton/day)					Ton/day
1	221	6.45	3.77	0.71	--	1.94	14.25	8.33	1.57	--	4.29	28.44
2	171	5.70	4.22	--	--	3.42	9.75	7.22	0.00	--	5.85	22.81
3	90	3.85	7.68	--	--	--	3.47	6.91	0.00	--	0.00	10.38
4	115	7.76	6.65	2.64	--	--	8.92	7.65	3.04	--	0.00	19.61
5	111	6.44	10.80	--	--	--	7.15	11.99	0.00	--	0.00	19.14
Total	708						43.54	42.10	4.61	--	10.14	100.38
		Wet Season (%)					Dry Season (Ton/day)					
1	215	4.85	5.90	--	2.51	1.15	10.43	12.69	--	5.40	2.47	30.98
2	180	9.77	6.56	0.23	0.56	2.32	17.59	11.81	0.41	1.01	4.18	34.99
3	93	4.70	4.95	0.77	--	--	4.37	4.60	0.72	--	--	9.69
4	115	3.62	6.21	1.90	2.57	0.35	4.16	7.14	2.19	2.96	0.40	16.85
5	124	4.38	6.71	--	1.00	--	5.43	8.37	--	1.24	--	15.04
Total	727						41.98	44.61	3.32	10.60	7.05	107.55
		Average (%)					Average (Ton/day)					
1	218	5.65	4.84	1.55	0.36	1.26	12.34	10.51	0.78	2.70	3.38	29.71
2	175.5	7.74	5.39	2.87	0.12	0.28	13.67	9.51	0.21	0.50	5.01	28.90
3	91.5	4.28	6.32	--	0.39	0.00	3.92	5.76	0.36	--	--	10.03
4	115	5.69	6.43	0.18	2.27	1.29	6.54	7.39	2.61	1.48	0.20	18.23
5	117.5	5.41	8.51	--	--	0.50	6.29	10.18	--	0.62	--	17.09
Total	717.5						42.76	43.37	3.96	5.30	8.59	103.96

Table 4:22 Weight of recoverable materials from SDSs in GCC

		Wt. of Recoverable Materials in Dry Season										
Zone	Total Waste Generated	Paper	Plastic	Metal / Tin	Leather & Rubber	Glass	Paper	Plastic	Metal / Tin	Leather & Rubber	Glass	Total
	Ton/day	Dry Season (%)					Dry Season (Ton/day)					Ton/day
1	221	5.69	4.20	0.78	1.12	4.40	12.58	9.29	1.73	2.48	9.73	35.82
2	171	8.27	6.24	2.12	0.29	1.62	14.14	10.67	3.62	0.49	2.77	31.69
3	90	5.23	7.37	0.15	0.16	4.43	4.71	6.64	0.13	0.14	3.99	15.60
4	115	4.89	2.57	--	--	2.16	5.62	2.96	--	--	2.49	11.07
5	111	9.44	10.26	6.84	3.59	4.57	10.48	11.39	7.60	3.98	5.07	38.52
Total	708						47.53	40.95	13.08	7.10	24.04	132.70
		Wet Season (%)					Dry Season (Ton/day)					
1	215	5.67	6.17	0.58	--	3.06	12.19	13.26	1.26	--	6.57	33.27
2	180	9.15	13.55	--	0.71	7.83	16.47	24.39	--	1.28	14.09	56.23
3	93	3.34	2.70	--	--	--	3.11	2.51	--	--	--	5.62
4	115	7.81	8.74	--	--	--	8.98	10.05	--	--	--	19.03
5	124	8.00	4.77	3.22	--	--	9.92	5.91	3.99	--	--	19.82
Total	727						50.67	56.12	5.24	1.28	20.66	133.98
		Average (%)					Average (Ton/day)					
1	218	5.68	5.19	0.68	0.56	3.73	12.39	11.30	1.49	1.23	8.13	34.54
2	175.5	8.71	9.89	1.06	0.50	4.72	15.24	17.32	1.85	0.88	8.27	43.55
3	91.5	4.29	5.04	0.07	0.08	2.21	3.94	4.63	0.07	0.07	2.04	10.76
4	115	6.35	5.66	--	--	1.08	7.30	6.50	--	--	1.24	15.05
5	117.5	8.72	7.52	5.03	1.79	2.28	10.21	8.79	5.89	2.10	2.67	29.65
Total	717.5						49.08	48.55	9.30	4.27	22.35	133.54

4.7.2 Revenue from Resource Recovery

Recovery of major portion of domestic solid waste would enable the respective authority to generate revenue which can compensate the solid waste disposal cost. Table 5.24 shows that with 100% recovery rate annual revenue that can be obtained will be more than 154.35 million BDT. However 100% resource recovery is not possible and according to Alamgir & Ahsan (2007), the amount of materials that can be recovered from the MSW in Bangladesh is about 70%. Table 4.23 shows also the market value of the potentially recoverable materials in GCC area.

Table 4:23 Revenue potentially recoverable materials

Recyclable Items	Unit Price* (BDT/ton)	With 100% Recovery		With 70% Recovery	
		Weight (ton/day)	Market Value (BDT/day)	Weight (ton/day)	Market Value (BDT/day)
Paper	4000	42.76	171035.2	29.93	119724.6
Plastic	4000	43.02	172067.6	30.11	120447.3
Metal	6000	4.58	27502.8	3.21	19252.0
Leather & Rubber	5000	5.30	26500.0	3.71	18550.0
Glass	3000	8.59	25779.9	6.02	18045.9
Total		104	422885.5	72.98	296019.9
Annual Revenue (Million BDT)		**154.35**		**108.04**	

*Price obtained from local recyclers who collect waste from SDSs / informal sectors

The very initiation of material recovery must be done at household level. The residents should be aware and practice segregation of waste at source. For this, GCC should provide adequate waste containers with color code that allows residents to sort their waste at household level. Alternatively, material recovery facility (MRF) can be installed at the SDS or final disposal site.

Table 4.24 shows the estimated revenue from potential resource recovery at SDS and associated cost at the SDS using material recovery facility. Revenue that can be earned from SDS is estimated as 195.17 million BDT per year whereas the operational & maintenance cost requires per year is 444.9 million BDT as shown in Table 5.26. A typical low-tech MRF unit will cost $10,000 per ton of the daily capacity (Muhammed Alamgir & Ahsan, 2007). The waste generated from the five zones of GCC is 717.5 t/d (261,705 ton/yr). The typical operation and maintenance (O&M) cost for a low-tech MRF is 20 $/t. Thus, the O&M cost for an MRF would be 1.21 million BDT which is more than 2 times of the potential revenue generation through resource recovery as shown in Table 4.24. Moreover, the time value of money is not considered within the year. So, this can be concluded that, it is not economically feasible to install an MRF at this moment with this current recoverable waste quantity. If the weight percentages of recoverable items at SDS are increased by a factor of 2.5 over the time then the annual operational and maintenance cost for MRF may be covered by the revenue earned form resource recovery. Based on the current scenario, segregation of waste at household level seems to be the best alternative to attain maximum recovery potential. However, integrated management system shall be developed at SDSs to collect the waste at sorted condition by incorporating 3R concept. This will pave the way for resource recovery and generation of expected revenue.

Table 4:24 Revenue potential from recovered materials through MRF at SDS and associated cost for a low-tech MRF

Revenue through Resource Recovery at SDS			
Recoverable Items	Unit Price* (BDT/ton)	Weight (ton/day)	Total (BDT/day)
Paper	4000	49.08	196320
Plastic	4000	48.55	194200
Metal	6000	9.30	55800
Leather & Rubber	5000	4.27	21350
Glass	3000	22.35	67050
Total Revenue (Million BDT/day)			0.534
Annual Revenue (BDT/day) with 100% recovery at MRF			195.17
Associated Cost for a Low-Tech MRF at SDS			
	Daily	Annual	Total
Total Generated Waste (ton)	717	261705	--
Capital Cost[1] (Million BDT @ 850000 BDT/ton)	--	--	609.45
Operational & Maintenance Cost[1] (Million BDT @ 1700 tk./ton)	1.21	444.9	--

[1](M Alamgir & Ahsan, 2007)

4.7.3 Reduction of Waste through Resource Recovery

With successful resource recovery it is also possible to achieve a significant reduction in waste quantity and volume that needs to be disposed. This reduction will reduce the number of trips required to transport waste from SDSs to final dumping site. As well as it will also reduce the stress on landfill area required. The volume of solid waste that can be reduced through resource recovery is presented in Table 4.25. The average density of urban solid waste at collection point is assumed to be 0.35 ton/m^3(BMDF, 2012; Hai & Ali, 2005; Yousuf & Rahman, 2007). Potential reduction in volume is observed to be 297.87 m^3/day in GCC area, about 14.5% of the total waste volume.

