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Municipal Solid Waste Management in the Kingdom of Bahrain:

Practices and Way for Sustainable Performance

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Declaration

I, Mariam Mohammed Abdulla Al-Ansari, hereby declare to the best of my knowledge, that apart from supervisory input and suggestions from my thesis assistant professors supervisors, this thesis is my own work and that all literature used and all information gathered from concerned parties been appropriately acknowledged, cited and referenced in accordance with the standard referencing practices.

I declare that this thesis has not been submitted for any degree to any other academic institutions.

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Abstract

The MSWM system in the Kingdom of Bahrain was evaluated comprehensively to identify its weaknesses and gaps. In addition, it quantified the current MSW generation, and projected the future generation, based on per capita generation. The MW landfill available spaces/volume and remaining lifespan were quantified for different recycling and compaction scenarios.

It was found in the conducted research that MSW disposal at Asker landfill increased by 74.421% from 1034921.1 tons in 2005 to 1805124.2 tons in 2016 (in 11 years), with a growth rate of 6.77%. This increase was associated with an increase of 65.69% in the disposal quantities of the DWS for the same period that was also associated with an increase of 54.17% in the population size.

An estimation of the remaining lifespan of the landfill based on different scenarios was found by using the available data and a mathematical modelling. It was shown that by the mid of 2018, Asker landfill site will reach its carrying capacity for the current baseline scenario, and therefore the current practice is considered unsustainable for handling the future MSW generation in the Kingdom of Bahrain.

A sanitary landfill must be considered as an urgent top priority action plan for the Kingdom of Bahrain was revealed, in order to cope with the near future MSW generation. In addition, the management of the already segregated MSW streams received at the landfill site can be relied on within the country's current capacity (e.g. C & D building waste, dead animals, WT) as a short-term work plan that can be initiated as a first step towards the a holistic management of this sector. Furthermore, improving the MSW compaction

efficiency at the landfill site as a short-term action plan would result in expanding its lifespan by a remarkable outcome.

The MSW disposal should not be relied solely on the disposal at sanitary landfill dedicated to such wastes; the principles of waste reduction, reuse, recycling and recovery should play a key role in the management of this sector within a long-term action plans.

Dedication

To ☺ ☺ ☺

Bahrain

My Late Father "God Bless His Soul"

My Mother "God Safeguard Her"

My Brothers and Sister

Dr. Hanan Albuflasa

My Friends

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Mariam Mohammed Al-Ansari

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Abbreviations

C & D	Construction & Demolition
CIO	Central Informatics Organization
DWS	Domestic Waste Stream
GDP	Gross Domestic Product
MoWMAUP	Ministry of Works, Municipalities Affairs, and Urban Planning
MOI	Ministry of Interior
MW	Municipal Waste
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NGO	Non-Governmental Organization
SCE	Supreme Council for Environment
TDF	Tyre Derived Fuel
UNEP	United Nation Environment Program
UNSD	Unite Nations Statistics Division
UoB	University of Bahrain
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WT	Waste Tyres

Chapter One

Introduction to the Study

Chapter 1

1.1 Introduction

Waste generation is a natural phenomenon of the life in earth, and Municipal solid waste (MSW) is just one type of waste generated, among others. This phenomenon has come up with a cost on the environment and its natural resources; where the daily practicing activities depend on extraction and utilization of huge volumes of resources to support it, and where most of these resources are landfilled after its consumption - as waste - without benefiting from these utilized resources.

MSW is an unwanted material that generally composed of food, paper, wood, fabrics, diapers, rubber, leather, plastics, metal, glass, and electronic refuses (Guerrero et al., 2013). The generators of the MSW can generally be classified as residential, commercial, institutional, industrial, C & D building waste and agricultural activities. Municipal Solid Waste (MSW) is one of the observable indicators of nation's sustainability, and its management is a key element for achieving sustainability.

MSW generation rates show a direct and positive correlation with population growth, economic development, and lifestyle modernization; this fact makes MSW management (MSWM) as one of the challenges facing countries, in the process of its collection, transportation and final disposal (UNEP, 2005). As per a study conducted by the World Bank, around 1.3 billion tons of MSW have generated annually worldwide, and by the year

2025 it is expected that the generation will reach to around 2,200 million tons annually (i.e. almost doubled) (Hoornweg & Bhada-Tata, 2012).

Inadequate waste management can create risks to the environment (Sarker, 2012), public health and as consequences may cause a negative impacts on the economy and the development plans as a whole (WHO, 2007); therefore the need for MSWM covering the tasks of generation, collection, transportation, processing for re-utilization and recovery and final sanitary disposal has become an important element for the country's sustainable development.

Traditional MSWM covers the tasks of waste collection, transportation, and disposal at landfills (Gotoh, 1989; Kollikkathara et al., 2009), this traditional management deals with the MSW as a problem that need to be landfilled rather than to be reduced and benefited from (Buclet, 2002); however, concerns regarding resource depletion and the requirement for their conservation have led to a calls for minimizing waste generation as a whole not only the MSW, and have led to calls for finding ways to recover the resources (i.e. materials and/or energy) from the waste streams not only the MSW, as the resources recovery from waste helps in minimizing the use of the natural resources and consequently reducing the depletion of the resources, and the requirement for disposal of used resources.

As a result the traditional concept and tasks of MSWM has evolved and become focused on reduction, reuse, recycling, energy and materials recovery and final sanitary disposal of streams that are categorized as non-recoverable (i.e. sustainable MSWM) taking into consideration the environmental, public health and acceptance and the economical aspects related to the tasks (Bhide & Sundaresan, 1983; Kollikkathara et al., 2009).

Nowadays, waste is considered as a resource and not as rubbish with no benefiting value (Zaman, 2010). Waste processing for re-utilization purposes can reduce resource consumption and can reduce waste landfilling, thus can bring economic benefits through materials recovery and through a reduction in resource extraction requirements for producing new products from virgin resources (UNEP, 2010), in addition, it can save land areas requirements from diverting the waste from final disposal at landfills.

In Bahrain, MSW generation quantities - based on MSW quantities delivered to the Asker landfill site - have been increasing over the past years, and this is mainly due to the population growth and the country economic development (Al. Ansari, 2012); In addition the change in Bahrain's population habits towards consumerism due to the change in the lifestyle has also contributed to the increase in MSW generation quantities. The huge amounts of MSW being generated become a challenge for the government in how to properly handle the growing quantity of MSW generated through daily life.

The importance of handling the MSWM is recognized, and the government has - up to date - secured financing to cover the operation costs of the MSWM for maintaining a hygienic living standard. However, till date, the management of the MSW in Bahrain is based on the collection, transportation and landfilling in an unsanitary landfill, that is under the responsibility of the Ministry of Works, Municipalities, and Urban Planning (MoWMAUP).

Two of the most challenging concerns regarding the current management system in Bahrain (among others) are:

- The rarely practicing of segregation activities (for the purposes of reusing, recycling and processing for resources recovery), and
- The high dependence on landfilling for the final handling of MSW. For the past 11 years, an average of 3888.8 tons per day of MSW is transported by private contractors to Asker landfill site - the only landfill site dedicated for municipal waste in Bahrain - where it mixedly landfilled.

These two concerns resulted in failing to enhance the prevention, reduction, re-using, recycling, and treatment for resources recovery in the Kingdom; these concerns are also challenged with the continuous increase in MSW generation. The concerns regarding the MSW management in the kingdom of Bahrain are due to several factors, such as (Supreme Council for Environment, 2015):

- Population growth;
- Accelerated economic development;
- Population high living standard (i.e. consumerism habits of the people);
- The MSW and specifically the DWS is mixed with other waste (e.g. hazardous waste), as no formal segregation is being practiced in the country, and what makes the situation more complicated is the mixed landfilling of all MSW streams at the landfill site;
- The dependence on landfilling, where the existing MSW landfill site is expected to reach its capacity in coming few years, keeping in consideration the country limited size and land availability, hence the

existing landfill site will not be able to accommodate the future MSW generation for long time period;

- Expansion of the urban areas; An approved plan by the government for the establishment of a new residential area in the next few years are near the existing Asker landfill site;
- The nearness of the landfill to residential area;
- The minor existence of MSW formal, organized segregation practice – either at the source of generation or at disposal site – except for some recyclable such as paper, aluminum cans, and plastic bottles which are being sold to the private unorganized collectors (i.e. the MSW are mixed by using a common collection and transportation system);
- The limited availability of facilities to recover resources or treat the MSW generated;
- The costs associated with the collection, transportation, disposal, and landfill operations;
- Not all waste streams entering the Asker landfill site (i.e. site that is dedicated for MSW streams) are classified as MSW as per the current regulations (e.g. dead Animals).
- Criteria for sanitary landfills have not been practiced, as no lining system provided for the site, no leachate drainage layer, no gas collection system and no groundwater monitoring boreholes provided at the site.

- Generation of landfill gases that contribute to global climate change, and pose a fire hazard at the site.

- Lack of legislation enforcing the prevention, reduction, resources recovery from the waste.

- Lack of public awareness regarding resources wastage.

MSW generation quantities continue to increase, and landfilling of MSW continues to be the dominant disposal method in Bahrain. The MSWM and specifically the landfilling in the country is going through a critical period, due to - mainly - scarcity of land area availability and the unavailability of suitable facilities to process the generation of the MSW, in addition to the unsanitary practice of landfilling.

The landfilling continues to be an area of concern in relation to environmental, economical and social issues, as the trend MSW generation difficult to be avoided, therefore careful effective management plans and practices are extremely needed in Bahrain now.

Taking population growth as an example of one factor affecting the MSW generation and management in Bahrain (i.e. as a factor contributing to the MSW generation and hence disposal rates at the landfill site); it can be said that with the growing population that is also associated with the current inconsiderable and unreliable public participation in the reduction practices - through source segregation - which is also linked with their increasing consumerisms habits, the availability of lands for continuous landfilling practices is limited. And this raise an urgent need for minimizing the quantities of waste going to landfills.

After the current expansion for the Asker landfill site in July 2016, replacing the existing MSW landfill when it reaches it carrying capacity become difficult and unsustainable solution for the kingdom of Bahrain, therefore the government must plan for a sustainable solution for its waste management by avoiding landfilling as much as possible, and by providing sanitary one for unavoided waste streams.

The MSW is a phenomenon of human life, therefore it is expected that this waste will continue to be generated till humanity exists; thus the current MSW management system in Bahrain need to be analyzed prior to recommending any improvements.

This research will focus on the issue of MSWM with the emphasis on estimating the existing landfill capacity in order to find options for extending is lifespan as the first step towards holistic improvements in the MSWM system.

1.2 About Kingdom of Bahrain

Kingdom of Bahrain is an archipelago of 36 natural islands, shoals, and small islets that vary considerably in area and structure; and as per Bahrain Central Informatics Organization (CIO) Bahrain is having a total area of 8269 Square Kilometers (land area of 769.59 Square Kilometers, sea area of 7499.41 Square Kilometers), Bahrain is located in the middle east that is located on the western central shores of the Arabian Gulf, to the east of the Kingdom of Saudi Arabia, and to the North-West State of Qatar,

bounded by latitude 25° 32 and 26° 20 North, and longitude 50° 20 and 50° 50 East (Central Informatics Organization, 2015), Figure (1).

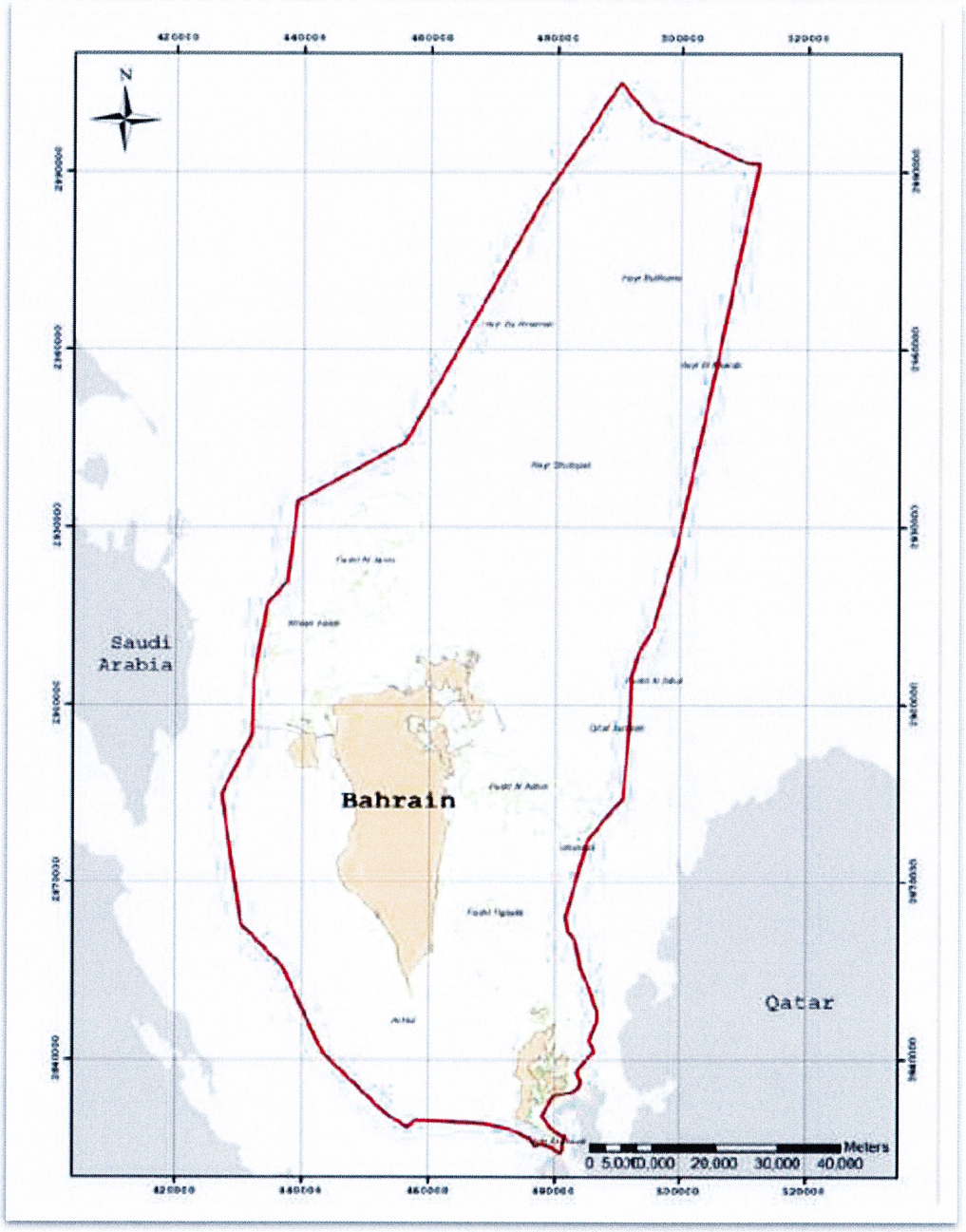


Figure (1)

Kingdom of Bahrain Islands and Surrounding Territorial Waters

(Bahrain Centre for Studies and Researches, 2006)

Bahrain land area has increased since 1970's through marine reclamation to satisfy the need of the accelerated population growth rate, the increase in industrial activities to support Bahrain economic development, along with the need for housing and infrastructure projects.