Table 4:25 Reduction of waste volume through resource reduction

	Zone	Paper	Plastic	Metal/Tin	Leather &Rubber	Glass	Total
Avg. Weight Reduction Potential (ton/day)	1	12.34	10.51	0.78	2.70	3.38	29.71
	2	13.67	9.51	0.21	0.50	5.01	28.90
	3	3.92	5.76	0.36	--	--	10.03
	4	6.54	7.39	2.61	1.48	0.20	18.23
	5	10.18	10.18	0.00	0.62	--	17.09
Total (ton/day)		42.76	43.35	3.96	5.30	8.59	103.96
Volume Reduction Potential (m^3/day)	1	35.26	30.02	2.24	7.71	9.66	84.89
	2	39.05	27.18	0.59	1.44	14.32	82.58
	3	11.19	16.45	1.02	--	--	28.67
	4	18.70	21.13	7.46	4.22	0.58	52.08
	5	17.97	29.08	0.00	1.77	--	48.83
Volume Reduction (m^3/day)		122.17	123.86	11.31	15.14	24.55	297.04
Overall Volumetric Reduction (%)							14.5

4.7.4 Analysis of Trip Reduction and Annual Savings

It is important to estimate the total cost required per trip to transport the solid waste from secondary dumping site to final dumping site. The route of vehicles is given in Figure 4.7. The estimated average round trip distance that a collection vehicle generally covers is about 30 km and 15km respectively from two dispatch station situated at zone 1 and zone 3. Considering the fuel cost (65BDT/liter) and average mileage 3km/liter (mileage of 15 ton truck and 3-5 ton truck is 4km/l, 2km/l respectively), average fuel cost per vehicle per round trip is estimated to be 500-900 BDT (conservancy department, GCC). In this study, an estimated round trip cost has been considered as 600 BDT.

Figure 4:7 Route of the Waste Collection Vehicle

The reduction of trips due to resource recovery was estimated and Table 4.26 shows the daily reduction of trips and the associated cost saving for SWM in GCC area.

Table 4:26 Trip Reduction through Recovery of Materials

Zone	Recyclable Waste (m^3/day)	No. of Trip Reduced	Average Cost (BDT/trip)	Reduction in Trip Cost (BDT/day)
1	87.07	11		6530
2	81.98	10		6149
3	27.65	4	600	2400
4	53.29	7		3997
5	47.87	6		3590
Total	297.87	38		22667

If the inorganic/recyclable compound is recovered, it is possible to reduce almost 38 trips per day as shown in Table 5.28 which results an economic gain of more than 82,73,455 BDT annually (22,667BDT daily) with 100% resource recovery.

As mentioned earlier, the waste management practices are a bit conventional and no advance techniques have been used, the expenses are mainly against the collection and disposal. GCC requires approximately 340 labor-hours per day which is the most expensive relative to other area of expenses. Table 4.27 shows a comparison of MSW management cost (BDT/ton) and potential revenue generation with 100% resource recovery.

Table 4:27 Annual operation cost for SWM and revenue for resource recovery potential and trip reduction in GCC

Cost		Revenue		
			100% Recovery	70% Recovery
Item	Amount	Item	Amount	Amount
Annual Salary[1]	47,310,000	Revenue from Resource Recovery	154,350,000	108,040,000
Fuel[2]	54,750,000	Fuel Cost Saving	82,73,455	5,791,418.5
Repair, maintenance and others[3]	45,00,000	--	--	--
Total Expenses (BDT/year)	106,560,000	Total Revenue (BDT/year)	162,623,455	113,831,418.5
Total Generated Waste (ton/year)	261,705	Total Generated Waste (ton/year)	261,705	
Cost for SWM (BDT/ton)	407	Revenue earned (BDT/ton)	621	434

[1]Salary for cleaning workers (340 persons @ 300BDT/day), drivers (56 persons @ 15000/month)

[2]Fuel cost = Approximate no. of trips currently made * Average round trip fuel cost * 365
= 250 * 600 *365 = 54,750,000 BDT/ year

[1,2,3]Salary data, fuel cost, trip numbers etc. have been obtained from field study and interview at conservancy department, GCC.

It appears that, if resource recovery is possible by 100%, it will generate a revenue (621 BDT/ton) which is more than 1.5 times of the existing expenses required per ton (407

BDT/ton) for currently practicing system of solid waste management. A comparison among the major cities of Bangladesh based on the cost required to manage per ton of waste is shown in Figure 4.8. It appears that Barishal city expenses the highest amount (1932 BDT) to collect, transport and dispose solid waste whereas cost per ton is lowest (236 BDT) in Rajshahi city. In Barishal, the reason for a higher cost is probably due to the number of cleaners appointed for SWM is highest than any other city (1.24 cleaners per 1000 population) and in Rajshahi city the ration is only 0.8. Also, in Barishal the number of collection truck is also less than any other cities (0.23 trucks per 15000 population), for which more cost can incur due to increased number of trip per vehicle and associated overtime cost. The cost for Dhaka, Chattogram, GCC, Pouroshovas and other urban cities do not vary widely and mostly differ due to waste quantity and collection efficiency.

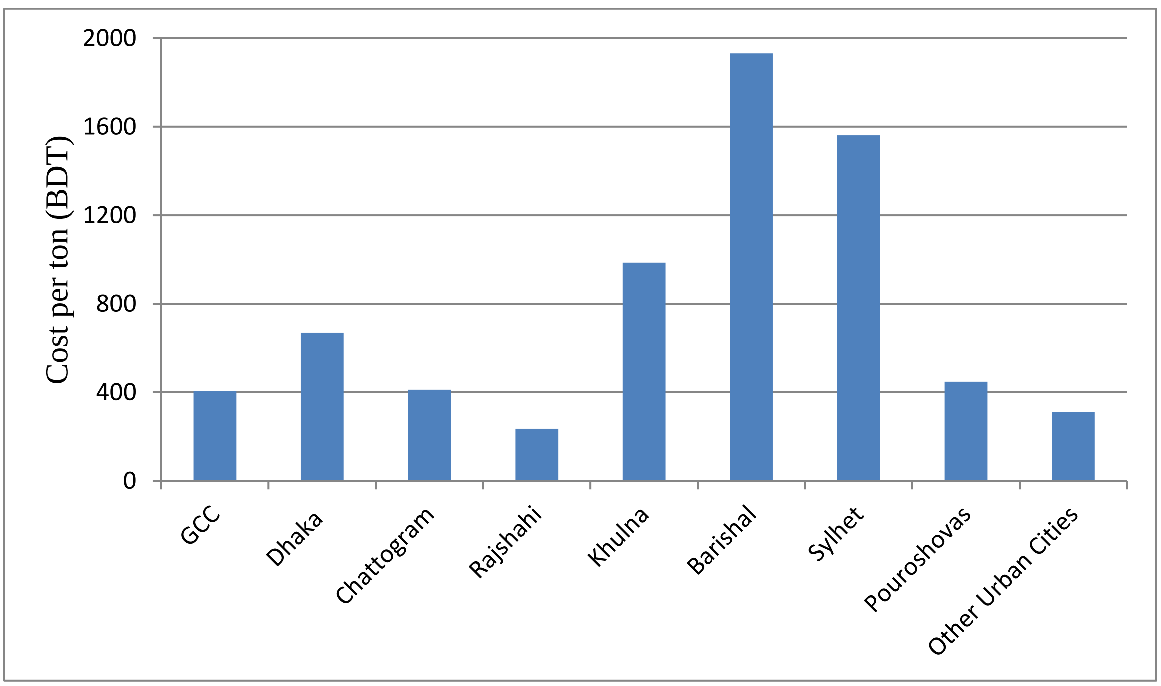

Figure 4:8 SWM cost per ton in major cities of Bangladesh

4.8 Impacts on land requirement for final disposal site

Based on the projected waste generation presented in Table 5.20, the requirement of future land area of disposal site is estimated in Table 4.28. The required area for disposal site is calculated by assuming a 6m dumping height and a compaction factor of 1.1 ton per cubic meter (Zurbrügg et al., 2005). For, GCC, current collection efficiency is near about 60% which can be improved over the time.

Table 4:28 Impact on landfill area based on the projected waste generation

Year	Projected SWG	Collection Efficiency*	With Existing System		With 3R Approach (100% recovery)**			
	ton	%	Volume of waste for disposal m^3	Area Required m^2/year	Volume of waste for disposal m^3	Area required m^2	Area Saving m^2	% of Area Saved for Land filling
2016-17	261624.2	60	142704.11	23784.02	121298.49	20216.42	3567.60	15
2021	341183.7	70	217116.90	36186.15	184549.37	30758.23	5427.92	15
2026	428946.1	80	350955.90	58492.65	298312.52	49718.75	8773.90	15
2036	569678.1	90	414311.35	69051.89	352164.64	58694.11	10357.78	15
Overall status in 2036			1125088.25	187514.71	956325.02	159387.50	28127.21	--

*Assuming, from 2021 collection efficiency will increase by 10% in every 5 years.
**An approximated amount of 15% reduction from the existing volume of waste has been considered as observed in this study (Table 5.27).

From Table 4.25, about 14.5% of volumetric waste reduction is noted with 3R approach. In Table 5.30, to determine volume of waste for disposal with 3R approach is determined using 15% reduced value from the volume of waste for disposal in the existing system. It appears that a total of 6.9 acres (28,127 m^2) equivalent land area can be saved if 100% resource recovery is possible.

4.9 Identifying Shortcoming and Drawback of the Current Practices

The solid waste management service in GCC is in a poor shape. The City Corporation is unable to adopt a modern solid waste management system due to the combination of several factors like lack of skilled human resources, inadequate fund and infrastructure and equipment and low awareness of the people in general (Rahman et al., 2018). The combination of these factors makes solid waste management at GCC very challenging.

4.9.1 Unplanned City Development

Gazipur is a densely populated city with increasing urban population posing severe challenges for SWM. Although a master plan is available for Gazipur area for drainage, traffic transportation, land use, solid waste management etc., but according to the city corporation monitoring report no action plan is prepared for infrastructure and public facilities under the master plan (Quarter-1, output monitoring report, LGED). Also land use of this city is very much mixed where many commercial, manufacturing units or factories, residential areas lie within the same area. Most of the industrial units do not have any disposal system and ultimate dependon GCC for waste disposal. As a result industrial waste mixed with the domestic or commercial waste.

Figure 4:9 Open burning of waste in roadside

Figure 4:10 Scattered disposal of waste at roadside

Open burning and scattered disposal of waste are prevalent in many places in GCC as shown in Figure 4.9 and 4.10. Sometimes, people tend to throw the waste in an open area or nearby drains as questionnaire survey reveals 4% of the residents throw their waste in the open space. These drains become stagnant due to unplanned dumping and irregular cleanliness. Situation becomes worse in rainy season when drain water overflows with waste in it. CARE Bangladesh, 2014 reported that in Tongi and Konabari waste disposal is a primary concern for the slum dwellers and a slum in Tongi (located in a government khash land) nearby drain remains the only options to dump domestic waste including plastic content.

4.9.2 Lack of Public Participation in SWM

In case of GCC, people are not aware and familiar with proper waste management practices. The concept of reuse and recycle is not yet a popular choice among the residents. Questionnaire survey reveals that only 15% respondents are acquainted with the segregation process. An integrated waste management requires active public involvement. However, GCC has established communication with several NGOs and local community to collect waste from households but educating the public is important to implement 3R concept.

4.9.3 Limitations in Primary and Secondary Collection

GCC is dependent on the private sector for primary collection. These private sectors use traditional tri-cycle vehicle for waste collection. Usually, in primary collection, the driver used to collect the waste manually and dump into his collection vehicle in a non-segregated condition. Sometimes they do manual sorting at source informally on the roadside which is inappropriate and make the roadside dirty again. With appropriate management system GCC can recover resources at source and earn revenue.

In case of secondary collection, GCC can collect up to 60% of waste generated in a day. The remaining portion is accumulation over the days and creating environmental disturbances. Also, the trips are not assigned based on vehicle availability rather prioritizing the zonal generation. In SDSs informal sector is responsible for major resource recovery but that is also unaccounted to GCC.

4.9.4 Organizational Challenges

Although GCC is the largest city corporation in Bangladesh, its conservancy department is running under staffed. The cleaners are appointed on muster roll and are not permanent employee of GCC. They are the main driving force for waste management in GCC area. As per field study, the daily fees of the cleaner is 300 taka and on average 10%-15% cleaners remain absent in the workplace. In DCC there are 7000 cleaners and 90 conservancy inspector and 20 supervisors (JICA, 2005). Compare to this the manpower of GCC is very negligible and the management faces regular challenges in SWM due this understaffed condition. The organizational hierarchy of conservancy department of GCC is as shown in Figure 4.11.

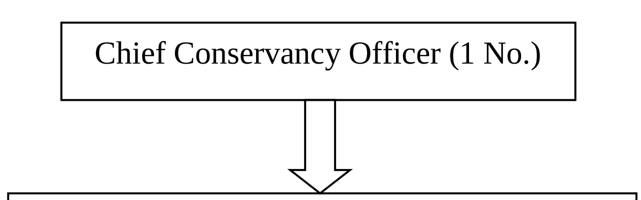

Figure 4:11 Organizational hierarchy of conservancy department of GCC

4.9.5 Land Fill Site

One of the major problems of SWM in GCC is the inadequate space for land filling. The current land filling site is located at Kadda, Baimai. The area of the site is 5 Acre and the land is owned by the Roads and Highway Department. Not owning a land for waste disposal is a major setback for the GCC. Current site is over stressed and GCC is recently planning to dump a small fragment of waste into a vacant land in Gacha Union (zone 2).

4.9.6 Summary

Table 4.29 outlines the limitations facing by the current management.

Table 4:29 Limitations and drawback of GCC in managing solid waste

Particulars	Details
Resource Constraints	➢ Inadequate collection vehicle ➢ Insufficient capital and human resource
Collection Efficiency	➢ Waste collection efficiency is in between 60-70% as claimed by GCC conservancy department ➢ Frequency of waste collection is not fix
Secondary Dumping Sites	➢ Do not facilitate material recovery ➢ Unprotected condition ➢ Unaccounted contribution of informal sector at SDSs ➢ Adequate number of SDS should be designated based on zonal waste generation characteristics
Transport	➢ Frequency of waste collection is not fix ➢ Collection vehicles are open and pollute environment while carrying waste ➢ Trips should be calculated as per zonal demand
Treatment and Disposal	➢ Inadequate space in final dumping site ➢ Current system is only limited to collection and dumping of waste ➢ Disposal site requires material recovery facility and composting plant
3R perspective	➢ No significant campaign to encourage waste reduction and storage at source ➢ No material is recovered and recycled in the current waste management system maintained by GCC

4.10 Approaches for Integrated Solid Waste Management (ISWM) Based on 3R

The integrated approach for solid waste management should be based on 3R concept through optimizing the management process of solid waste from all the waste generating sectors and involving all stakeholders. 3R concept is becoming a guiding factor for the management of solid waste now-a-days. 3R Based ISWM system shall cover all the aspects related to solid waste management; starting from waste segregation at storage, collection, transfer, sorting, treatment and disposal. Data from current solid waste characterization and quantification provide a basis for developing integrated solid waste management system based on 3R concept in GCC area.

The proposed ISWM approach is based on the components of 3R starting from segregation of waste components at household level, collection and transportation of the segregated components to SDS and final disposal site from SDS. An evaluation framework was also developed to measure the performance the proposed approach.

4.10.1 Source Reduction and Segregation at Household Level

Source reduction is on the top level in municipal solid waste management due to solving waste problems at the source. It will save the raw material and subsequently waste collection, transportation and treatment procedure. It is equally important to educate residents so that they understand the outcome of source reduction and they take part in the integrated system by reducing their waste generation. To reduce generation of waste at the very first place requires good motive of the industry people as they are producing most of the consumable items which is actually contributing to the overall waste stream. Selection of raw materials and advanced processes may reduce the amount of non-degradable items. Typical elaboration of reduction at source options and sub-options are given at following Table 4.30

Table 4:30 Typical elaboration of 'reduction at source' checklist

Reduction at Source	
Element	Options
Selection of products / raw materials	Choose degradable packaging materials
	Use recycled materials
Packaging of products	Exclude unnecessary packaging materials from any products at industry level
	Promote recycled and degradable packaging products
Educate Users	Create awareness

After waste reduction, source segregation falls in the second most desired step in the SWM hierarchy. As of now, there is no physical existence of sorting of solid waste in almost all of the households in GCC. There are very few households or institution who store their generated solid waste separately but the existing collection system forced them to dump the waste into the same stream. To enable the residents to store their waste in a segregated way, this study is proposing the following steps incorporating 3R concept:

Step 1: Designate color coded waste container according to waste type: To facilitate waste segregation at source, a specific color code should be designated to major categories of waste such as organic, paper, plastic etc. The proposed color code and type of the waste containers/bins are provided in Table 4.31

Step 2: Supply multiple waste containers to households: According to a previous study the average household size in Gazipur city is 4.07 (BBS, 2013). Considering this, current number of household is about 6,14,250. GCC needs to supply color coded bin to respective households. As it can be difficult to purchase and supply waste containers to all the households at a time, this can be done phase wise starting from selected wards at first and gradually it can be spread zone wise.