Numerous Bahrain northern and north-eastern coastal areas were reclaimed for residential, industrial, and recreational purposes; As a result, the land area has increased from around 661.09 square kilometers in 1952 to 769.56 square kilometers in 2014 (Central Informatics Organization, 2015), as clearly shown in Figure (2).

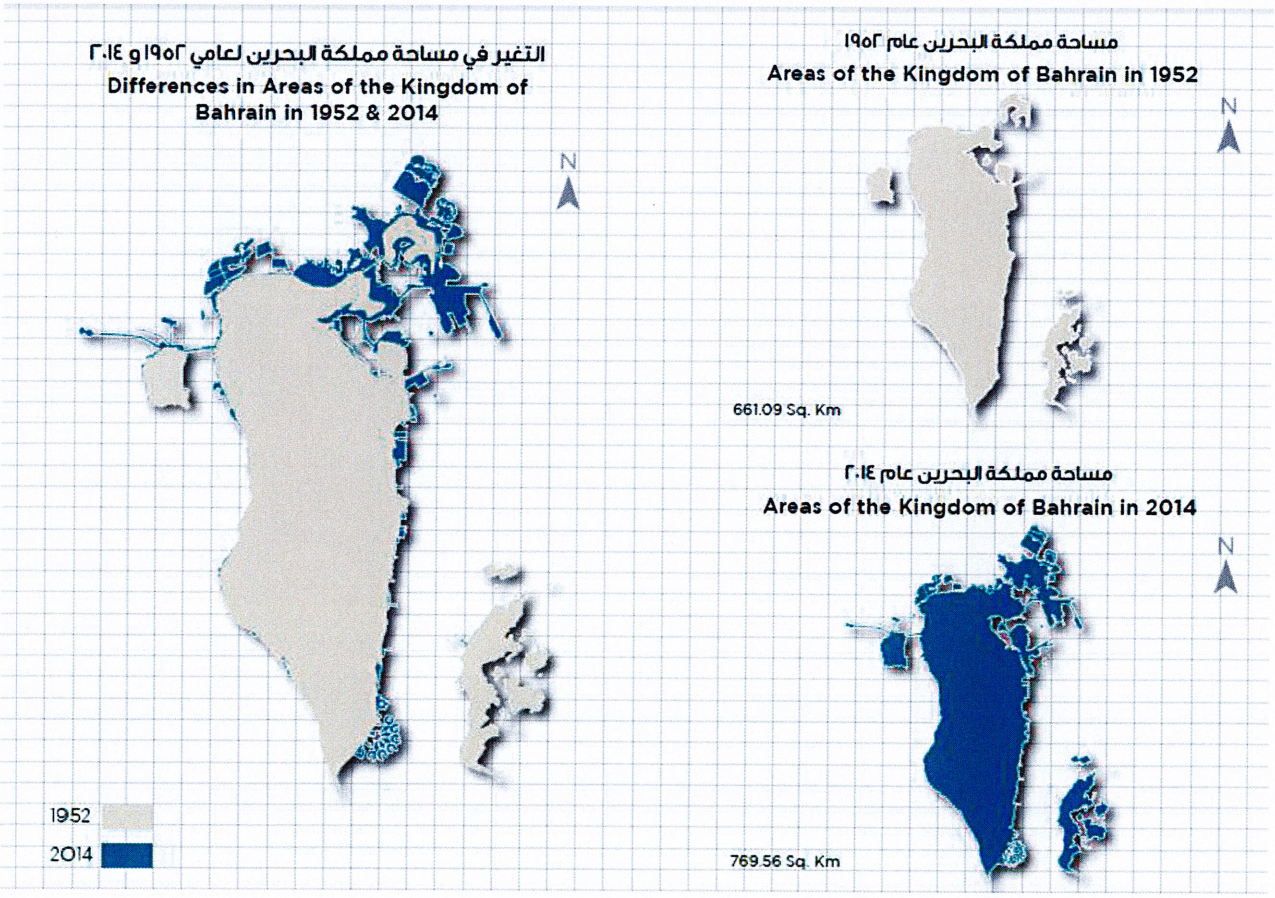


Figure (2)

Kingdom of Bahrain Increase in Land Area (Central Informatics Organization, 2015)

The climate in Bahrain is arid and hot in summer with a high percent of humidity, and mild in winter with sparse rainfall. Vegetation is of the limited extent where terrestrial land is predominately desert with limited inland waters.

The terrestrial ecosystem is dominated by the desert environment in Bahrain, except a slight fertile belt along the northern and north-western part of the Kingdom (Larsen, 1983). Due to the development, valuable agricultural land in Bahrain has been lost. Many agricultural lands have been placed with residential and industrial areas as the demand has continued to accommodate housing units and economical/industrial facilities (Supreme Council for Environment, 2015).

Marine ecosystem in Bahrain is diverse with coral reefs, mangrove, mudflats, seagrass beds, and swamps (Sheppard, et al, 1992). As an example, sea-grass beds provide nursery grounds and food for turtles, dugongs, shrimps and a variety of other marine organisms (Bahrain Centre for Studies and Researches, 2006).

Bahrain has achieved a considerable level of development socially and economically; and as a small country undergoing high socio-economic growth, challenges remain regarding the sustainable management practices to ensure the environmental elements are appropriately protected.

The population of the Kingdom of Bahrain is considered as one of the densest population in the world, where the density reached to 1705 person per square kilometer in the year 2014 (Central Informatics Organization, 2015). Most of Bahrain population is living the northern part of the country, mostly along north-eastern part, knowing this fact (i.e. the concentration of

the people in one part of the country), a careful consideration should be taken from the government regarding the future development plans for the country.

Bahrain government has made significant improvements in raising the living standard for the country's population by investing in basic services such as healthcare, education, sewage and waste management ... and so forth. As a result the country's population is increasing in a continuous trend, where the population increased from 621 thousand person in 1999 to 1.316 million person in 2014, and it is expected that the population will reach 1.593 million persons in 2020 and 2,257,000 million persons in 2030 (Central Informatics Organization, 2015). The population projections for the Kingdom of Bahrain for the period from 2015 to 2032 were gathered from the Central Informatics Organization (CIO) and used for the purpose of this research.

The economy of the Kingdom of Bahrain is considered as diversified economy, and is rapidly shifting from oil based to economical, industrial and services based country. Bahrain's economic growth is 5% annually on average. The non-oil sector contributed to 79.2% of total GDP in 2013. The main sectors that contribute to GDP are (Ministry of Information Affairs, 2014):

- Oil sector (20.8% of the Total GDP)
- Financial institutions (16.7% of the Total GDP)
- Manufacturing industries (14.5% of the Total GDP)
- Transport and communications (6.8% of the Total GDP)

- Construction works (6.6% of the Total GDP)
- Real estate (4.1% of the Total GDP)
- Hotels and restaurants (2.4% of the Total GDP)
- Other service (18.7% of the Total GDP)

Bahrain government strategies and action plans to diversify the country economy has led to a stabilized economy that supports the development in the country.

1.3 Research Problem

Small land area, population growth, economic development, lack of treatment facilities, and the growth in consumerism habit of Bahrain population – due to the change in the lifestyle and lack of awareness - are causing a significant increase in MSW generation (Al. Ansari, 2012; Supreme Council for Environment, 2015).

Bahrain MSW disposal has peaked to around 1.8 million tons in 2016; that are landfilled at Asker landfill - the only existing landfill site in Bahrain that accommodates MSW - located in the southern governorate of the country.

The MSW quantity is expected to increase, as Bahrain government attempts to support its economic and social development through investing in the industrial and services sectors. Current landfill is assessed to be unsustainable for the Kingdom of Bahrain on a long term, due to the facts the landfill ground are not engineered as sanitary landfills, it emits gases and

produces leachate which affects soil and ground water where no collection system is provided for these streams.

The management of MSW is going through a critical situation and period in the Kingdom of Bahrain and represents a challenge for its government due to mainly high landfilling quantities.

The issues of the current operation of the landfill site are associated with wind-blown litter and dust, birds, pests and bugs attracted by waste, leachate generation, foul smells, greenhouse gases generation that contribute to global climate change and pose a fire hazard at the site in the long term (Supreme Council for Environment, 2015).

This MSW disposal system unavoidably could generate pollutants that migrate to the surroundings (i.e. soil, groundwater, surface water, and the ambient air); this can cause adverse impacts on the environment and to public health and property, and consequently can impact adversely the county's economy. In addition, the disposal of the wastes means wasting the possible resources attainable in the waste streams.

Therefore, there is an urgent need in Bahrain for a sustainable MSWM system. The Continuous disposal of the MSW rather than segregation and processing for the purpose of the re-utilization and thereby gaining benefits from them, is putting an urgent need for evaluating the current MSWM system performance in Bahrain, and puts an urgent need for the development of a sustainable MSWM system that can reduce the quantities of MSW going to the landfill, thus saves land space and at the same time creating social, economic and environmental benefits to Bahrain.

1.4 Research Questions

The questions that are expected to be answered at the end of this research are:

- What is the current state of the MSWM system in Bahrain (i.e. Generation, classifications, relevant regulations, the role of the concerned authorities, management practices, Asker landfill site, weaknesses, and gaps)?
- What is the main pressure on the country from the current MSWM system that needs to be enhanced?
- What are the problems associated with Asker landfill site?
- How long can the operation of Asker landfill site last applying different scenarios?
- What actions can be taken to extend the MSW landfill lifespan?
- What actions can be taken (recommendations) to improve the efficiency of the MSWM system in Bahrain?

1.5 Research Objectives

The increase in the disposal quantity of the MSW in the country that is associated with limited land area availability that is also associated with unreliable segregation activities, are the most the challenging issues in the Kingdom of Bahrain with regards to MSWM sector.

The aim of this research work is to investigate the state of the MSWM in the Kingdom of Bahrain with the emphasis on the existing MSW landfill site in order to explore its condition, specifically the estimation of its lifespan and carrying capacity, through exploring different scenarios for extending its lifespan as a first step towards a holistic improvements in the MSWM system.

In order to fulfill this aim, some sub-objectives have been incorporated to make the research aim clearer:

- Investigate the current scenario of the MSWM system in the Kingdom of Bahrain (i.e. Generation, classifications, relevant regulations, and the role of the concerned authorities, management practices, weaknesses, and gaps).
- Investigate the existing MSW landfill condition.
- Predict future MSW generation.
- Investigating the opportunities for extending the landfill lifespan through modelling different scenarios.
- Recommend action plans to improve the MSWM system in the country.

Scenarios for MSWM future will be presented in order to visualize the need for a change in the current system.

Hope this research can aid in quick and useful decisions regarding MSWM system in Bahrain.

1.6 Research Significance

This thesis is considered significant because the Kingdom of Bahrain generates great quantities of MSW; this waste is mostly disposed at Asker landfill site – the only dedicated landfill for MSW – with a minor segregation and collection practices for mainly exporting purposes. The capacity of Asker landfill site will not be able to cater the future MSW continuous generation. So, there is a pressing need for MSWM that minimizes the need for its disposal.

The time when the waste was just viewed as rubbish that had to be landfilled is gone, with the realization that the waste contains resources that can be processed for the purpose of its re-utilization, which in turn can provide economic and social benefits. MSWM is not just collecting, transporting and disposing of it; it is the tasks of its collection, transport, processing (i.e. reusing, recycling, treatment for recovery), and sanitary landfilling of remained unrecoverable materials.

Critical decisions have to be made and important actions to be taken; amongst them considering waste segregation either from the source or at the disposal site as a first step towards minimizing the landfilling practice, as the remaining area for the disposal are becoming shorter.

The capacity of the Asker landfill site will not be able to accommodate the future need for MSW handling. MSW generation with the population growth, the country ongoing economic and social developments, are expected to increase; thus, MSWM sector has become one of the major development challenges that need to be evaluated in order to investigate the opportunities for it enhancements to cater future generation, in order to

reduce the dependency on the landfilling practice and to minimize the adverse impacts associated with this practice on the environment, the society, and the county's economy.

In addition, one of the significant problems in managing the MSW in Bahrain is that the MSW is being landfilled mixed (i.e. dead animals, commercial, domestic, non-hazardous industrial rejects, Agriculture waste, construction and demolition building waste (C & D).

An Appropriate waste management is the effective utilization of resources and one of the most important elements of the MSWM system is waste streams segregation, and this element of waste management is rarely practiced in the country. In Bahrain, mixed MSW is still being disposed at the Asker landfill site, and such approach to the MSWM cannot be continued for a long time since as Bahrain is suffering from land scarcity in addition to other environmental, social, and economical consequences related to such practice.

Data and information availability regarding Bahrain's MSWM system is considered rare; few studies had been implemented in the Kingdom of Bahrain to analyze the management practices and to quantify the landfill lifespan.

Hope this research work will serve - as a reference - to the Bahrain government and to the researchers in this field, by providing a thorough assessment of MSWM in Bahrain, what the gaps and weaknesses associated with MSWM are, and specifically the Asker landfill site capacity.

This research will provide:

- Thorough baseline information on the current MSWM in the country.
- An alarm on the MSWM system gaps and weaknesses.
- A live model that can be utilized, by the researcher and the decision makers, to visualize the remaining lifespan of landfill area, to visualize the remaining space, and to visualize the required spaces for the future, for baseline scenarios and for different optional recycling and compaction action plan scenarios.

1.7 Definition of Terms

- **Waste:**

Materials that are not the product produced for the market (i.e. generated in association with the production of the main products and has no further use for its generator and need to be landfilled). Wastes can be generated through raw materials extraction, raw materials processing into products, consumption of products, and other activities (UNSD, 1997).

- **Municipal Solid Waste:**

Non-hazardous solid waste, that constitute of household wastes, food and vegetable wastes, offices rubbish, it also comprises of the wastes that can be composted that arise from residential, commercial and industrial areas, parks and recreational facilities, education and health facilities, social activities and does not comprise hazardous waste, as defined by SCE President Order No. 3 of 2006 amended by Order No.

7 of 2013 with respect to Hazardous Waste Management, Kingdom of Bahrain.

Municipal solid waste is also defined as an unwanted material where the responsibility of its handling (i.e. collection, transportation, and disposal/treatment) is managed by the municipalities' affairs of the countries. The MSW generally composed of food, paper, wood, fabrics, diapers, rubber, leather, plastics, metal, glass, and electronic refuses (Guerrero et al., 2013).