Step 3: No Segregation, No Collection Policy: To ensure proper segregation, it should be circulated strongly that waste will not be collected if they are not sorted according to the designated color code. GCC needs to implement this at field level otherwise it cannot be possible to recover the expected resource.

Table 4:31 Proposed types and color code for waste containers/bins

Color Code	Container Type	Waste Item
Green 	➢ Single compartment container ➢ Leak proof ➢ Size: 20L (appx. capacity is 7-10 kg) ➢ With foot paddle	➢ Food/kitchen waste (Dairy, fruits, vegetables, tea leaves, grass cuttings etc.) ➢ Any other waste that is degradable
Blue Color	➢ Double compartment container to segregate paper and plastic waste ➢ Leak proof ➢ Size: 10L (appx. capacity is 3-5 kg) ➢ With foot paddle	Paper Waste: ➢ Newspaper, envelopes, books, magazines etc. ➢ Cardboard ➢ Paper packaging Plastic Waste: ➢ Plastic bottles ➢ Plastic packaging ➢ Polythene bag

 		
Yellow Color  	➢ Single compartment container ➢ Leak proof Size: 10L (appx. capacity is 3-5 kg) ➢ With foot paddle	➢ Glass item ➢ Metal Item ➢ Aerosol Can, Battery and others

4.10.2 Primary Collection

The household waste in GCC area consists of biodegradable waste (vegetables, leftover foods), non-biodegradable waste (paper, plastic, metal, glass etc.); thereby handling these will be complicated. As it is expected that, collection of the segregated waste from household shall be done according to the color code as shown in Table 6.2 and delivered to SDS. For this, collection vehicle requires simple modification. At present, there are about 500-600 vans (tri-cycle van) which collect waste from the households in GCC area. All of these vans are single compartment as shown in Figure 4.12 and wastes are loaded in that compartment in mixed state. As this study proposes segregation of waste at household, the primary collection vehicles are needed to be modified to transfer the collected waste in segregated condition to SDS. A modification of multiple compartments is proposed instead of the conventional single compartment primary collection vehicle as shown in Figure 4.13. It can be seen that the compartment for organic content has been kept larger than other compartments.

Figure 4:12 Existing collection vehicle type with single compartment to collect waste from household

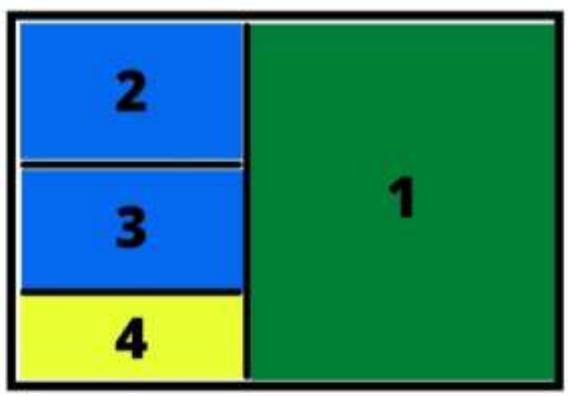

Figure 4:13 Modified compartment style for primary collection vehicle

1- Organic Content; 2-Paper; 3-Plastic; 4-Others (glass, metal etc.)

Several elements or checklists are required to be maintained for primary collection as shown in Table 4.32

Table 4:32 Typical elaboration of primary collection checklist

Primary Collection	
Element	Options
Containers(at source)	Waste sorted in color coded containers
Collection Method	Door to door
	Directly from source (bazar, market etc.)
Collection Vehicle (household to SDS)	Non motorized tri-cycle van (with multiple compartments)
	Small capacity motorized van/truck (with multiple compartments)
Waste type	Sorted

Frequency Selection	Daily
Collection Fees/Charges	Monthly subscription based

4.10.3 Management at Secondary Dumping Site

While the primary role of the SDS is the accumulation of waste convenient to its sources, the primary role of secondary dumping site is the bulking of waste for its economic and environmentally acceptable onward transport to treatment or disposal facilities. The result of having SDSs eliminates uncertainties for urban waste collection systems, by providing a stable network of reception stations against which they can be optimized. It enables that waste to be taken to, and rapidly discharged at, a fixed location within each sector of the urban area. Establishing such SDSs also encourages the gradual investment in improved waste handling vehicles and equipment, to serve reasonably predictable waste throughputs. The SDSs should work as a material recovery facility. All sorts of non-biodegradable items should be sorted out from this facility so that only the waste which required treatment or disposal should be transported to the treatment facility or the ultimate disposal site. This will reduce the amount of waste to be transported to the ultimate disposal site.

The next step after source reduction and segregation, reuse and recycling is next in the waste management hierarchy. To maximize the reuse and recycling potential, the SDSs are needed to be function adequately as per 3R guiding principle. For this, SDSs in GCC should be facilitated with the following features:

- SDSs should be isolated from the highway through a barrier (wall / fence)
- Required proper loading and unloading facilities for collection vehicles
- Recyclables (paper, plastic, others) should be deposited in respective container/location at SDS maintaining the similar color code.
- Facility to sell and transfer the recoverableitems to the respective vendor at SDSs. Sufficient space for material weighing system shall be provided at the SDSs
- Only the organic contents will be carried out from the SDSs to the final disposal site

4.10.4 Transfer, treatment and safe disposal

Already GCC is facing difficulties in managing space for land filling and the rate at which waste is about to increase it requires more land if any other alternatives are not taken into consideration. Reduction in waste quantity through recovery of recyclable waste material in the earlier stage (Household level / SDSs) will reduce the stress on further transfer, treatment and disposal processes at final disposal site. Successful resource recovery will reduce the number of trips and land filling area requirement.

Considering the amount of solid waste quantity and composition generated in GCC, an integrated landfill with resource recovery facility should be established by GCC giving priority to the 3R concept. The new landfill site shall consider the diversion and conversion of bulk part of the waste into resources (compost, biogas, energy, inorganic waste recycling) instead of landfill. This study proposes to transfer only the organic waste into the final disposal site. The final disposal site shall be consisting of composting plant, biogas plant or any waste-to-energy based technology and land filling options.

Major concerns related to waste transfer, treat and disposal are listed in Table 4.33.

Table 4:33 Concerns related to waste transfer, treat and disposal

Element	Major concerning Points
Transport	Transport waste (organic contents only) from SSD to Final Disposal Site
Transfer	Unloading method/facility/rate
	Sorting and storage
	Reloading method/facility/rate
Treatment	Composting
	Anaerobic Digestion
	Refuse Derived Fuel (RDF)
Disposal site	Involves project planning, land filling schemes, trade-off between travel distance and land price
	Operational facilities
	Monitoring facilities
Operation & Control	Waste reception and control, waste handling and placement: Involves reception, placement, compaction plus operation and maintenance of all

	associated gas, leachate, general site facilities and infrastructure
	Leachate handling and treatment
	Environmental monitoring
	Restoration
Resource Requirement	Land, Finance

4.10.5 Recovery Potential through Several Treatment Options in GCC

In this study, it has revealed that, waste stream in GCC is dominated by the organic fractions (83.5%) accumulating 598 tons annually. Upon segregation, this organic fractions has the potential to be converted into recovered resources such as compost, biogas and refuse derived fuel. BMDF (2012) has mentioned in their study that Bangladesh met the standards those are required to produce the recovered products mentioned above. Table 4.34 shows the recovery potential of different treatment options in GCC area.

Table 4:34 Estimated value of recovered materials for different treatment option in GCC

Recovery Particulars	Treatment Option		
	Composting	Anaerobic Digestion	Refuse Derived Fuel
Type of Waste Required	Food, vegetables, fruits, plant residues	Food, vegetables, fruits	Paper, plastic, wood waste
Required Quantity	Medium	Medium	Low
Project Scale	Household to large	Household to large	Household to large
Investment	Low to medium	Medium to high	Low to medium
Potential Production	1/4 ton compost per ton of organic waste	50m^3 biogas per ton of organic waste	3000-4000 K.Cal/kg calorific value
		1.2 KW electricity per m^3 of organic waste	0.9ton ton RDF pellets per ton of waste (paper, plastic, textile)
Potential Recovery in GCC (100% recovery)	149.5 ton compost/day	29900 m^3 biogas/day	77 ton RDF/day
		35880 KW electricity/day	
Estimated Value of Recovered Material in GCC	$12707/day	$7534.8/day	$3850/day

Source: (Enayetullah, 2017)
Note: Organic fraction produced per day = 598 ton; Waste fraction available for RDF = 85.78 ton/day; Composed value assumed at $85/ton; Electricity price assumed at $0.21/KWh; RDF price assumed at $50/ton. This rate and price is based on several project run by Waste Concern.

However, engaging private sector to treat organic and recycled waste requires huge investment in addition to land requirement. In regard to the treatment of waste, number of approaches mentioned above may be considered simultaneously. The first approach could be selecting a site based on the short-term demand and crisis considering the space availability and convenience. But the preferred one should be the long-term site which can provide all the activities of an integrated waste management services. In any case, land filling should be the least priority after utilizing the organic content to several waste-to-energy options.

4.11 Approach for Evaluating 3R Based ISWM System

The proposed approach for ISWM considers that waste segregation will begin at household level. To receive the overall status of the approaches taken to implement 3R strategy, it is important to start the evaluation process from the step of primary collection (house to house) followed by evaluation in secondary dumping sites. Individual spreadsheets have been developed to evaluate the proposed approached at various steps of the ISWM system.

Spreadsheet to record the waste quantity collected in segregated condition at household level or from any other nearby sources (community bins, bazaar etc.) is provided in Annex III. This is applicable for each primary waste collection vehicle.

Spreadsheets to record overall waste quantity (item/type wise) deposited in a designated SDS in a day and wastes transferred to the disposal site / recycling industry are provided in Annex IV and V.

4.11.1 Summary of the proposed approach

The proposed approach for SWM in GCC area allows reduction, reuse and recycle opportunity. To summarize, a flow diagram for the ISWM system is developed and shown in Figure 4.16.The difference between the current system and proposed ISWM system can also be seen in Figure 4.15 and 4.16 respectively.

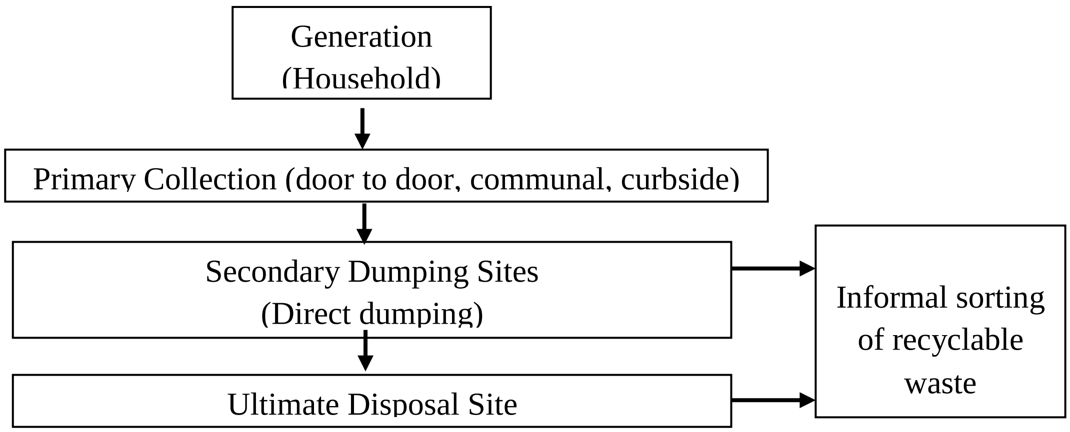

Figure 4:14 Currently practiced SWM system

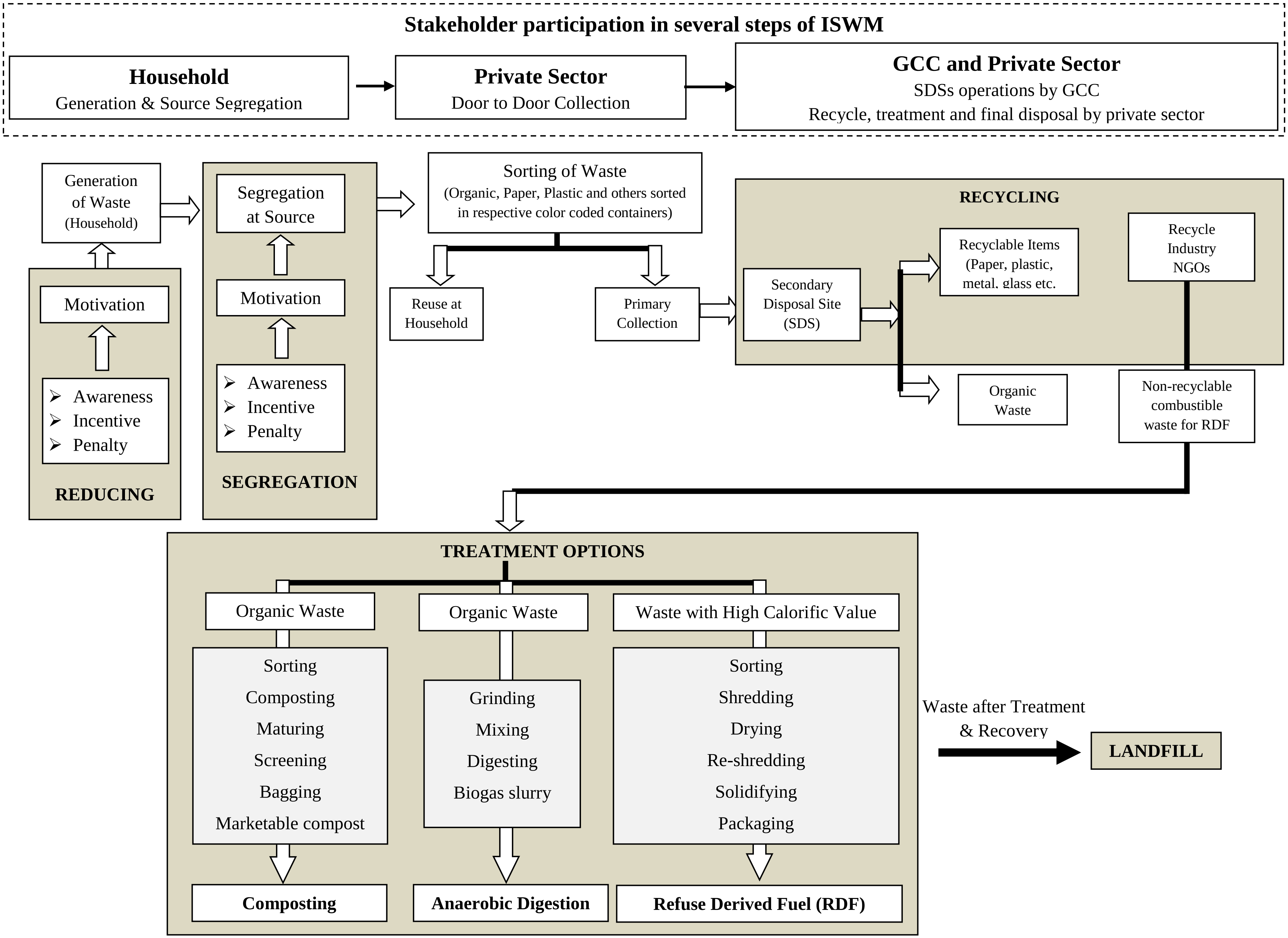

Figure 4:15Proposed ISWM system for GCC based on 3R approach

CHAPTER:5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study focused on the determination of solid waste generation rate, waste composition, opportunities for implementing 3R strategy in different levels based on a hypothetical approach. Based on the study the following conclusions can be made:

1. The average solid waste generation rate in household is 0.352 kg/capita/day and 0.364 kg/capita/day at dry and wet season respectively. The overall generation rate was found to be 0.358 kg/capita/day. The daily amount of waste generated in GCC at household level was found as 717.5 ton.

2. In waste composition, it has been found that, the organic contents dominate among all other waste types. The average waste is composed of 83.4% organic contents (84.4%in dry season and 82.41 in wet season) at household level. Whereas in secondary dumping sites, the average organic content was found at 77.04% (72.33% in dry season and 81.75% in wet season).

3. In case of inorganic waste content, SDSs showed higher percentage (22.96%) in case of inorganic contents compare to household waste composition (16.6%). This indicates that wastes coming at SDSs from other streams (restaurants, markets, commercial establishments, industries etc.) contain higher amount of inorganic contents.

4. Paper and plastic waste were found in maximum quantity at both household and SDSs. At household level, average paper and plastic waste accounted for 5.75% and 6.34% respectively followed by glass (0.91%), leather & rubber (0.66%), metal (0.62%) and others (2.27%). In SDSs, the inorganic portion consisted of paper (6.75%), plastic (6.66%), glass (2.81%), leather & rubber (0.59%), metal (1.37%), textile (1.52%) and others (3.27%) respectively.

5. From projection of waste generation, it is forecasted that the average generation rate may rise up to 0.42 kg/capita/day accumulating 1561 ton daily by 2036.