- **Municipal Solid Waste Management:**

Controlling the generation, collection, transport, processing, and disposal, managing and monitoring of municipal solid waste materials.

- **Landfill:**

A land area used to dispose of waste (Tchobanoglouset et al., 1993).

- **Resource Recovery:**

A process of obtaining useful material or energy from the waste.

- **Landfill gases (LFG):**

Gases generated due to the decomposition of organic materials in landfill sites. LFG is composed of nearly 50% methane (CH_4), 50% carbon dioxide (CO_2) and a small fraction of non-methane organic gases (US EPA, 2017).

- **Leachate:**

Liquids that flow through the stored waste materials within the landfill site. It combines the liquids that are present in the waste stream itself, the atmospheric humidity that is held by the waste materials, the infiltration of the groundwater and the precipitation (e.g. rainwater) that comes in contact with the waste material (Pichtel, 2005).

- **Waste Tyre:**

A tyre becomes a waste once it cannot longer be used even after retreading the tyre for transportation purpose - due to safety reasons - because of damage, defect or wear to the tyres; this definition covers passenger cars, race/competition cars, trucks, light trucks, buses, mini buses, aircraft, truck used for agriculture purposes, two-wheels (i.e. Motorbikes and bicycles), industrial trucks and off-road tyres (WBCSD, 2008).

Chapter Two

Theoretical Framework and Literature Review

Chapter 2

2.1 Introduction

All human activities are - mostly - associated with some kind of waste generation, of which the MSW streams are some. MSW generation is greatly related to the population growth, economic development and consumption pattern (Hoornweg & Bhada-Tata, 2012). The absence or weakness of an efficient and effective MSW handling system can worsen the environmental quality if not managed properly, which in turn can impact the human health, and consequently exert pressure on the economy and the development plans.

The definition of MSW differs between countries because the definition depends mainly on the country's legal definition and the handling management system of the waste streams. Generally, MSW is defined as waste streams that are generated from homes, commercial activities, offices and public institutions, and are managed by or on behalf of municipal authorities (Habitat, U. N., 2010).

With regards to the Kingdom of Bahrain legislations, MSW is defined as:

Non-hazardous solid waste, that constitutes of household wastes, food, and vegetable wastes, offices rubbish, it also comprise of the wastes that can be composted that arise from residential, commercial and industrial areas, parks and recreational facilities, education and health facilities, social activities and does not comprise hazardous waste.

This definition is legally legislated through SCE President Order No. 3 of 2006 amended by Order No. 7 of 2013 with respect to Hazardous Waste Management, Kingdom of Bahrain (Appendix (1)).

C & D, non-hazardous industrial (e.g. waste tyres (WT), sludge's generated by sewage treatment plants operations and by other operational facilities in the kingdom, and the bottom ash generated by medical waste and sewage treatment plants incinerators), dead animals and agricultural wastes, commercial wastes, in addition to domestic waste, are considered as part of solid wastes streams that are received and landfilled at Asker landfill site (i.e. practically its final handling is managed by the MoWMAUP).

Although, the waste streams that are landfilled at Asker landfill site is not in accordance with the definition specified in the SCE president order specified above; however, for the purpose of this research MSW will be referred to the waste streams that are received at the landfill site and managed there by MoWMAUP.

MSW composition is the most complex and heterogeneous waste streams; it comprises of food, furniture, papers, fabric/clothes, leathers, rubbers, metal scraps, packaging materials, glasses, dishes, plastics, wood and miscellaneous non-hazardous wastes.

Although MSW is mostly non-hazardous in its nature, it also comprises of residential, commercial, and institutional hazardous waste such as electronics, electrical equipments, medicines, lights ... and so forth; that can pose a hazard to the environment and public health (Tchobanoglous et al., 1993).

The awareness of the need for sustainable development of the earth and specifically its natural resources resulted in introducing sustainable waste management concept as part of the holistic development process, with an ultimate goal of ensuring the sustainability of the natural resources for future generations. Reports showed that waste streams can be processed, and can be benefited from in different ways (Morrissey & Browne, 2004); therefore, it should be considered as a resource that can provide benefits to the society, environment and the economy, provided that a proper management action plans are implemented.

2.2 Sustainable Development and MSWM

MSWM is among the most significant challenges being faced the countries all over the world towards the sustainable development of their resources.

MSWM is considered as one of the most important services governments provide for their population to ensure a hygienic living environment and conservation of their resources. The poorly managed MSW can pose threats to public health, can pollute the environment, and consequently can have a negative impact on the countries' economy and development as a whole. Therefore, the challenge that faces the countries in managing their MSW is the creation of a sustainable system.

Population growth, rapid economic development, and the rise in living standards of the communities, led to rising in MSW generation that is added to the quantities that already has been generated; and as a result caused

challenges for the countries for their management, especially with the limited land areas carrying capacity for handling the waste streams (Saeed, Hassan & Mujeebu, 2009).

The accumulation of the continuously generated MSW without being recycled or reused is reducing with time the ability of the environment for handling the quantities of waste - including MSW streams – that are continuously generated (Gertsakis & Lewis, 2003).

An increase in the natural resources consumption, and consequently the increase in the waste generation have been reported (Wenheng & Shuwen, 2008); this is another challenge faces the development sustainability. Natural resources provide raw materials for goods production and for services provision, that are essential for the economic development. Waste is directly associated with resource scarcity and causes adverse environmental, social and economical impacts.

Generation volumes of MSW that are associated with depletion of natural resources have shifted its management concerns from minimizing the risks to public health and environment into finding and implementing ways for handling wasted resources so that future generations not disadvantaged from resource scarcity (Chandak et al., 2010), and have encouraged the movement towards sustainable management practices (Rahimifard et al., 2009).

Reports showed the quantities of MSW generation is growing; in year 2002, approximately 2.9 billion capita in urban areas generated around 0.64 kg of MSW/capita/day, while in year 2012 around 3 billion capita in the urban areas generated around 1.2 kg of MSW/capita/day, and it is estimated

that by the year 2025 the generated amount will probably increase to around 1.42 kg of MSW/capita/day for 4.3 billion capita in urban areas (Hoornweg & Bhada-Tata, 2012). Global MSW generation is estimated to increase to 2.2 billion tons of MSW per year in 2025 from 1.3 billion tons of MSW per year in 2010 (Hoornweg & Bhada-Tata, 2012).

Wilson (2007) in his research (Development drivers for waste management), outlined three alarms that need action plans with regards to MSW management as follows:

1. Environmental Degradation: management of the issues related to pollution of air, water, and soil in addition to issues related to climate change and water scarcity.

2. Human Health: maintaining hygienic living conditions for human.

3. Resource Management: returning materials for beneficial reuse, to ensure productivity and food security.

MSWM is an issue of growing concern for sustainable development; the reasons attributed to this are the continuing challenges of (Ojeda-Benitez & Beraud-Lozano, 2003):

- The continually growing world populations.
- The continual economies development.
- The continual change of consumption patterns towards more consumerism habits.
- The scarcity of natural resources.
- The scarcity of land availability for disposal.

To the extent in which MSW keeps generating and natural resources are depleting the need for sustainable management practices become essential to ensure future sustainability, in order to minimize social, environmental and economic impacts (i.e. to ensure development, sustainability).

Sustainable development was brought into the world communal discussions and into the shared agenda for development in 1987; it is officially defined in the Brundtland Report - our common future - as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (The World Commission on the Environment and Development, 1987); it aims at ensuring continued economic development, providing a healthy living environment for people, and protecting the environment natural resources for current societies and for future generations (Pradhan, 2008).

Waste management is considered as one of the important elements that support the sustainable development (Ashley et al., 1999) as affirmed by the United Nation conference on environment and development in Rio de Janeiro in 1992.

In order for the MSWM system to be sustainable, it requires that the management of waste streams (i.e. Generation, storage, collection, transfer, treatment and disposal) to be operated within a cost effective system, in a way that ensures a healthy environment for the community and in a manner that ensures the safety and protection of the environment and its natural resources (Taiwo, 2009).

Nilsson-Djerf & McDougall (2000) outlined the sustainable MSWM system characteristics; where it should:

- Prevent depletion of natural resources (to ensure that the current generation are not consuming what should be left for the future generation)
- Prevent pollution
- Be accepted by the public and does not pose risks to their living environment
- Be economically manageable

Figure (3) shows the waste management - including MSW - involvement in the sustainable development.

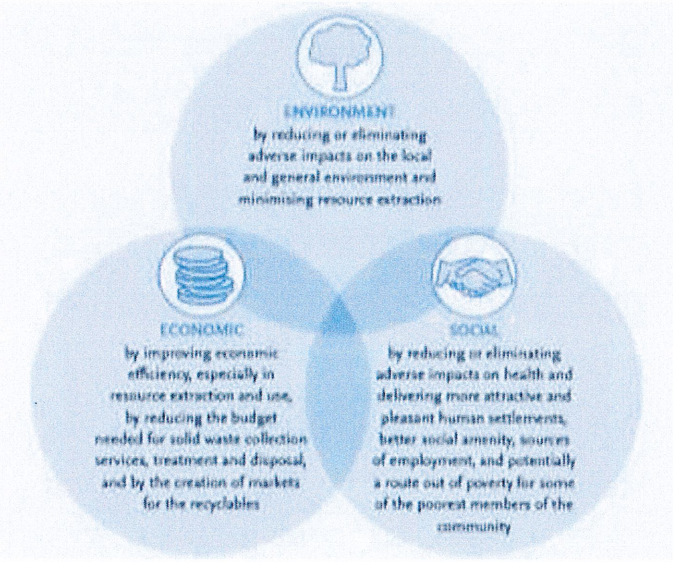


Figure (3)

Waste Management Involvement in Sustainable Development

(UNEP, 2013)

Traditionally, MSWM system covered the tasks of waste collection, transportation, and disposal at landfills (Kollikkathara et al., 2009); this traditional management is dealing with the waste as a problem that needs to be disposed of rather than to be reduced or benefited from (Buclet, 2002); waste minimization, recycling, and reuse waste does not receive considerable attention.

The traditional disposal of the MSW landfilling significantly occupies huge spaces of land resources and had impacts on these resources specifically in unsanitary landfill areas, this traditional practice of landfilling become an issue that matters the governments and communities.

However, the traditional of MSWM system has evolved. The need to conserve the limited natural resources has shifted the waste management practices - from just collecting and transporting the waste for disposal at landfill - to focus on waste prevention and minimization instead of just focusing on the disposal of the waste; Currently waste is considered as a resource with benefited value and not as garbage (Zaman, 2010), and requires changes in lifestyle, consumption and production patterns to gain benefit from it (Zarate et al., 2008).

Considering waste as a resource can reduce can reduce resource consumption and thus waste landfilling, thus creating economic benefits through materials recovery and through a reduction in resource requirements for the production of new products (UNEP, 2010).

The MSWM nowadays focuses on the elements of the waste management hierarchy (UNEP, 2005), that concentrates on the concepts of prevention/reduction, reusing, recycling, conversion (e.g. Energy and

materials recovery and treatment) and finally the disposal in sanitary landfills of unusable materials taking into consideration environmental aspects, public health and the economic feasibility (Bhide & Sundaresan, 1983) (i.e. Sustainable Municipal Solid Waste Management).

This evolves in MSWM practices - that are guided mainly by the waste management hierarchy - came in response to the scarcity and depletion of the natural resources, and increasing quantity and complexity of the MSW composition all over the world.

The basic aspects that have to be considered when planning for a sustainable MSWM system should take into consideration social, economical and environmental requirements, through the following practical management system elements:

- Generation;
- Collection;
- Transportation;
- Processing/Treatment; and
- Disposal

Sustainable waste management "that focuses on waste management hierarchy priorities" are implemented widely in the European Union and other developed countries; through by first eliminating or reducing waste generation; then finding alternative uses for the generated waste through reuse, recycle, recover; and finally disposing the residual waste in a safe sanitary manner Figure (4).

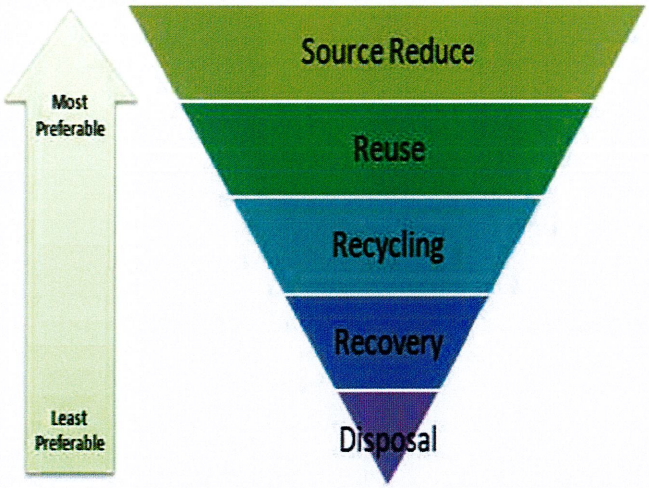


Figure (4)

Waste Management Hierarchy Preferences (Fagan & March, 2009)

Thus, the sustainable management of the MSW could be achieved by prioritizing - as practical as possible - the management process in accordance with the following waste management hierarchy preferences:

1. **Waste prevention/reduction:** This is the first practice required for waste management (the preferred practice).

   This practice encourages less utilization of materials - such as unnecessary packing materials - which results in less waste generation (fewer resources utilization), it also involves the use of clean technologies in producing products in which the generation of waste can be reduced; this approach conserves natural resources and reduces cost implications associated with further waste handling process and landfilling, and thereby reducing impacts on the environment and its sustainability.

2. **Waste Reuse:** This practice involves numerous/several uses of certain products in its original form (i.e. extending the lifetime of a product); this approach conserves natural resources and reduces cost implications associated with further waste handling process, reduce the requirement for avoidable landfilling, and thereby reducing impacts on the environment and its sustainability.

3. **Waste Recycling:** this approach can be practiced through reprocessing of a used product into a new product.

   This approach may be associated with costs, environmental and other implications; therefore, careful evaluation is needed before going for this option. However, in general, this practice reduces the need for landfilling if properly conducted after a proper evaluation.

4. **Energy Recovery:** This practice involves extracting energy and/or material from wastes; this helps in reducing volumes of wastes before landfilling, and may be associated with costs and environmental implications, therefore careful evaluation is needed.

5. **Sanitary Landfilling/Disposal:** The last and least preferred option when waste is generated is a final disposal of non-recoverable resources at the landfill sites that should be sanitary constructed.

This hierarchy is currently considered as the most effective guiding principle for managing any kind of waste streams including MSW. Although the waste management hierarchy has taken different forms with time, however, the management hierarchy has remained focusing on benefiting and making maximum use of the goods and generates less waste, with last and least preferred option of disposal/landfilling.