6. This study also analyzed the resource recovery potential from the generated solid waste. It has been found that, on average a total of 104 tons of solid waste can be recovered daily from the waste stream which mainly consists of paper (42.76), plastic (43.02), glass (8.59 ton), metal (4.58 ton), leather and rubber (5.30 ton).

7. With 3R based ISWM system, it can be possible to generate revenue of 154.35 and 108.04 million BDT annually from the recoverable materials with 100% and 70% recovery rate respectively.

8. Total number of average trips currently made per day is about 250 to transfer the waste from SDSs to the final dumping site at Kadda, Baimail. Currently GCC claim that the MSW collection efficiency is about 60%. Whereas according to this study, to collect only the domestic waste with 100% efficiency, it is required to make 256 trips per day.

9. With 100% recovery of potentially recoverable materials by applying 3R concept at household, it is estimated that, volumetric reduction of solid waste will be 14.5%. This reduction will allow 38 numbers of trips reduction per day with a saving in fuel cost of 22667 BDT daily.

10. In existing management practices, the cost of waste management is 407 BDT per ton. With 100% and 70% recovery of recoverable materials, it is possible to earn revenue of 621 BDT per ton and 434 BDT per ton respectively.

11. Ensuring volume reduction through 3R practices, space required for future land filling can be reduced up to 7 acres by the end of 2036 with 100% resource recovery.

5.2 Future Scopes

In order to elaborate an integrated waste management plan and to implement a sustainable waste management system for GCC further research is necessary. The following areas are suggested for investigation:

1. As this study focuses on the domestic waste generation and composition, further study on commercial, industrial and medical waste can be carried out to determine the municipal solid waste characteristics in GCC.

2. Based on the household waste composition data revealed from this study, applicability for community based composting can be studied in future.

3. Numbers of SDSs required for waste management in GCC have not been identified in this study; there is a scope to conduct a study to identify the number of SDSs required as well as the location of SDSs.

4. Although this study briefly outlined the organizational lacking in terms of manpower and resources, a detailed study in future on manpower and resource requirement for waste management in GCC can be beneficial.

5. Informal sector contributes significantly in waste volume reduction through reclaiming recyclable materials. Future study on informal sector's contribution in GCC will provide a better scenario on resource recovery perspective.

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APPENDIX I: Zone Wise Collected Data on Solid Waste

Table A1Solid waste data collected from households in GCC (Zone 1, Cycle 1)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	21.17	85.68	6.35	65.80	0.073	0.022	13.33	75.41	4	50.6	0.046	0.014
Gardens	--	--	--	--	--	--	--	--	--	--	--	--
Paper	1.91	7.75	1.8	18.65	0.023	0.02	1.06	6.02	1	12.7	0.013	0.012
Plastic/Polythene	1.12	4.54	1.1	11.40	0.017	0.02	0.61	3.46	0.6	7.6	0.009	0.009
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	0.00	0.00	0	0.0	0.000	0.000
Glass/Bottle	--	--	--	--	--	--	0.41	2.31	0.4	5.1	0.002	0.002
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather							0.89	5.03	0.8	10.1	0.006	0.005
Wood	0.50	2.02	0.4	4.15	0.002	0.0017	1.38	7.78	1.1	13.9	0.006	0.005
Battery	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	24.70	100.00	9.65	100.00	0.11	0.062	17.68	100.00	7.9	100.0	0.081	0.046

Table A2Solid waste data collected from households in GCC (Zone 1, Cycle 2)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	24.00	83.12	7.2	61.49	0.0828	0.0248	15.83	78.36	4.75	54.6	0.0546	0.0164
Gardens	0.25	0.87	0.1	0.85	0.0024	0.0010	0.00	0.00	0	0.0	0.0000	0.0000
Paper	1.49	5.16	1.4	11.96	0.0175	0.0165	0.74	3.69	0.7	8.0	0.0088	0.0082
Plastic/Polythene	0.87	3.00	0.85	7.26	0.0133	0.0131	1.68	8.33	1.65	19.0	0.0259	0.0254
Dirt, Ashes, Brick Chips	0.57	1.97	0.5	4.27	0.0007	0.0006	0.57	2.81	0.5	5.7	0.0007	0.0006
Glass/Bottle	1.12	3.89	1.1	9.39	0.0058	0.0056	0.00	0.00	0	0.0	0.0000	0.0000
Metal/Tin	0.41	1.43	0.4	3.42	0.0046	0.0044	0.00	0.00	0	0.0	0.0000	0.0000
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	1.38	6.81	1.1	12.6	0.0057	0.0046
Battery	0.165	0.57	0.16	1.37	0.0002	0.0002	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	28.87	100.00	11.71	100.00	0.1272	0.0662	20.20	100.00	8.7	100.0	0.0957	0.0552

Table A3 Solid waste data collected from secondary dumping sites in Zone 1

Waste Type	Cycle 1								Cycle 2							
	Dry Season				Wet Season				Dry Season				Wet Season			
	Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight	
	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%
Food waste	38.67	83.18	11.6	60.73	40.67	72.57	12.2	50.83	23.33	59.03	7	33.85	40	75.5	12	55.35
Gardens	0.00	0.00	0	0.00	5.00	8.92	2	8.33	2.55	6.45	1.02	4.93	5.00	9.44	2	9.225
Paper	1.91	4.12	1.8	9.42	2.98	5.32	2.8	11.7	2.87	7.27	2.7	13.06	3.19	6.02	3	13.84
Plastic/Polythene	1.84	3.95	1.8	9.42	3.67	6.55	3.6	15	1.76	4.46	1.727	8.35	3.06	5.78	3	13.84
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	5.11	12.94	4.5	21.76	0.09	0.17	0.08	0.369
Glass/Bottle	2.65	5.71	2.6	13.61	2.35	4.19	2.3	9.58	1.22	3.10	1.2	5.80	1.02	1.93	1	4.613
Metal/Tin	--	--	--	--	--	--	--	--	0.62	1.56	0.6	2.90	0.62	1.17	0.6	2.768
Rubber	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	0.89	2.25	0.8	3.87	--	--	--	--
Wood	--	--	--	--	1.38	2.45	1.1	4.58	--	--	--	--	--	--	--	--
Textile	1.41	3.04	1.3	6.81	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	--	--	--	--	0.74	1.88	0.72	3.48	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	0.42	1.07	0.41	1.98	--	--	--	--
Total	46.48	100	19.1	100	56.04	100	24	100	39.53	100	20.67	100	52.98	100	21.68	100

Table A4 Solid waste data collected from households in GCC (Zone 2, Cycle 1)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	22.00	85.80	6.6	65.67	0.0759	0.0228	16.00	72.92	4.8	51.2	0.0552	0.0166
Gardens	--	--	--	--	--	--	2.00	9.11	0.8	8.5	0.0190	0.0076
Paper	1.06	4.15	1	9.95	0.0125	0.0118	2.02	9.21	1.9	20.3	0.0238	0.0224
Plastic/Polythene	1.22	4.78	1.2	11.94	0.0188	0.0185	1.12	5.12	1.1	11.7	0.0173	0.0169
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	0.82	3.18	0.8	7.96	0.0042	0.0041	0.27	1.21	0.26	2.8	0.0014	0.0013
Metal/Tin	--	--	--	--	--	--	0.10	0.47	0.1	1.1	0.0011	0.0011
Rubber	--	--	--	--	--	--	0.24	1.12	0.24	2.6	0.0019	0.0018
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	0.41	1.61	0.33	3.28	0.0017	0.0014	--	--	--	--	--	--
Battery	0.124	0.48	0.12	1.19	0.0001	0.0001	0.1856	0.85	0.18	1.9	0.0002	0.0002
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	25.64	100.00	10.05	100.00	0.1133	0.0586	21.94	100.00	9.38	100.0	0.1199	0.0679

Table A5 Solid waste data collected from households in GCC (Zone 2, Cycle 2)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/day	%	kg/day	%	m^3	m^3	kg/day	%	kg/day	%	m^3	m^3
Food waste	23.33	83.75	7	61.84	0.0805	0.0241	20.33	75.91	6.1	50.0	0.0701	0.0210
Gardens	--	--	--	--	--	--	--	--	--	--	--	--
Paper	2.02	7.26	1.9	16.78	0.0238	0.0224	2.77	10.33	2.6	21.3	0.0325	0.0306
Plastic/Polythene	1.02	3.66	1	8.83	0.0157	0.0154	2.14	8.00	2.1	17.2	0.0330	0.0323
Dirt, Ashes, Brick Chips	0.34	1.22	0.3	2.65	0.0004	0.0004						
Glass/Bottle	1.02	3.66	1	8.83	0.0052	0.0051	0.92	3.43	0.9	7.4	0.0047	0.0046
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	0.63	2.33	0.5	4.1	0.0026	0.0021
Battery	0.124	0.44	0.12	1.06	0.0001	0.0001	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	27.86	100.00	11.32	100.00	0.1257	0.0675	26.79	100.00	12.2	100.0	0.1429	0.0906

Table A6 Solid waste data collected from secondary dumping sites in Zone 2

Waste Type	Cycle 1								Cycle 2							
	Dry Season				Wet Season				Dry Season				Wet Season			
	Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight	
	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%
Food waste	20.00	63.23	6	62.63	16.33	52.32	4.9	25.39	21.67	62.52	6.5	37.88	34	70.22	10.2	51
Gardens	2.50	7.90	1	10.44	0.00	0.00	0	0	2.50	7.21	1	5.83	7.25	14.97	2.9	14.5
Paper	3.19	10.09	3	31.32	3.72	11.93	3.5	18.13	2.23	6.45	2.1	12.24	3.09	6.37	2.9	14.5
Plastic/Polythene	2.55	8.06	2.5	26.10	7.14	22.88	7	36.27	1.53	4.42	1.5	8.74	2.04	4.22	2	10
Dirt, Ashes, Brick Chips	1.14	3.59	1	10.44	--	--	--	--	5.11	14.76	4.5	26.22	--	--	--	--
Glass/Bottle	0.00	0.00	0	0.00	3.57	11.44	3.5	18.13	1.12	3.24	1.1	6.41	2.04	4.22	2	10
Metal/Tin	1.34	4.24	1.3	13.57	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	0.44	1.42	0.4	2.073	0.20	0.58	0.18	1.05	--	--	--	--
Wood	0.63	1.98	0.5	5.22	--	--	--	--	--	--	--	--	--	--	--	--
Textile	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	0.29	0.91	0.2 8	2.92	--	--	--	--	0.29	0.83	0.28	1.63	--	--	--	--
Total	31.63	100	9.5 8	100	31.22	100	19.3	100	34.66	100	17.16	100	48.4 2	100	20	100

Table A7 Solid waste data collected from households in GCC (Zone 3, Cycle 1)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	23.33	90.72	7	75.27	0.0805	0.0241	24.67	88.60	7.4	70.8	0.0851	0.0255
Gardens	--	--	--	--	--	--	--	--	--	--	--	--
Paper	0.96	3.72	0.9	9.68	0.0113	0.0106	1.39	5.01	1.31	12.5	0.0164	0.0154
Plastic/Polythene	1.43	5.55	1.4	15.05	0.0220	0.0215	1.27	4.54	1.24	11.9	0.0195	0.0191
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	--	--	--	--	--	--	--	--	--	--	--	--
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	0.5155	1.85	0.5	4.8	0.0013	0.0013
Total	25.72	100.00	9.3	100.00	0.1137	0.0563	27.84	100.00	10.45	100.0	0.1222	0.0613

Table A8 Solid waste data collected from households in GCC (Zone 3, Cycle 2)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	23.33	83.75	7	61.84	0.0805	0.0241	23.00	86.35	6.9	67.0	0.0793	0.0238
Gardens	--	--	--	--	--	--	--	--	--	--	--	--
Paper	2.02	7.26	1.9	16.78	0.0238	0.0224	1.17	4.39	1.1	10.7	0.0138	0.0129
Plastic/Polythene	1.02	3.66	1	8.83	0.0157	0.0154	1.43	5.36	1.4	13.6	0.0220	0.0215
Dirt, Ashes, Brick Chips	0.34	1.22	0.3	2.65	0.0004	0.0004						
Glass/Bottle	1.02	3.66	1	8.83	0.0052	0.0051						
Metal/Tin	--	--	--	--	--	--	0.41	1.55	0.4	3.9	0.0046	0.0044
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	0.63	2.35	0.5	4.9	0.0026	0.0021
Battery	0.124	0.44	0.12	1.06	0.0001	0.0001	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	27.86	100.00	11.32	100.00	0.1257	0.0675	26.64	100.00	10.3	100.0	0.1222	0.0648

Table A9 Solid waste data collected from secondary dumping sites in Zone 3

Waste Type	Cycle 1								Cycle 2							
	Dry Season				Wet Season				Dry Season				Wet Season			
	Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight	
	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%
Food waste	26.00	74.50	7.8	48.15	40.00	93.64	12	81.63	26.00	74.50	7.8	48.15	26.67	90.76	8	74.77
Gardens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paper	0.53	1.52	0.5	3.09	--	--	--	--	0.53	1.52	0.5	3.09	--	--	--	--
Plastic/Polythene	2.65	7.60	2.6	16.05	0.82	1.91	0.8	5.442	2.65	7.60	2.6	16.05	0.82	2.78	0.8	7.477
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	1.43	4.09	1.4	8.64	--	--	--	--	1.43	4.09	1.4	8.64	--	--	--	--
Metal/Tin	0.10	0.30	0.1	0.62	--	--	--	--	0.10	0.30	0.1	0.62	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Leather	0.11	0.32	0.1	0.62	--	--	--	--	0.11	0.32	0.1	0.62	--	--	--	--
Wood	0.38	1.07	0.3	1.85	--	--	--	--	0.38	1.07	0.3	1.85	--	--	--	--
Textile	3.70	10.59	3.4	20.99	1.90	4.45	1.9	12.93	3.70	10.59	3.4	20.99	1.90	6.47	1.9	17.76
Battery	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	34.90	100.00	16.2	100.00	42.72	100.00	14.7	100	34.90	100.00	16.2	100.00	29.38	100.00	10.7	100

Table A10Solid waste data collected from households in GCC (Zone 4, Cycle 1)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	14.77	63.07	4.43	39.52	0.0509	0.0153	16.67	76.84	5	50.8	0.0575	0.0172
Gardens	2.75	11.75	1.1	9.81	0.0262	0.0105	--	--	--	--	--	--
Paper	2.00	8.54	1.88	16.77	0.0235	0.0221	0.85	3.92	0.8	8.1	0.0100	0.0094
Plastic/Polythene	1.94	8.28	1.9	16.95	0.0298	0.0292	1.83	8.42	1.79	18.2	0.0281	0.0275
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	0.23	1.05	0.2	2.0	0.0003	0.0003
Glass/Bottle	--	--	--	--	--	--	0.15	0.71	0.15	1.5	0.0008	0.0008
Metal/Tin	1.24	5.28	1.2	10.70	0.0137	0.0133	0.82	3.80	0.8	8.1	0.0092	0.0089
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	0.11	0.51	0.1	1.0	0.0007	0.0006
Wood	--	--	--	--	--	--	--	--	--	--	--	--
Total inorganic waste	5.18	22.11	4.98	44.42	0.0671	0.0647	3.99	18.41	3.84	39.0	0.0490	0.0475
Battery							0.4124	1.90	0.4	4.1	0.0005	0.0004
Aerosol Can	0.722	3.08	0.7	6.24	0.0018	0.0018	0.6186	2.85	0.6	6.1	0.0015	0.0015
Total	23.41	100.00	11.21	100.00	0.1460	0.0922	21.69	100.00	9.84	100.0	0.1085	0.0667

Table A11 Solid waste data collected from households in GCC (Zone 4, Cycle 2)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	21.33	87.58	6.4	68.97	0.0736	0.0221	13.67	84.96	4.1	65.1	0.0471	0.01
Gardens	--	--	--	--	--	--	--	--	--	--	--	--
Paper	1.70	6.99	1.6	17.24	0.0200	0.0188	0.53	3.31	0.5	7.9	0.0063	0.01
Plastic/Polythene	1.22	5.03	1.2	12.93	0.0188	0.0185	0.64	4.00	0.6 3	10.0	0.0099	0.01
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	--	--	--	--	--	--	--	--	--	--	--	--
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather							0.74	4.63	0.6 7	10.6	0.0047	0.00
Wood	0.10	0.41	0.08	0.86	0.0004	0.0003	0.50	3.11	0.4	6.3	0.0021	0.00
Battery	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	24.36	100.0 0	9.28	100.00	0.1128	0.0597	16.09	100.00	6.3	100.0	0.0700	0.0356