The waste management hierarchy sets out the preferred/sustainable practices sequences of waste management practices - including MSWM - from the most sustainable preferable to the least preferable one, with ultimate goal of reducing the waste that goes to the landfills by preventing waste generation and reduce waste generation, through treating the waste as resource - with a benefit value - rather than thing need to be disposed/landfilled.

The importance of moving the MSWM towards resources recovery is encouraged by the fact that this movement has positive impacts on both the environment and the economy if properly conducted after conducting viability studies that cover social, environmental, and economical aspects.

Recovery of resources from waste reduces pressure on natural resources and reduces the environmental pollution from producing goods from virgin materials, because of reusing the recovered resources (Craighill & Powell, 1996), and consequently reduces the volumes of waste that need to be disposed of/landfilled. Resources recovery reduces the requirements for landfilling, landfill sites consequently, and reduces the pollution associated with landfills.

Waste management hierarchy encourages the handling of waste streams - including the MSW - in sustainable manners without forcing strict practices.

While landfilling is the least preferred management option in the waste management hierarchy for handling the generated waste streams (including MSW); however, this option remained till now the main method for handling the continuous generation of the MSW in Bahrain.

2.3 Landfilling

MSW has the potential to pollute the environmental elements (air, water resources, and land), if the landfilling practice is not properly managed, thus affecting directly and indirectly human health and affecting negatively the economy and the development plans.

Tchobanoglouset et al. (1993), define the landfill as a land area that is used to dispose of waste. Thus, Landfilling is the practice of tipping the waste into the landfill.

Amongst the existing final waste (MSW not excluded) handling alternatives such as reusing and recycling, landfilling is still extensively practiced worldwide and remained part of waste management system. Landfilling is considered as the only final waste treatment method that can handle all type of materials that are presented in the waste streams, including MSW streams; it also considered as the simplest method when compared with other handling options (e.g. incineration).

The waste disposal in landfills usually goes through biological, chemical, and physical processes that lead to the production of leachate and landfill gases (Al-Jarrah & Abu-Qdais, 2006). Followings present a number of common problems associated with landfilling practice, as discussed by Lee & Jones-Lee (1993):

- Leachate migration that could negatively impact the groundwaters and the surface waters qualities; that consequently affect the public health, aquatic life, these medias aesthetics values, and as a consequence the economy.

- Landfill gases and odor emissions (e.g. methane, H_2S, CO_2); that could consequently affect public health, aquatic life, plants and other biological organisms, pose fire and explosions, and as a consequence the economy.

- Illegal discarding at roadsides and open areas near the landfills; that consequently affect the public health, areas aesthetic value, and as a consequence the economy.

- Traffic congestion of trucks delivering the waste streams; this consequently results in air pollution, affect the public health, and areas aesthetics value, and as a consequence the economy.

- Dust and messes blowing; that affects the public health and areas aesthetics value.

- Offer living areas for insects, vectors, rodents, and birds; that could affect public health, create a nuisance, and pose aircraft risk; and as a consequence the economy.

- Lessening properties value nearby landfills and across the passage roads of the trucks delivering the waste streams.

In many countries - Bahrain is part of - landfilling is practiced by discarding the MSW streams into a pit/hole, where there is no lining system, no leachate and landfill gases capturing systems are provided, and where no monitoring system is placed at the site to control any hazard contamination at the proper time.

In order to avoid any potential hazards posed by disposal/landfilling, sanitary landfilling have been introduced for the sound final handling of unavoidable waste streams.

Engineered sanitary landfill has been recognized for solid wastes landfilling purposes – including MSW streams – to eliminate or at least reduce the hazards to the public health or the environment of unsanitary landfilling. The sanitary landfills confine the solid wastes into small spaces that are lined, and cover it with a soil layer at the end of each operation day; also leachate and landfill gases capturing systems are provided (US EPA, 2017) Figure (5).

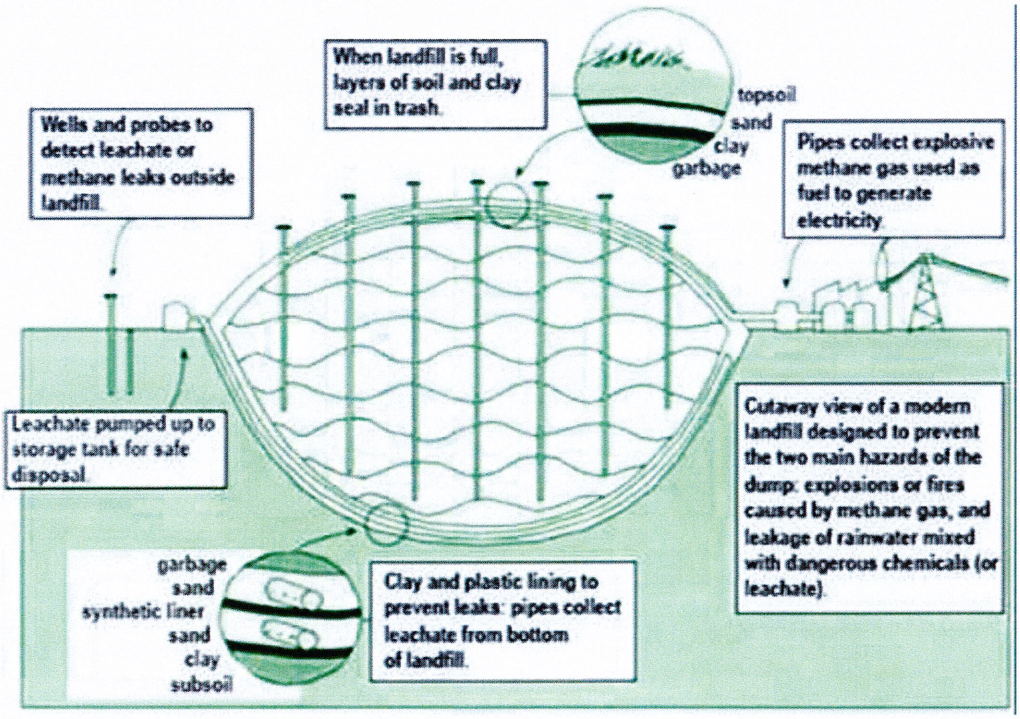


Figure (5)

Sanitary Landfills (US EPA, 2017)

2.4 Waste Sector in The Kingdom of Bahrain

The wastes generated in the Kingdom of Bahrain are classified into the following three categories as per the country legislations and management system practices:

1. Municipal waste, which is managed by the MoWMAUP in collaboration with administrative governorates municipalities, SCE, and the private sector.

2. Industrial waste, which is managed by SCE in collaboration with MoWMAUP, and the private sector.

3. Healthcare waste, which is managed by the Ministry of Health in collaboration with SCE, MoWMAUP, and the private sector.

The common practices for final handling of wastes generated in the Kingdom are landfilling.

Bahrain government manages two landfill sites in the country, one landfill site is located in Asker area that is dedicated for unsanitary landfilling of non-hazardous waste generated in the country (i.e. Asker landfill site is currently the only landfilling area in Bahrain dedicated for the final handling of MSW); and the other landfill site is located in Hafeera area (near Asker landfill site) dedicated for sanitary landfilling of hazardous wastes generated in the country.

In addition, with regards to waste handling/management practices in Bahrain; there exists additional practices that deal with some streams of the MSW, as following (Supreme Council for Environment, 2015):

- Few operational waste management facilities in Bahrain, for recycling of used oil (for the purpose of re-usage in Bahrain and for exporting).
- Extraction of metal scrap (mostly aluminum) for exporting.
- Recovery of plastics.
- Collection, compaction, and exporting of paper.
- Composting of mixed organic, garden and wastes animal manure has started in the Kingdom in 1997 and still operated on a very small scale for producing organic fertilizers for landscaping and farming applications in the Kingdom.

Al Sabbagh et al. (2012) in her paper (Resource management performance in Bahrain: a systematic analysis of municipal waste management, secondary material flows, and organizational aspects), and Al. Ansari (2012) in his paper (Municipal solid waste management systems in the Kingdom of Bahrain); both presented a performance review of MSW management in Bahrain. The researchers revealed some inadequacies in the management system, mainly:

- Lack of legislations.
- Lack of cooperation between concerned parties (authorities, the private sector, NGO's, users).
- Lack of funding, lack of MSWM facilitation corridors (i.e. collection, transportation, and disposal).
- Limited recycling facilities.
- MSW is not considered a concern to Bahrain's public.
- Heavy lack of waste prevention, reduction, and recycling efforts.
- Municipalities for public awareness campaigns to encourage waste reduction, reuse, and recycling make limited efforts.

From a financial point of view, Al Sabbagh concluded that the MSW management system appears to be stable, with very low percentage of the total cost spent on environmental control of waste disposal, and there are no incentives and no budget for diverting wastes from disposal to recycling.

Both researchers in their papers concluded that a bulk of MSW being landfilled in a controlled, but not a sanitary engineered landfill. Moreover, specifically, Al. Ansari (2012) reported the concerns associated with the MSW landfilling practice at Asker landfill site, which need to be addressed to avoid negative future consequences, those concerns are:

- The absence of site planning.
- The lack of funding for site improvements and new site equipment's.
- The unreliable cellular tipping practice.
- The unreliable MSW covering practice
- The generation of landfill gases.
- The generation of leachate generation.
- The existence of fire risks.
- The existence of bird hazards.

Al Ansari (2012), also evaluated the generation quantities of MSW in relation with population growth, and economic growth (e.g. country Gross Domestic Product (GDP) and National income - as factors of economic growth), and have revealed a positive proportional relationship between these factors and the MSW generation and specifically the DWS, and thus imposing further pressure on the country to manage this waste streams.

In addition, Al. Ansari (2012) in his paper (mentioned above), showed - through surveying Bahrain governorates - that the majority of surveyed

residents are satisfied with the MSWM services provided in the country except for middle and northern governorates where the respondents of this two governorates showed their dissatisfaction with rubbish bins conditions capacity and location, also the surveyed residents made some recommendations with regards to improving the containers condition, capacity, locations, frequency of sweepning and collection, enhancement of monitoring and inspection activities, and initiating public awareness campaigns.

In relation to the waste management sector in the Kingdom of Bahrain, its worth to generally refer to the management of the hazardous waste management in Bahrain to reflect that this type of waste is being managed separately.

The management of healthcare waste is under the responsibility of the Ministry of Health in coordination with SCE, where the SCE is the responsible Authority for permitting the strategies of handling this type of waste in the kingdom, permitting the treatment technologies, permitting healthcare waste transporters, in addition SCE is responsible for monitoring the emissions to the air and the management of bottom and fly ashes generated from the healthcare waste incineration - that is operated in the country since the year 2000 till date by a private sector.

Whereas, the hazardous industrial wastes are being managed by SCE, where most of this type of waste is being landfilled at the Hafeera Landfill Site (i.e. The landfill site that is dedicated for the disposal of the hazardous waste generated in Bahrain), and some are being treated under the supervision of SCE or transported outside the country also under the supervision of SCE and in accordance with the 1989 Basel Convention on

the Control of Transboundary Movements of Hazardous Wastes and their Disposal Procedures.

In addition, there is one private landfill site in the Kingdom being operated by the Bahrain Petroleum Company (BAPCO) dedicated for their oily waste/sludge, and few pits/sumps located at Bahrain Oil Field operated by TATWEER Petroleum Company and Bahrain National Gas Company (BANAGAS), where SCE monitors these sites in terms of pollution control.

2.5 Summary of the Literature Review

The review of the literature on the MSW and its management aspects was the first major step in identifying, synthesizing, and integrating relevant topics related to this research work.

Both online and written documents were searched and reviewed for the following topics combinations: municipal solid waste definition and contents; waste/municipal solid waste management practices, challenges and hierarchy, sustainable development and municipal solid waste; waste/municipal solid waste generation and factors affecting the generation, waste/municipal solid waste disposal/landfilling; landfills, waste/municipal solid waste legislations; waste/municipal solid waste projections; waste/municipal solid waste management scenarios approach for evaluating future prospectives, waste/municipal solid waste model development and mathematical equations, critical analysis; waste sector in the Kingdom of Bahrain.

The literature related to the scenarios approach, critical analysis, MSW projections, mathematical equations, model development, is comprehensively detailed in the relevant sections in chapter three for the purpose of easing the description and understanding the methods implemented in analyzing the Kingdom of Bahrain case.

The literature review was used to develop the analytical framework for this research, specifically in critically analyzing the current MSWM system, and in projecting future MSW generation, scenarios construction, model development, and scenarios analysis.

Chapter Three

Methods and Procedures

Chapter 3

3.1 Introduction

For the Kingdom of Bahrain, the need for a sustainable MSWM system is an urgent matter, mainly due to its small land area associated with high population size and the accelerated economic development. The MSWM strategy for the kingdom, up to writing this thesis, is not announced nor approved by the government, and hence no targets are specified.

Nowadays, the MSWM systems comprise of interrelated practices aiming at minimizing the disposal options and shifting the practices towards waste re-utilization through reusing, recycling, and processing for resources recovery. Such shifting in actual practices requires baseline data and information to aid the decision making on the needed actions to enhance the weakness of the existing system.

Therefore, this research was conducted mainly to understand and assess the current MSWM system in the Kingdom of Bahrain to identify the challenges, opportunities and hence recommend what needs improvement in the current system.

The research was conducted through an extensive analysis of the current system and developing scenarios to determine the sustainable alternatives for Bahrain.

A descriptive qualitative method to describe the current system was applied in this research; additionally, this research applied a quantitative method to present the quantities of the MSW being disposed at the country

landfill area/space available, and to project both the quantities expected to be generated, the life span of the landfill and space required or disposal. The quantitative method help to forecast the generation growth of MSW and landfill area availability and lifespan for the coming years.

Site visits and interviews with officials were also conducted as the primary data collection to disclose the actual condition of the current management system.

Also, scenario development method was employed in this research to draw a picture of what will the situation be in future through. Scenarios planning and analysis is a methodology that is used to explore the future consequence of a change in the current practices (i.e. to present how the future of an issue may present based on "if" another approach – to the current - is implemented) (Kahn &Wiener, 1967). This methodology was implemented in this research, to explore the consequences of a decision that has to be made now.

3.2 Application of Scenarios Methodology in the Assessment of Future Plans

Developing methodologies to examine complex issues related to the sustainable development, such as waste management systems is essential. The main challenge that faces the sustainable development is examining future pathways under complex and uncertain conditions (Swar, Raskin & Robinson, 2004). The population is growing and the economy is developing, and if no actions were taken, this will lead to further pressure on the existing

MSW management system. In order to estimate the consequences of the growing MSW generation, scenarios planning and analysis methodology were applied to assess how the future might unfold.