Table A12 Solid waste data collected from secondary dumping sites in Zone 4

Waste Type	Cycle 1								Cycle 2							
	Dry Season				Wet Season				Dry Season				Wet Season			
	Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight	
	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%
Food waste	40.00	80.84	12	57.55	36.6 7	73.26	11	46.0 3	36.67	81.75	11	58.20	43.6 7	90.76	13.1	75.50
Gardens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paper	2.02	4.09	1.9	9.11	5.11	10.20	4.8	20.0 8	2.55	5.69	2.4	12.70	2.61	5.42	2.45	14.12
Plastic/Polythene	0.41	0.82	0.4	1.92	6.84	13.66	6.7	28.0 3	1.94	4.32	1.9	10.05	1.84	3.82	1.8	10.37
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	--	--	--	--	--	--	--	--	1.94	4.32	1.9	10.05	--	--	--	--
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Wood	0.19	0.38	0.15	0.72	--	--	--	--	--	--	--	--	--	--	--	--
Textile	5.11	10.33	4.7	22.54	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	1.44	2.88	1.4	5.86	--	--	--	--	--	--	--	--
Aerosol Can	1.75	3.54	1.7	8.15	--	--	--	--	1.75	3.91	1.7	8.99	--	--	--	--
Total	49.48	100.00	20.85	100.0 0	50.0 5	100.0 0	23. 9	100	44.85	100.0 0	18.9	100.0 0	48.1 1	100.0 0	17.35	100

Table A132Solid waste data collected from households in GCC (Zone 5, Cycle 1)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	14.00	79.86	4.2	55.26	0.0483	0.0145	11.40	80.37	3.42	61.7	0.0393	0.0118
Gardens	--	--	--	--	--	--	1.00	7.05	0.4	7.2	0.0095	0.0038
Total organic waste	14.00	79.86	4.2	55.26	0.0483	0.0145	12.40	87.42	3.82	69.0	0.0488	0.0156
Paper	1.49	8.50	1.4	18.42	0.0175	0.0165	0.72	5.10	0.68	12.3	0.0085	0.0080
Plastic/Polythene	2.04	11.64	2	26.32	0.0314	0.0308	1.06	7.48	1.04	18.8	0.0163	0.0160
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	--	--	--	--	--	--	--	--	--	--	--	--
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	17.53	100.00	7.6	100.00	0.0972	0.0617	14.18	100.00	5.54	100.0	0.0737	0.0396

Table A14 Solid waste data collected from households in GCC (Zone 5, Cycle 2)

Waste Type	Dry Season						Wet Season					
	Raw/Initial Weight		Dry Weight		Volume		Raw/Initial Weight		Dry Weight		Volume	
					Raw	Dry					Raw	Dry
	kg/ day	%	kg/ day	%	m^3	m^3	kg/ day	%	kg/ day	%	m^3	m^3
Food waste	16.67	85.66	5	64.94	0.0575	0.0172	14.67	88.32	4.4	70.4	0.0506	0.0152
Gardens	0.00	0.00	0	0.00	0.0000	0.0000	0.00	0.00	0	0.0	0.0000	0.0000
Total organic waste	16.67	85.66	5	64.94	0.0575	0.0172	14.67	88.32	4.4	70.4	0.0506	0.0152
Paper	0.85	4.37	0.8	10.39	0.0100	0.0094	0.61	3.65	0.5 7	9.1	0.0071	0.0067
Plastic/Polythene	1.94	9.96	1.9	24.68	0.0298	0.0292	1.00	6.02	0.9 8	15.7	0.0154	0.0151
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	--	--	--	--
Glass/Bottle	--	--	--	--	--	--	--	--	--	--	--	--
Metal/Tin	--	--	--	--	--	--	--	--	--	--	--	--
Rubber	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	0.33	2.01	0.3	4.8	0.0021	0.0019
Wood	--	--	--	--	--	--	--	--	--	--	--	--
Battery	--	--	--	--	--	--	--	--	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--
Total	19.46	100.0 0	7.7	100.00	0.0973	0.0559	16.61	100.00	6.2 5	100.0	0.0752	0.0388

Table A15 Solid waste data collected from secondary dumping sites in Zone 5

Waste Type	Cycle 1								Cycle 2							
	Dry Season				Wet Season				Dry Season				Wet Season			
	Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight		Raw/Initial Weight		Dry Weight	
	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%	kg/ day	%
Food waste	13.33	52.07	4	25.16	26.00	83.81	7.8	64.46	30.00	74.57	9	47.75	24.67	80.99	7.4	57.36
Gardens	--	--	--	--	1.00	3.22	0.4	3.306	--	--	--	--	--	--	--	--
Paper	2.13	8.31	2	12.58	1.06	3.43	1	8.264	4.26	10.58	4	21.22	3.83	12.58	3.6	27.91
Plastic/Polythene	4.18	16.34	4.1	25.79	2.96	9.54	2.9	23.97	1.68	4.19	1.65	8.75	0.00	0.00	0	0
Dirt, Ashes, Brick Chips	--	--	--	--	--	--	--	--	0.00	0.00	0	0.00	0.00	0.00	0	0
Glass/Bottle	--	--	--	--	--	--	--	--	3.67	9.13	3.6	19.10	0.00	0.00	0	0
Metal/Tin	3.51	13.69	3.4	21.38	--	--	--	--	--	--	--	--	1.96	6.43	1.9	14.73
Rubber	1.84	7.17	1.8	11.32	--	--	--	--	--	--	--	--	--	--	--	--
Leather	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Wood	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Textile	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Battery	0.62	2.42	0.6	3.77	--	--	--	--	0.62	1.54	0.6	3.18	--	--	--	--
Aerosol Can	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	25.61	100	15.9	100	31.02	100.00	12.1	100	40.23	100	18.85	100	30.46	100	12.9	100

APPENDIX II: QUESTIONNAIRE

Integrated Solid Waste Management of Gazipur City focusing on 3R Concept

(English Translation)

Date:	
Name:	
Age:	
Educational Qualification:	
Family Member:	
Earning Member:	
Average monthly income:	

Onsite segregation & storage	1. What do you use for storing household waste? a) Dustbin b) Polythene/bag c) Open space d) Throw away 2. If dustbin, what type of dustbin you use? a) Plastic b) Metal c) Others 3. How many baskets do you have in your house? a) One b) Two c) More than two 4. If more than one, then how you store the waste? a) Separated b) Mixed 5. How do you dispose pet bottle/ container/water bottle/can etc.? a) with kitchen waste b) in separate bin c) throw out d) reuse e)sell 6. How to you dispose hazardous waste (battery, spray bottle, knife etc.) a) with kitchen waste b) in separate bin c) throw out d) sell
Primary Disposal	7. Where do you dispose the waste? a) door to door collection b) drop at nearby dustbin c) Throw out d) not specified 8. Do you pay monthly for this? a) No b) less 100 taka monthly c) 100-200 taka monthly d) More than 200 taka monthly 9. Do you agree to pay for door to door collection? a) Yes b) No c) If reasonable
Waste Management Concept	10. If City Corporation provides you multiple bins to store waste separately, would you prefer to do it? a) Yes b) No c) May be 11. Which type of disposal system you prefer? a) door to door collection b) dispose to dustbin c) Any one 12. City corporation dump the collected waste in an open place, is it right? a) Yes b) No 13. If No, then why? [to check the knowledge of pollution], the interviewer will select any of the following options based on the answer. a) environmentally aware b) not aware c) moderately aware

APPENDIX III: Comprehensive Spreadsheet for ISWM System Evaluation at source

Spreadsheet for evaluation of collection at source (From household, community bins, bazaar etc.)

Collection Vehicle ID.: | Capacity (ton): | Driver's/Collector's Name:

Designated SDS No. & Location:

Date:

Trip No.	Location	Waste Collected in kg (to be measured in SDS while unloading)												**Total (kg)**
		Household				Community Bins				Other Sources				
		Organic	Paper	Plastic	Others	Organic	Paper	Plastic	Others	Organic	Paper	Plastic	Others	
	Total (kg)													

Signature of the Driver/Collector

Signature of the Supervisor at SDS

APPENDIX IV: Comprehensive Spreadsheet for ISWM System Evaluation at SDS for Receiving Waste

Spreadsheet for incoming waste evaluation at SDS

SDS No.: | SDS Location:

Date:

Vehicle ID	Trips per day	Incoming waste (kg) from primary collection vehicles				Incoming waste (kg) from other sources				Total Organic Waste (kg)	Total Recovered Waste (kg)				
		Organic	Paper	Plastic	Others	Organic	Paper	Plastic	Others		Paper	Plastic	Glass	Leather & Rubber	Others
Total															

Signature of the Supervisor at SDS

Conservancy Officer

APPENDIX V: Comprehensive Spreadsheet for ISWM System Evaluation at SDS for waste disposal

Spreadsheet for transferring waste to final disposal site or recovery facility															
SDS No.:			SDS Location:												
Date:															
Vehicle ID			Organic waste transferred to final disposal site						Waste sold/supplied to recycled industry						
	Trip no.	Trip time	Capacity		Organic waste carried		Total trips/day	Total organic waste transferred (ton)	Paper	Plastic	Glass	Leather & Rubber	Others		
			ton	m^3	ton	ton/m^3			ton	ton	ton	ton	ton		

Signature of the Supervisor at SDS

Conservancy Officer