The Scenarios are generally defined as a description of future consequence that results from the past and current decisions (Kahn &Wiener, 1967). Scenarios are constructed in order to visualize the future consequences of a change, and based on scenarios modelling outcomes plans will be prepared. The scenarios methodology does not predict the future (i.e. gives only one option for the future), however, it allows for considering a range of possible futures Figure (6); therefore, it has been recognized as one of the best application to examine future pathways (Swar, Raskin & Robinson, 2004), that enables decision makers to take a decision for changes based on knowing the past and current situations in order to reach a better future related to the issue of concern.

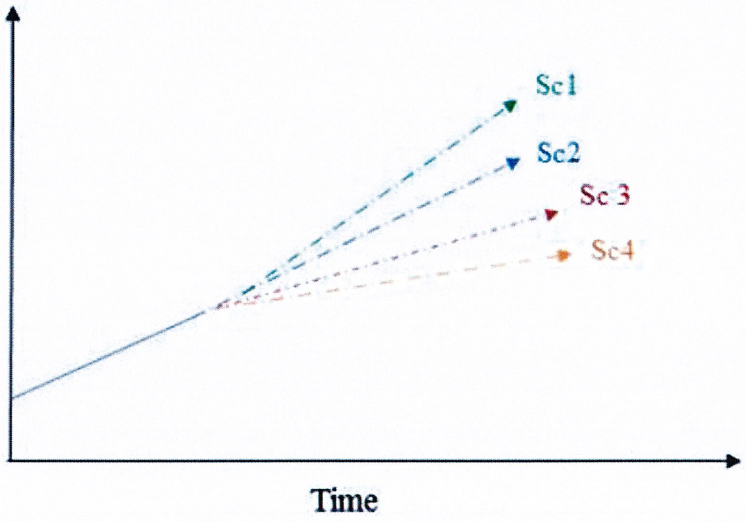


Figure (6)

Scenarios Concept

The use of systematic scenarios methodology has started as a method for army planning issues post the second world war during the 1950's; then this approach was further developed during 1970's and used in the business sector by Royal Dutch Shell Petroleum Company (Lorenz, 1990).

After that, this methodology started widely systematically used as a valuable strategic planning tool starting after the 1992 Rio conference on environment and sustainable development, to address sustainable development concerns that are associated with population growth, production and consumption patterns, waste generation and environmental impacts ... and so forth.

This methodology is being applied for different purposes and in various sectors such as water resources management, climate change, land use planning, transportation planning, waste management, crisis management (e.g. civil defense exercises), business developments, technology development and usage ... and so forth.

With regards to the waste management system, this methodology is considered as one of the effective tools towards developing a sustainable management system that is economically feasible, socially acceptable and environmentally viable (Nilsson-Djerf & McDougall, 2000), as this methodology helps in focusing analyses on the issues of concern.

This methodology is usually used to describe the effects of a (regulation / decision / policy / strategy / technology) in the future if they were implemented.

3.2.1 MSWM Scenarios Planning for Bahrain

Through exploring scenarios type in the literature, it can be said that there are several different types of scenarios that has been discussed and implemented (Van der Heijden, 1996; Alcamo & Ribeiro, 2001; Börjeson et al., 2006; Mahmoud et al., 2009), and in general, scenarios can be divided into three main categories; explorative, predictive and normative.

In 1997 Van der Heijden, and in 2006 Börjeson et al., indicated the targets to be achieved for each scenario as follows:

1. **Explorative Scenarios (probable futures):**

   Answers "What can happen?" question, in order to come up with adaptive strategies to change the current situation.

2. **Predictive - "What if" – Scenarios (possible future):**

   Answers "What will happen?" question, in order to manage the impacts of specific policies.

3. **Normative Scenarios (preferable future):**

   Answers "How can a specific target be reached?" question, in order to describe the future against pre-specified goals.

In this research, the explorative scenario was implemented, which is the most widely used (Van der Heijden 1996; Bennett, Peterson, & Levitt 2005; Bohensky, Reyers, & Van Jaarsveld 2006; Henrichs et al. 2010). The explorative scenario helps in exploring a range of possible future alternatives to the current system, rather than just visualizing how to reach one target for the future as the case of the other types of scenarios (i.e. the predictive and

normative). Moreover, this scenario helps in understanding the key worries; it incorporates alternative perspectives and helps in making the decision more resilience (Peterson et al., 2003).

3.2.2 Scenarios Development Process

From the literature, the scenario development process is conducted in different ways with no specific restricted steps (Van Notten et al., 2003; Castella, Ngoc Trung, and Boissau, 2005; Börjeson et al., 2006); as a result, in this research, the following 5 stages shown in Figure (7) were developed and applied for the purpose of this work.



Figure (7)

Scenarios Development Process

The following is a detailed explanation of the steps given in Figure (7).

1. **Identification of the (Focal Issue):**

   This stage involves the identification of the issues that need to be changed/enhanced. The identification of the problems is based on discussing the following question: what is the focal/key

impact/pressure of the current MSWM system in the Kingdom of Bahrain?.

2. **Assessment of the MSW Baseline Elements and Identifying The Trends:**

   The aim of this stage is to identify the driving forces that are most likely to have the most influence on the concerns of the future of the issue, and to determine the factors that are likely to change the direction of the future.

   This stage is conducted in two parts: data gathering and critically analyzing the data in order to discover the trends; the two parts cover the generation, regulations, institutions, management practices, weaknesses, and gaps, which is explored, critically analyzed and reported.

3. **Critical Analysis:**

   According to the Oxford Dictionary, critical analysis is defined as: "*Objective analysis and evaluation of an issue, in order to form a judgment*". To make the definition simple, it can be said that critical analysis/thinking is the evaluation of facts (given information and data) about the subject matter to make a reasonable judgment. Nosich (2012) explained the process of critical analysis to follow three discussion stages, that is:

   a. Asking questions about the issue (e.g. What is happening?, What is the history?; what data do we have?; what our problems are?; what do mean by … ?; what options are there?; what is important?; How

does that apply to our case?; What difference it could make? … and so forth).

b. Trying to answer those questions by reasoning them.

c. Believing the results of the reasoning.

Through these discussion stages, the current MSWM system in the Kingdom of Bahrain has been conceptualized, analyzed, synthesized in order to reach a reasonable judgment. The discussions were focused on the followings:

a. Evaluating the data gathered, and generating the trend lines.

b. Evaluating the system weakness and the gaps (e.g. Legal framework, institutional framework, management practices, landfill site … and so forth).

c. Evaluating the factors that affect the MSW streams generation.

d. Finding the relation between the different factors affecting the MSW generation, and seek for a possible hidden factor (e.g. Market for opportunities, awareness, social and religious ethics, regulations, concerned institutions collaboration … and so forth) that could influence the result as a whole.

e. Discussing and evaluating the improvement needs, and Evaluating the opportunities and challenges that could affect the decisions.

f. Discussing the model that could facilitate the data analysis.

4. Scenarios Construction:

This stage was conducted through brainstorming the available data, by focusing on the main/focal issue (i.e. landfilling of mixed MSW streams in our case), taking into the consideration the past and the current trends, with the aim of extending the lifespan of the landfill as a first step towards the system sustainability.

The scenarios were constructed through:

a. Using the current trends to generate the future trends based on the different factor.

b. Discussing and using existing landfill data that are related to the area and the depth of the disposal pit, type of the waste being received, and compaction rate.

c. Discussing different national and international practices to find the suitable scenarios based on challenges and opportunities.

Bases on time limits for conducting the research, the resources available (e.g. data availability, cooperation from concerned authorities … and so forth), feasibility limits (software's, input from other academic specialty such as economics, team employment from assessing market feasibility, long-term analysis for some hidden factors … and so forth) we reached to the scenarios that are discussed in chapter four.

5. Model Development and Scenarios Analysis:

At this stage, the constructed scenarios were analyzed through asking: what are the implications of the scenarios on the aim that we need to reach (i.e. expanding the MSW landfill site lifespan).

Bringing the answer to this question will help in defining action plan options that need to be implemented in order to enhance the current system for a better future.

A model that suits the Kingdom of Bahrain requirements for calculating how long the existing landfill site can last have been developed and applied for analyzing the developed scenarios. The model was developed in Microsoft Excel in order to project future MSW landfilling quantities (volume), and then subtract these quantities from landfill current capacity; by this, the lifespan in which current capacity is likely to be shortened is projected based on different scenarios that have been discussed in chapter four of this research.

Model development depends on the available data, and involves the following steps:

a. Profiling the baseline scenario for MSW landfilling quantities.

b. Projecting future MSW generation based on the projected population obtained from CIO.

c. Developing future recycling scenarios for the MSW and for the DWS.

d. Subtracting the annual MSW future projection landfilling quantities from available landfill space, to estimate the landfill lifespan based on different proposed scenarios.

Finally, the scenarios analysis results were used to formulate the recommendations for extending the lifespan of the only MSW landfill site exists in the country, as the first step towards implementation a holistic sustainable management system that employs recovery schemes/plans in the country.

3.3 Future Projections

Population growth, economic development and the change in the community lifestyle towards a rise in their living standard has increased the generation of the MSW in Bahrain.

The projection of MSW generation plays an important role in its management, in order to seek for improvements to the current waste management systems, especially with the case of continuous dependence on mixed MSW landfilling practice in the case of the Kingdom of Bahrain.

An appropriate planning for future MSWM system relies heavily on quantifying the problem (i.e. increasing MSW generation quantities), as without current preparations for future projections, governments may fail to manage the continuous accumulating MSW in a sustainable manner especially with the fact of limited land area availability for landfilling practice.

Therefore, future scenarios were constructed based on the projection of future MSW generation, and then the results of scenarios modelling were analyzed in order to come up with a suitable judgment of what futures might look with the different scenarios.

The generation of MSW has a direct correlation with population size, as the population size increases the MSW generation increases as a result (Al. Ansari, 2012; Sjöström & Östblom, 2010; Saeed, Hassan & Mujeebu, 2009; Manaf, Samah & Zukki, 2009; Alam et al., 2008). In addition, the economic development has its impact on developing the communities' living standards and as results increase their consumerism habits, that consequently results in increasing their generation of the MSW.

The per capita MSW generation that is the quantity of MSW generated/will be generated by a person in one day or one year in a country is strongly correlated to the gross domestic product (GDP). High-income countries generate more per capita MSW compared to low-income countries (Sharholy et al., 2007).

GDP and population growth can be included in the MSW projection calculations; however, according to Phiri & Godfrey (2012), there will be a duplication to use both the population growth and GDP in projecting the MSW generation, as both of these factors show a positive correlation with waste generation. Accordingly, in this research, future MSW quantities have been projected based on the MSW that has been received at Asker landfill site for the period from 2005 to 2016 and the projected population.

This research work incorporated the followings to calculate the projections:

- Projection of the population size (which is already projected to the year 2030 by CIO).
- Waste generation projection, which was calculated based on calculating the average per capita generation for the period from 2005 to 2016 where the per capita for each year is calculated separately and then averaged. The average is used for projection of MSW generation to the year 2030.
- Projecting landfill lifespan and land space requirements, through proposing different recycling rates of the MSW streams and DWS.

The growth rate and the percent of the change were used to serve this research work analysis for both the population and MSW generation. The percent change represents the change in the quantity/size across the whole time period (i.e. from time one (T1) to time two (T2)), while the growth rate represents the average size of the change per year/month across a time period.

$$\textbf{[Change percent of the N variable]} = ((N_{T2} - N_{T1}) / N_{T1})\, x\, 100 \qquad \textbf{(1)}$$

$$\textbf{[Growth rate for the N variable]} = [((N_{T2} - N_{T1}) / N_{T1}) / No\ of\ years\ between\ T1\ and\ T2]\, x\, 100 \qquad \textbf{(2)}$$

Where, (N) is the population size and/or the MSW generation, according to the related subject being discussed; and (T) is the time of relating discussions.

The base year for this calculation (T1) was 2005, and the current year (T2) is the year 2016.

In addition, the percent compositions of one type waste stream from the total MSW streams were calculated applying the following equation:

$$[\textbf{Percent of M stream of the total MSW streams}] = (M\ quantity\ (tons)\ /\ total\ MSW\ quantity\ (tons))\ x\ 100 \quad \textbf{(3)}$$

Where, (M) is different single stream presented within the overall MSW streams.

The projection of waste generation for the future from the year 2017 was calculated based on the calculation of the average per capita generation for a period of the 11 years as an average (i.e. 2005 – 2016), given the total MSW disposed in the landfill and Bahrain population of the for the same period.

The per capita MSW generated, is the total waste generated in the country in a given year divided by the population of that same country in the same year; (assuming that all the MSW generated in the country are disposed at the landfill site – i.e. 100% collection; which are justifiable for the Kingdom of Bahrain due to the presented clean areas for all the cities).

As mentioned in the previous paragraph, the average per capita was calculated to project the future generation, based on calculating each year separately from 2005 to 2016.

This average per capita was further multiplied by the projected population for the period 2017 – 2030 (i.e. Projected by the CIO) to obtain the MSW generated for the same period. The calculations of the domestic waste stream that are related directly to the population are also calculated using the same method but only for domestic waste stream disposal quantities.

3.3.1 Projecting the MSW generation based on Population Size and Per Capita Generation

Projections for the MSW generation to the year 2030 were made by factoring the projected population size and the average per capita generation. The mathematical calculation for this projection depended on the future population projected by CIO and the average per capita waste (MSW and DWS) generation for the period 2005 – 2016 (that were calculated from the actual MSW disposal quantities), using the following equation:

$$\left[\begin{matrix}\textbf{Per Capita MSW generation}\\ \textbf{(tons/capita/year)}\end{matrix}\right] = \frac{Quantity\ of\ MSW\ generated\ (tons)\ in\ a\ given\ year}{population\ size\ in\ that\ year\ (capita)} \quad \textbf{(4)}$$

- Based on 2005 – 2016 actual data

$$\left[\begin{matrix}\textbf{Average Per Capita MSW Generation}\\ \textbf{(tons/capita/year)}\end{matrix}\right] = \frac{Sum\ of\ Per\ Capita\ MSW\ for\ each\ year}{11\ (years)} \quad \textbf{(5)}$$

- Based on 2005 – 2016 actual data

$$\left[\begin{matrix}\textbf{Average Per Capita DWS Generation} \\ \textbf{(tons/capita/year)}\end{matrix}\right] = \frac{Sum\ of\ Per\ Capita\ DWS for\ each\ year}{11\ (years)} \quad \textbf{(6)}$$

- Based on 2005 – 2016 actual data

[Future Projected MSW Generation in a year (tons/year)]

$$= (Average\ Per\ Capita\ MSW\ (tons/Capita))\ x\ (Population\ size\ in\ that\ year) \quad \textbf{(7)}$$

- Based on 2005 – 2016 average calculated data from the equation (5)

[Future Projected MSW quantities (kg/day)]

$$= (Population\ size(Capita))\ x\ (Average\ Per\ Capits\ MSW\ (tons/capita\ /year))\ x\ (Number\ of\ days\ (365\ days/year))\ \div\ (1000\ (kg/ton)) \quad \textbf{(8)}$$

- Based on 2005 – 2016 average calculated data from the equation (5)

[Future Projected DWS Generation in a year (tons/year)]

$$= (Average\ Per\ Capita\ DWS\ (tons/Capita))\ x\ (Population\ size\ in\ that\ year) \quad \textbf{(9)}$$

- Based on 2005 – 2016 average calculated data from the equation (6)

[Future Projected DWS quantities (kg/day)]

$$= (Population\ (Capita))\ x\ (Average\ Per\ Capits\ DWS\ (tons/capita\ /year))\ x\ (Number\ of\ days\ (365\ days/year))\ \div\ (1000\ (kg/ton)) \quad \textbf{(10)}$$

- Based on 2005 – 2016 average calculated data from the equation (6)

3.3.2 Projecting landfill area requirements for MSW Disposal

Landfill area availability was projected based on the calculation of the area available since July 2016 that is equal to 600000 square meters ($6 \times 10^5\ m^3$) with a depth of 15 meters (i.e. Disposal pit depth) that is equal to 9000000 cubic meters ($9 \times 10^6\ m^3$), given that at the current disposal method 1.7 m^3 are required for a ton of MSW (include the covering material).

The equations used for the calculations of area remaining and additional area requirement for MSW generations in the country are:

[Total Volume/Space Used Yearly (m3) "Length *x* Width *x* Depth"]

$$= Total\ MSW\ Generated\ Yearly\ (tons)\ x\ 1.7(m^3/ton) \quad \textbf{(11)}$$

- Based on a requirement for 1.7 m^3 per a ton of MSW

[Total Remaining Volume/Space Used Yearly (m3) "Length *x* Width *x* Depth"]

$$= Remained\ Space/Volume\ From\ Previous\ Year\ (m^3) - Total\ Volume/Space\ Used\ (m^3)\ this\ year + Additional\ Space/Volume\ Given\ (m^3) \quad \textbf{(12)}$$

- Based on a requirement for 1.7 m^3 for a ton of MSW
- Based on 600000 m^2 *x* 15 m → area given in July 2016

[Required Additional Area for Landfilling (m3) "Length *x* Width *x* Depth"]

$$= Total\ Required\ Volume/Space - Total\ Available\ Volume/Space)(m^3)\ /\ 15m \quad \textbf{(13)}$$

- Based on 15 m depth of the disposal area

In addition, for the recycling scenarios; equations 11, 12, 13 were repeatedly used for the calculations of the remaining area and the additional area requirements for MSW generation.

* it's worth to mention in order to justify the use of the above equations, a linear correlation historical data for the past 11 years were utilized to calculate the average per capita generation for that period, and the calculated average per capita were then incorporated in the developed model along with CIO projected population to predict the future, and this method is justified by itself with regards to calibrating the results. In addition, the historical data time limit was set for only the 11 past years as there no existence of the huge variation in the economy and the lifestyle during this period, however, if we took a longer time period (let say 31years) variations will exist.

3.4 Previous Researches Review

A literature review was used to identify the topics related to MSW subject. Lots of published studies have addressed the MSW and its management internationally, while nationally few studies covered the same subject.

Thorough literature review of the concepts related to MSW and its management was conducted depending on published and unpublished reports and publications from governmental and non-governmental, national, regional and international sources. Published and unpublished national reports provided by MoWMAUP and SCE were reviewed thoroughly.

In addition, a comprehensive online database search (i.e. web search) was conducted by keywords related to MSWM. University of Bahrain (UoB) online library was comprehensively utilized for conducting this research work.

The literature review facilitated in this research to describe and to identify the MSW definition, legislations, generation sources, contents, MSWM challenges, sustainable development and MSWM, waste management hierarchy, landfilling, factors affecting MSW generation and waste sector in the Kingdom of Bahrain related matters; it also helped in setting up the framework for MSW projections, scenarios development for evaluating future prospectives, critical analysis, mathematical equations related to the subject and model development for scenarios analysis.

The literature review of this research work followed the following steps:

1. Identification of the keywords and themes related to the research topic.
2. Searching for sources related to the research topic.
3. Drafting a chapter that summarizes and combine the literature review outcomes in researcher wording with citing and referencing the used literature sources.
4. Repeating steps two and three as needed.
5. Producing the final literature review chapter.

3.5 Data Collection

The aim of data collection stage of this research work is to gather data related to MSW in Bahrain, in a consistent manner to serve the objectives of the research, in order to:

- Develop baseline information for the continued measurement of the system performance.
- Have comprehensive information on the quantity and type of MSW materials, in order to prioritize the recovery opportunities.
- Measure the effectiveness and efficiency of the existing system for collection, transportation, recycling, processing for resources recovery, and disposal of MSW streams.

Data Collection was based on the following principles to ensure reaching the objective of the research:

- **Validity:** This refers to the appropriateness and the extent to which a measure accurately reflects the concept that is intended to measure.
- **Reliability:** This involves consistency and the extent to which the objective of the research is achieved.
- **Time Limit**: data collection is based on the last 11-year timeline (2005 – 2016); as the time limit is critical for data analysis and reliability.

This research was carried out qualitatively and quantitatively. The qualitative method was conducted in order to evaluate and describe the MSWM practices challenges, difficulties and opportunities thoroughly,

through reviewing the information and data gathered from different sources, such as face-to-face and telephone interviews, fields' observations and document analysis. The quantitative method was conducted in order to analyze MSW disposal quantitatively.

In order to build the baseline scenario and to propose scenarios, data were collected from both primary and secondary sources to enable accomplishing the aim of the research.

3.5.1 Primary Data Collection

Considering the scarcity of published information and data regarding the MSWM system in the Kingdom of Bahrain, and in order to gather that information in the country, primary data were collected through semi-structured face-to-face and telephone interviews (i.e. open-ended questions regarding MSW issues) with relevant officials from both MoWMAUP, SCE and this research academic supervisor; in which a question leads to another, depends on the interviewee's replies.

In this regard, some question was prepared in order to allow "the researcher" to start the interview and to guide her during the interview and to allow her to ask additional questions as needed.

The aim of this approach is to understand the current condition of the MSWM system in the country from the respondents' point of views in their simple wording and to allow "the researcher" to ask additional questions related to the research topic.

The objectives of the face-to-face or telephone interviews were to obtain the following data and information:

- The role of the governmental institutions involved in the MSWM system.
- The role of private collection companies in MSWM system.
- The regulations related to MSWM in Bahrain.
- The problems associated with MSWM practices in the Kingdom.
- MSW disposal quantities and composition.
- Asker landfill site characteristics and conditions.
- WT generation and its management in the country.
- Model development requirements.
- Scenarios development requirements.

In addition, as part of primary data collection, field visit observations were conducted to examine the MSW practices in Bahrain. In order to have an indication of the state of waste management in the country, several communal collection points have been visited and photos were taken, different waste transportation truck has been seen, and the Asker landfill site has been visited and photos were taken. These visits provided the opportunity to understand the MSW management system in the Kingdom in the following matters:

- Presence and condition of the MSW communal bins.

- Satisfaction with the number and capacity of the MSW communal bins.
- The distance of communal containers from the residents.
- The condition of areas surrounding the MSW communal bins.
- Scavenging activities.
- The condition of MSW transportation.
- Condition and characteristics of Asker landfill site.

3.5.2 Secondary Data Collection

In addition to primary data collection, other data were collected through other references who address additional information and data that are needed to accomplish the aim of this research. The purpose of gathering secondary data is that it consume less time to gather and analyze "over the primary data", as the data is already available.

The results of the primary data collection were combined with the review of secondary data that were collected from the published, unpublished, and online and hardcopy books, website, scientific papers, and statistics related to MSW in the country and related to population, regulations, and Asker landfill site. Also, the scientific papers reviewed were to understand the process of scenario planning.

In this research work, waste generations per capita were assumed to be related only to population growth for both the MSW and DWS (other factors are assumed to be consistent as explained in the data analysis section

of this chapter) and then it is averaged for both total MSW and DWS, and then it is assumed to be unchanged until the year 2030.

Regulations, population statistics, published and un-published reports, papers, and articles on Bahrain MSW related concerns were reviewed, and needed secondary data were taken and referenced appropriately.

In summary, the data collected for accomplishing this research from both the primary and secondary sources were as follows

Table (1):

- Data on Bahrain's population were gathered from the Central Information Organization.
- Regulations related to MSW matter were gathered from Bahrain's legal affairs website.
- Data on Bahrain's MSWM were collected from the concerned authorities (i.e. Ministry of Works, Municipalities Affairs, and Urban Planning, and the Supreme Council for Environment) to identify the MSW streams and generation sources, waste collection, transportation, and disposal at the landfill site.
- Data on the Asker landfill site characteristics were gathered from the landfill site operation staff.
- Data on the amount of MSW delivered to from Asker Landfill site statistics for the period 2005 – 2016 were gathered from the landfill site operation statistics.

Table (1)

Data Gathered

Data	Sources
About Kingdom of Bahrain	Central Information Organization Supreme Council for Environment Ministry of Information Affairs Bahrain Centre for Studies and Researches Published And Unpublished Reports, Papers and Articles
Current and Projected Population Statistics	Central Information Organization
Regulations	Legal Affairs Website
Institutional Framework	Ministry of Works, Municipalities Affairs, and Urban Planning Supreme Council for Environment
Historical Waste Generation Statistics	
Waste Segregation System	
Waste Collection System	Ministry of Works, Municipalities Affairs, and Urban Planning Supreme Council for Environment
Waste Transportation	Published and Un-Published Reports, Papers and Articles Site Observations Google Earth Maps
Waste Reusing, Recycling and Recovery System	
Waste Disposal System	
Landfill Site Conditions and Capacity	Ministry of Works, Municipalities Affairs, and Urban Planning
MSW Streams Proportions	Supreme Council for Environment Site Observations

Data	Sources
DWS Composition	A thesis submitted to UoB "Municipal Organic Solid Waste in the Kingdom of Bahrain: Occurrence, Management, and Contribution Toward Green House Gases Emissions"

The private sector and the community participation were not included in this research, as their involvement requires a focused research work and it is recommended that future works cover their role.

3.6 Overall MSWM System Data Analysis

Analysis of the data gathered is done in order to assess the existing MSWM condition and pattern in the country. The analysis of the data was a challenging task due to the availability of a large and unstructured raw data that were gathered from the interviews, data collection and the literature reviews; therefore, the data were reformatted and presented in paragraphs, tables, and graphs in a manner that serves the objectives of this research. Also, critical analysis method was conducted as part of data gathered analyzing the process, through several comprehensive discussions between the researcher and the supervisor.

Tables were used mainly in presenting the input and in analyzing data, and the graphs were used for presenting the statistical data to ease its understanding.

Microsoft Excel was used for data entry, for statistical analysis, and for scenarios analysis through model development. The Microsoft Excel

spreadsheet was used to find the correlation between the population with the MSW and the DWS generation (per capita yearly and daily generation), in addition, this spreadsheet was used to project the future generation (based on assuming that most of the MSW streams generated are disposed at the Asker landfill site), and to analyze the waste streams different recycling scenarios impact on the landfill site.

Google Earth map was used to predict the distances between the landfill site and the capital center, and to predict the distances between the landfill area and Asker village.

Photographs were taken during field visits in order to understand the MSW collection, transportation, and landfilling/disposal practices of the management process.

Data on the MSW delivered to the Asker landfill site was collected for a period of 11 years, from the year 2005 to the year 2016.

Time-series analysis quantitative techniques were used in order to make future projections based on the historical values of this same variable.

To extrapolate the future, the MSW compositions were interpreted into the model; in addition, the DWS compositions were also interpreted in the model. The DWS composition were obtained from the thesis submitted to UoB in June 2016 labeled "Municipal Organic Solid Waste in the Kingdom of Bahrain: Occurrence, Management, and Contribution Toward Green House Gases Emissions" submitted by Ms. Eman Ali Salman in her partial fulfillment of the requirements for her master degree in Environment and Sustainable Development Master program, where she conducted field survey at Asker landfill site for DWS composition in the year 2015.

Equations mentioned in this chapter were developed and incorporated in Microsoft Excel sheets in order to analyze the results of the current scenario and the proposed future scenario in order to come with recommendations that suits the needs of the Kingdom of Bahrain to cope with increasing MSW generation quantities in a sustainable manner that reduces the pressure on the landfill area that is associated with the fact of area scarcity in the Kingdom.

3.7 Initial Writing

a) Draft the various sections of the thesis

b) Undertake additional research where necessary

3.8 First Draft Issuance

a) Compile and collate sections in the first draft of the dissertation

b) Check the flow of the dissertation

c) Undertake any additional editing and research

3.9 Final Draft

a) Submission Preparation

b) Final proof-read and editing

c) Chapters Compilation, printing, binding, and submission

3.10 Assumptions and Limitations

Improvement of MSWM is a complex process that involves many interrelated elements such institutions involved, regulations, financial aspect, community involvements, country's economy... and so forth; therefore, it is difficult to address all MSWM related elements in a single research. As a result, there were some limitations during conducting this research work, as followings:

- Data collection through documents review: few published documentation about MSWM system in the Kingdom of Bahrain were found.

- Data collection through interviews: the collection of primary data with a representative from governmental bodies and this research supervisor, where the role of other stakeholder involved in MSWM systems such as communities, NGO's, private sector and recyclers involvements is recommended to be investigated thoroughly in other research work.

  Many interviewees were cautious about providing information related to difficulties associated with MSWM system in the Kingdom of Bahrain. Thus, the researcher expended a lot of time in explaining the importance of this research.

- Information gathering from field observations: rapid field observations were conducted, where not all towns and villages all around Bahrain have been covered due to time limitations.

- Time limitation for covering all aspects related to the study, for example, a survey were initially started by implementing a desk survey with regards to segregation and recycling businesses in Bahrain through surveying SCE and commercial registration of the Ministry of Industry, Commercial and Tourism databases, and initial list of those businesses have been prepared; and the plan was to verify if these businesses are in operation, however, due to time limits couldn't accomplish the task.

For developing alternative scenarios for the MSW and due to data limitation, the following assumptions were considered:

- The pollution from the management process – from generation to disposal - to the soil, water and air from the proposed scenarios was not evaluated, although it has its influence on the decision-making process, and in this regards it is recommended that research work covering these impacts to be investigated thoroughly in a separate study as this is considered as a crucial element of decision making in MSWM planning.

- The generation of MSW is considered to be based on MSW landfilled, as no official reliable data available on reusing and recycling activities in Bahrain, and most of the generated quantities of MSW in the country are disposed at the Asker landfill site.

- MSW and DWS generation per capita is calculated from the average amount disposed at the Asker landfill site and the population for the period of 11 years from 2005 – 2016.

- Since the quantity of MSW generation is subject to factors, such as population, economic development, and the income level and awareness of the population; Economical factors of the country and the income level and the awareness of the people was assumed to remain consistent and unchanged for the period 2005 – 2030.

- MSW streams (i.e. dead animal, C & D building waste, commercial waste, domestic waste, garden waste, non-hazardous industrial waste) assumed to be related to the person's lifestyle and their daily activities, and therefore the projection calculations for MSW generation were calculated based on the average per capita generation of the MSW as a whole.

  For example, households generate C & D building waste during implementing maintenance and renovation for their homes and/or during construction their new homes, also the landfilling of the ashes and the people themselves indirectly generate sludge from sewage treatment plants.

- A year equals to 365 days.

- The period from July to December equals to 6 months, which is 184 days.

Chapter Four

Results, Discussion, and Recommendations

Chapter 4

4.1 Introduction

MSWM is considered as one of the challenging issues in the Kingdom of Bahrain with the trends of increasing its disposal quantities in a mixed manner. Appropriate MSWM practices comprises of MSW handling at the source of generation, collection, transferring, treatment for resources recovery, transportation and final sanitary landfilling of remaining waste streams that options for their recovery and re-utilization is not available; however, in the Kingdom of Bahrain, the MSWM practices comprises mainly of three activities, where the MSW generated are collected, transported, and landfilled/disposed of.

The MSW collection and transportation in the Kingdom is considered satisfactory; however, the practices associated with waste management hierarchy (i.e. elimination of waste, minimization, reusing, recycling, recovery and sanitary disposal) are till date not regulated nor practiced in considerable amounts.

The current MSWM practices are heavily reliant on landfilling, that is considered as the least desired waste treatment practice (i.e. weighted to be at the bottom of the management hierarchy), which are the least environmentally friendly practice but the easiest management options.

Population growth, economic development, land scarcity, associated with lack or even absence of regulations and policies that enforces

segregation and recovery practices, lack of awareness (at both the public and governmental levels) of the value of the waste streams as a resource for other options and the inefficient recycling and processing for resources recovery infrastructure within the country; have contributed to huge quantities of potential recycled waste being discarded into rubbish bins and then landfilled at the landfill site.

Bahrain is facing a challenge with regards to MSW landfilling. In Bahrain, no lining system provided for the site, no leachate nor gases collection system and no monitoring system provided for Asker landfill that receives the MSW streams; the landfill are consuming land areas, consuming resources "that can be recovered", and causing air, water, and soil pollution; therefore, there is a need to address the MSW generation with a sustainable approach rather than just landfilling it.

The scale of MSW generation and the requirement for the diversion of the waste streams from landfilling practice "are" of concern to the Kingdom of Bahrain due to – mainly - its small land area associated with its high population. Statistics show that MSW disposal quantities are grown in the country and will continue growing if the management practices remained with the same manner, where an organized MSW streams practices of prevention, minimization, re-utilization, recycling and/or treatment for energy and material recovery are not addressed properly.

Currently, an average of 3888.8 tons of MSW is sent to the Asker landfill site every day (based on the data for last 11 years period from 2005 - 2016), this reflects that Bahrain needs an effective and fast appropriate solution before the saturation of the existing landfill area, as if landfilling

practice is continued, this will result in the requirement for more or new landfill space/area which is also considered as a challenging issue or in another word "no easily possible" for the kingdom of Bahrain.

To prevent this future complications with the regards to MSWM, Bahrain must take immediate actions to minimize waste generation, segregate waste streams in order to enhance re-utilization, recycling and/or treatment for energy and material recovery and sustainable disposal.

MSW mixed streams that are disposed at the landfill comprise of a valued "i.e. prized" quantities of recyclable materials such as organic materials, paper, plastic, metal, rubber materials, glass, and other resources such as energy. The recovery opportunities/activities are available and being practiced worldwide; however, these activities is - till date - at an infant stage in the Kingdom of Bahrain (no official data are available, nor a systematic institution for managing and organizing the activities associated with resources recovery from the waste).

The management practices "if" shifted towards re-utilization, recycling and/or treatment for energy and material recovery of these materials (if retrieved), would probably reduce the quantities of waste streams required to be disposed at the landfill site, and would - at the same time - have a positive input to the economy, will save land areas required for disposal and will save the natural resources from consuming.

Scenarios methodology was conducted in this research in order to explore the need for a change in the current MSWM practice. Scenarios approach – as described in chapter three - is considered as valued tool that enables the decision makers to set the country development plans for the

future, based on comprehending the current state (i.e. understanding the current situation, enables examining the opportunities and improvements that could be implemented in the MSWM system of the Country).

4.2 Municipal Solid Waste Management System in Bahrain

4.2.1 MSWM Regulations and Institutions

The management of the MSW continues to be a high priority for the Kingdom of Bahrain government, and this is because the management of the waste sector including the MSW streams is considered as one of the most challenge sector facing the development in the country.

As a result, the government of Bahrain supported the improvement and development of MSW management sector in the country long time back by the establishment of the first municipality responsible for the cleaning and collection of the MSW along with other governmental administrative works in the Kingdom in July 1919.

With regards to the management of the MSW institutional framework, Bahrain is divided into 4 governorates: Al Manama, Al Muharraq, Northern and Southern administrative areas as shown in Figure (8).

This division of the administrative areas makes it easier and manageable for the government to control the administrative works related

to the municipalities including the management of the MSW sector in the kingdom.

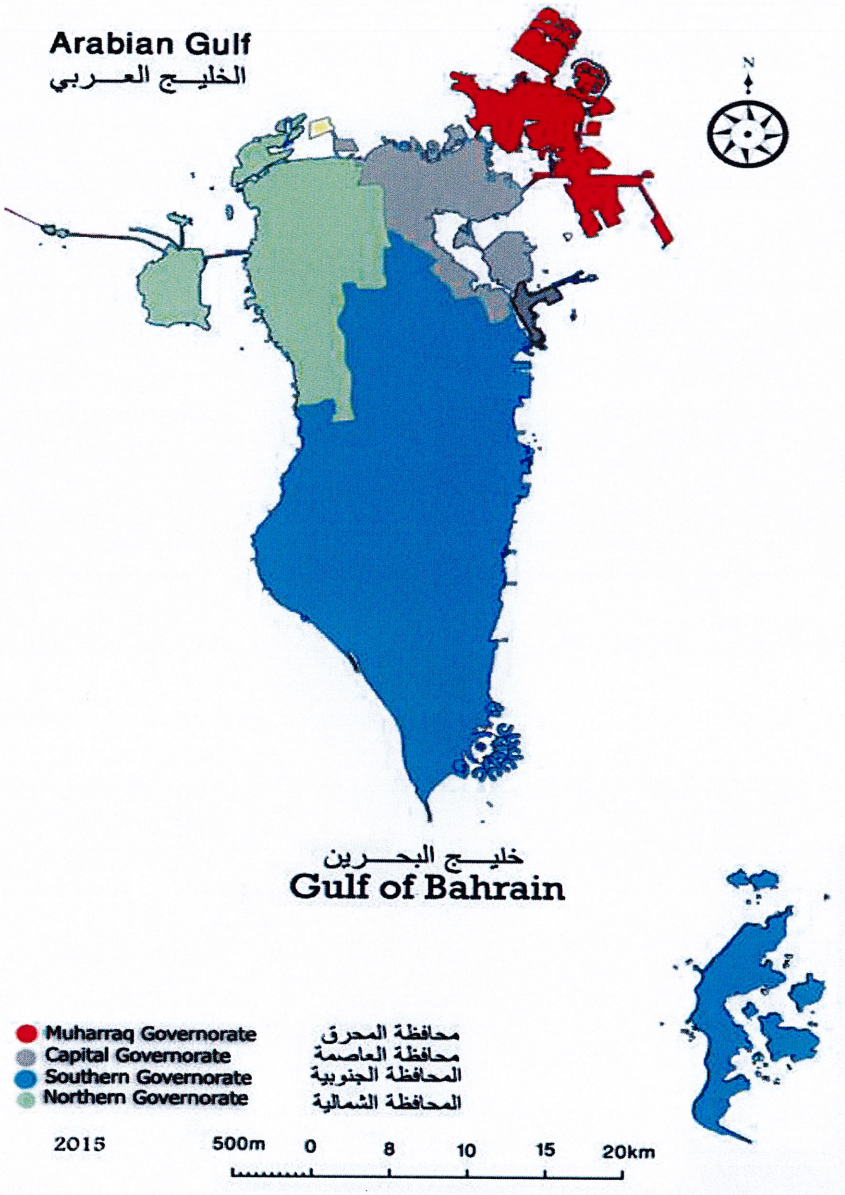


Figure (8)

Kingdom of Bahrain Administrative Boundaries-Governorates

(Bahrain Survey and Land Registration Barue, 2015)

Currently, as the development in the country grown, the responsibility of the MSW management has gained stronger support by the government and promoted its responsibility to a ministerial level, where it now is under the responsibility of the Ministry of Works, Municipalities Affairs and Urban Planning (MoWMAUP) in collaboration with the municipalities of the four administrative area-governorates (i.e. for the management and collection of the MSW within the boundaries of each governorate: Capital, Muharraq, Northern and Southern) along with the Supreme Council for Environment (SCE).

The MoWMAUP is responsible for tendering and contracting cleaning, collection, and transportation services of the waste streams that are classified as domestic waste in its nature from all around Bahrain including street sweeping (i.e. from residential, commercial, agricultural, recreational, services and industrial areas), also the responsibilities of MoWMAUP covers practical supervision of those contractors through the four municipalities; also the MoWMAUP responsible of Asker landfill site operations, and responsible for the preparation of disposal quantities statical data.

The Supreme Council of Environment (SCE) has also a role in the MSW management; SCE responsible for setting the country sound waste management strategies and plans including MSW as per the Legislative Decree No. 21 of 1996.

SCE is also responsible for approving the disposal of non-hazardous industrial waste in the Asker landfill site. In addition, SCE monitors the management of bottom and fly ashes generated from the health care waste

incineration plant that is operated by the private sector, where the bottom ash is being sent to the Asker landfill site, and the fly ash is being sent to the Hafeera landfill site that (i.e. The landfill site that is being allocated specially for the disposal of Hazardous waste generated in the Kingdom of Bahrain) (SCE, 2015).

SCE is also responsible for licensing/approving waste "various streams" management and treatment facilities (i.e. MSW, hazardous waste, medical waste, sewage ... and so forth) through studying their environmental feasibility as well social feasibility considering the economical values of those projects to the country; additionally SCE is responsible for the enforcement of permits conditions in order to ensure facilities compliance to the environmental regulations and to control any environmental impacts that may arise during the operation of those facilities.

Ministry of Industry, Commerce and Tourism are responsible for commercial registration of those private establishments who are dealing with the management of the waste streams in terms of collection, transportation, recycling and treatment facilities and trading of waste streams.

In order to enable the responsible institutions to perform their role in MSW management, Kingdom of Bahrain enacted several regulations for the waste management in order to control its impacts on the environment and public health, these main regulations related to MSW management according to the search made by the researcher in Bahrain legal affairs website:

- SCE president Order No. 3 of 2006 amended by the Order No. 7 of 2013 with respect to hazardous waste management. This order defined

the Municipal Waste (MW) "in the context of the Kingdom of Bahrain" as non-hazardous waste, that comprises of household wastes, food and vegetable wastes, and offices rubbish, it also comprise of wastes that are generated from residential, commercial and industrial areas, parks and recreational facilities, educational and health facilities, in addition to social activities "that can compost" and does not contain hazardous waste identified in this order.

- Ministerial Order No. 10 of 1999 with respect to Environmental Standards for air and marine water) amended by the Ministerial Orders No. 2 of 2001 Ministerial Order No. 3 of 2001. This ministerial order assigns the environmental authority in the kingdom (currently SCE) to control the emissions to the air and the discharges to the marine environment from development projects/facilities "including MSW management and treatment facilities".

- Ministerial Order No. 1 of 1998 with respect to Environmental Evaluation of Projects. This ministerial order assigns the environmental authority in the kingdom (currently SCE) to evaluate development projects "including MSW management and treatment facilities" before issuing their conditional environmental license.

- The legislative decree No. 21 of 1996 with respect to the environment amended by the legislative decree No. 8 of 1997 with respect to the environment. In order to protect the environment from all pollution sources such as waste streams(i.e. pollution to air, water resources, and soil), this legislative decree was enacted

Regarding the MSW, this decree prohibited any person or project from storing or disposing of the waste in any manner which does not comply with the systems, standards, and methods specified by the environmental authority.

This legislative decree assigned SCE to set the country's plans regarding for the sound management and control measures that regulate the collection, segregation, transportation, and disposal of waste of all type of wastes generated in the country including the MSW streams.

- Municipal Order No. 5 of 1990 with respect to the fines/expenses of the removal of building demolition wastes, industrial wastes, garden wastes, unfamiliar rubbish, sewage, analysis and sedimentation residues. This ministerial order specified a fine of BD 10.000 for each shipment for the removal of building demolition wastes, industrial wastes, garden wastes, unfamiliar rubbish (i.e. non-hazardous solid waste streams).

- Municipality Order No. 1 of 1977 with respect to organizing MW collection and disposal activities. Regarding the MSW, the ministerial order made it mandatory for the municipalities' affairs to provide the sufficient type and quantities of waste containers in public areas.

  This ministerial order enforced the country residents and the commercial activities owners to provide proper storage containers for their solid waste and prohibited them from throwing their rubbish in streets and public areas; also this order specified for the residents and commercial activities the containers criteria to be a metallic or plastic

containers, and polyethene bags; in addition this ministerial order specified the violation fees of BD 2.000 to be paid within three days from the date of offence.

- Municipality Order No. 5 of 1977 with respect to organizing municipal waste (MW) collection and disposal. This ministerial order mandated the municipalities' affairs and ministry of health to allocate suitable disposal site for MW.

  This order enforced the municipalities' Affairs to provide sufficient number of waste contained in public areas, streets, and public areas. The order also mandated the industrial, garden; C & D building waste and hazardous waste generators to collect and transport their waste at their own expense to a certain disposal area which is to be specified by the municipalities' affairs. The permission for collecting and transporting MSW should be granted from the municipalities' affair in addition to the timings for the collection and transportation as per this municipality order.

- Law No. 3 of 1975 - amended by legislative decree No. 18 of 1978 amended by legislative decree No. 16 of 1989 amended by legislative decree No. 16 of 1993 - with respect to Public Health.

  These laws concerned mainly with public health and sanitation, and assigned the Ministry of Health several roles related to environment and public health protection related to sanitation and MW such as cleaning public restrooms/toilets and emptying sewage tanks, in addition to collection and transportation of rubbish from houses, markets, hotels, shops and public areas. These legislations buildings

owners to provide adequate numbers of containers for their waste and prohibited them from disposing of liquid waste together with their domestic solid waste unless obtaining a written approval from the concerned authority for doing so.

The 1989 legislation prohibited throwing building demolition, industrial and garden waste in public and private areas, and without prejudice to any more severe penalty, punishable violates this provision will render a fine of not less than BD 50.000 and not more than BD 100.000; also the 1989 legislation prohibited throwing toxic or hazardous waste in public and private areas, and without prejudice to any more severe penalty, punishable violates this provision will render imprisonment not exceeding the duration of one year and a fine of not less than BD 100.000 and not more than BD 300.000 or either.

And as legislations developed in the country with time, the roles assigned to the Ministry of Health regarding the management of MW has been re-assigned to the Ministry of Works, Municipalities Affairs and Urban Planning and the Supreme Council for Environment.

A fast tack and critical overview of the existing regulations and institutional framework were conducted to understand the existing weaknesses and gaps, in order to facilitate the scenarios formulation based on this overview. Therefore, it is recommended that a comprehensive evaluation of the regulation and institutional framework to be conducted as part of a separate future research works related to the MSWM field.

Legislations related to MSW management in Bahrain is evaluated (by this thesis researcher and supervisor) to be outdated with a failure to be in

line with current international sustainable practices with regards to MSW system; for example, there is no yet a national regulation nor policy for MSW segregation, also the national regulations lacks provision for the enforcement of the waste management hierarchy (i.e. prevention, reduction, recovery and finally sanitary disposal for non-recoverable materials).

Also, the regulated authorities did not play a significant role in the planning and implementation of an effective and sustainable MSW management system in the country.

The government need to consider revision of the MSW legislations and the institutional framework towards covering the followings:

- Clear identification of different waste streams and their management responsibility (i.e. authorities, generators, collectors).
- Enforcement of MSW segregation practices
- Enforcement of MSWM hierarchy.
- Assigning the recyclable waste streams producer (e.g. tyres, plastics, papers, glasses) the responsibility of their waste (i.e. Producer Responsibility).
- Encourage the private sector to invest in resource recovery projects.
- Establishment of an adequate institutional framework for the enforcement of the regulations and for adequate monitoring (i.e. adequate work-force/personnel and adequate tools).
- Adequate stringent actions and higher fines for violating regulations.

4.2.2 MSW Streams Classification

The definition of MSW in terms of its compositions/constituents varies from country to country. In Bahrain, the MSW comprises of solid waste generated from households, offices, public institutions such as schools, street sweepings, parks and garden, commercial, and industrial activities.

The MoWMAUP classifies the waste being disposed at Asker landfill site into six streams categories according to their generation source; dead animals, C & D building waste, commercial, domestic (including the waste coming from areas and streets sweeping), gardens, and non-hazardous industrial wastes.

Landfill operators are required – at the landfill site weighing system facility - to compute/weight, categorize and set the disposal fees according to these six categories of the MSW streams prior to disposal under their supervision.

As per the MoWMAUP, the objective of this classification is to enable the identification of the waste streams enters to the Asker landfill site so that comparable data, in order to easily presented, and analyzed.

As defined by SCE President Order No. 3 of 2006 amended by Order No. 7 of 2013 with respect to Hazardous Waste Management, and as observed from the landfill site visit and through consultation with SCE specialists and the landfill site staff; the six MSW streams comprise of the following materials at their solid state:

- **Domestic waste:**

  This waste stream is comprising of organic wastes in terms of food, paper, cardboard, plastics, clothes, glass, cans, bottle, metals, coal burning ashes, and household hazardous wastes (i.e. consumer electronics, batteries, cooking oils) that are generated by households, schools, open markets, and streets sweepning …and so forth.

- **Commercial waste:**

  This waste stream excludes materials with chemical or reactive nature such as solvents, oils; it comprises a waste materials such as paper, cardboard, plastic, wood, and glass, metals from commercial/business enterprises, shopping malls, warehouses, and hotels.

  The commercial wastes are very similar to domestic waste, accordingly their disposal fees at the landfill site is the same.

- **C & D building wastes:**

  Comprise of blocks, concrete, gypsum, wood, metals … and so forth, that arises from ground excavation works, construction, maintenance, and demolition of buildings and infrastructures such as roads, pavements, and bridges.

- **Dead animals:**

  Comprise of animal's dead body or body parts from farms, slaughterhouses and street sweepning, and can be reused again for composting "on condition that those suitable hygienic conditions are provided for doing so".

- **Garden waste:**

  Comprise of and garden, crops and orchards trimmings from farms, and composting from this waste streams can be benefited; this waste stream excludes pesticide contaminated residues.

- **Non-Hazardous Industrial Waste:**

  Comprise of non-hazardous solid waste generated from industrial sector operated in the kingdom; and it exclude hazardous waste such as chemicals, oils (the hazardousity of the waste is determined by SCE prior to disposal), this waste include wastes (tyres, non-hazardous ash from incinerators, sewage sludge, non-hazardous sludge from industrial processes).

Following Table (2) describes, the classification of MSW in Bahrain.

Table (2)

Classification of MSW in Bahrain

MSW	Generator	Typical Composition
Domestic	Residences, schools, hospitals, open markets, offices, prisons, street cleaning, public parks, public beaches, public recreational areas	Organic waste, paper, cardboard, plastic, wood, textile, leather, coal ash, glass, metal, furniture, napkins, kitchen and personal usage oils and creams, electronics and electrical equipment's, fluorescent lights, batteries, spray cans, medicines, bandages cotton containing blood (although the underlined items are considered hazardous items but people dispose of them together with other domestic waste generated by them).

MSW	Generator	Typical Composition
Commercial	Hotels, shopping centers, stores, restaurants	Paper, cardboard, plastic, organic waste, glass, wood, metal, textile, leather
C & D	Residences and building repairs, new site construction, roads and bridge repairs, sites renovations, sites demolitions	Concrete, wood, soil, aggregate, steel, gypsum
Dead animals	farms, slaughterhouses, street sweepning	Dead body, body parts
Garden	Gardens, farms	Crops, orchards trimming
Non-Hazardous Industrial	Industrial activities, treatment processes	Waste Tyres, non-hazardous ash from incinerators, sewage sludge, non-hazardous sludge from industrial processes

From visual observations at the Asker landfill site during field visits conducted as part of this research work, MSW comprises mainly of C & D building wastes, organic waste, kids' napkins, cloths, papers and cardboards, tyres, woods, electrical pieces, furniture, broken glasses, metals, medicines, crops. MSW generally comprises of the following waste types:

1. **Compostable Materials:**

   Such as foods, wood, crops, orchards trimming, sewage sludge, non-hazardous sludge from industrial processes, textile, leather, fruits, and vegetables.

2. **Recyclable Materials:**

   Such as paper, cardboard, plastic, glass, metals, waste tyres.

3. **Hazardous Materials:**

   Such as electronics and electrical equipment's, fluorescent lights, batteries, spray cans, medicines, bandages cotton containing blood, animal's dead body and body parts.

4. **Inert Materials:**

   Such as soil, concrete, aggregate, non-hazardous ash from incinerators, coal ash, and gypsum.

Most of these wastes brought mixed to the landfill site, and the reason for this is the use of common trash bins to collect them without segregation.

According to data provided for this research work by the MoWMAUP, on the MSW disposal statistics at Asker landfill, and as per their categories, the compositional percentage of each MSW streams disposed at the site for the last year (i.e. 2016) and for the average of 11 years for the period from the year 2005 - 2016, are as in Table (3):

Table (3)

MSW Streams Fractions

MSW Category	2016	Average of (2005 – 2016)
Dead Animals	0.33 %	0.81 %
C & D Building Waste	39.3 %	32.67 %

MSW Category	2016	Average of (2005 – 2016)
Commercial Waste	17.7 %	23.83 %
Domestic	28.1 %	28.96 %
Garden Waste	9.3 %	8.45 %
Non-hazardous Industrial Waste	5.3 %	5.28 %

The data presented in Table (3) shows a consistent MSW streams over the last 11 years, where no considerable variation are recorded in the disposal fractions between the MSW streams.

These data statistics show that C & D building waste, domestic and commercial wastes make the top three highest wastes streams disposed of at the landfill, as shown in Figure (9).

4.2.3 MSW Generation

Consideration of the waste generation should be the first element in the planning process of the waste management sector.

Table (A) in the appendix (2) provides a historical data on the quantities of MSW streams disposed at Asker landfill site based on information provided by the MoWMAUP for the period from the year 2005 to the year 2016.

Figure (9) represents graphically all MSW streams disposed at the site, according to the six categories mentioned in the previous section.

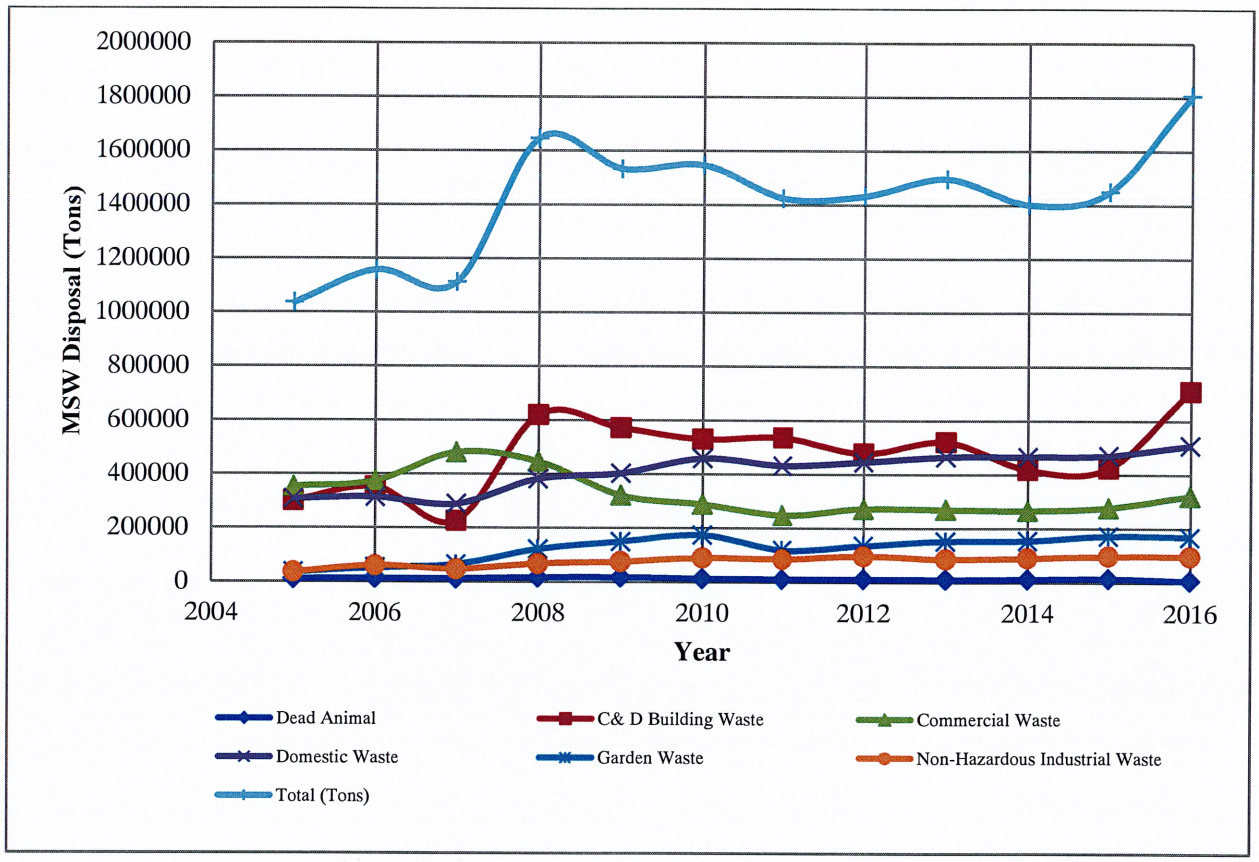


Figure (9)

MSW Disposal Quantities at Asker Landfill Site (tons)

(MoWMAUP, 2017)

The data show an increase of 74.42% in the total MSW disposal quantities from 1034921.1 tons in 2005 to 1805124.2 tons in 2016, in 11 years, with a growth rate of 6.77%.

From the data obtained from the MoWMAUP, the MSW is dominated by high C & D building wastes with an average of 32.67% of the total MSW streams for the period of 2005 – 2016; followed by domestic wastes, then by

commercial, garden, non-hazardous industrial and dead animals waste streams consequently.

The site visits observations have agreed with this official data given by MoWMAUP regarding the dominance of the MSW streams. Table (4) shows the average percent composition of each MSW streams from the total MSW for the past 11 years (2005 – 2016).

Table (4)

Average Percent Composition of the of MSW Streams

Dead Animal	C& D Building Waste	Commercial Waste	Domestic Waste	Garden Wate	Non-Hazardous Industrial Waste
0.81%	32.67%	23.831%	28.96%	8.45%	5.28%

The statistics shows that during the period from 2008 - 2013, C & D waste were the highest constituent of the overall MSW landfilled in the kingdom and then it decreased only in the year 2014, after that it increased again starting from the year 2015 and it reached its peak in 2016 with a disposal quantity of 708632.1 tons as can be seen in records provided by the MoWMAUP in Figure (9).

The increase in C & D waste during the mentioned periods could be due the vast economical development occurred in the kingdom during this period and mainly in the construction sector.

Domestic waste stream (DWS) (i.e. Waste stream that is generated mainly by people, placed in bins and left for the Municipality out-sourced

private contractor to collect) landfilling quantities comes directly after C & D building waste as said above, with a percent fractions of 29.6% of the total MSW in 2005 and 28.11% of total MSW disposal quantities in 2016.

The disposal quantities of the domestic waste show that there is 65.69% increase in the disposal quantities in the year 2016 compared to the year 2005 with a growth rate of 5.97%.

Additionally, Figure (9) shows also that the disposal quantities of the waste stream that are generated by the commercial establishments have decreased during the period 2007 - 2014 and it increased again starting from the year 2015.

While the disposal quantities of the garden waste streams and non-hazardous industrial wastes streams that are generated from the industrial sector working in the kingdom, have showing an increasing and decreasing trends during the period 2005 – 2015 with a dominance of increasing trend.

The dead animal's disposal quantities remained within the range of 9064 to 165071 tons/year during the same period.

Overall, the trend of MSW disposal rates shows a continuous increase in the past 11 years, this trend reflect that Bahrain needs an effective urgent alternative to the waste disposal at the only one landfill available currently for the MSW, as the increase in the disposal quantities are expected to be continued if the Kingdom of Bahrain continued with the same management routine is continued in dealing with MSW.

4.2.3.1 MSW Generation, Population, and GDP

Regarding the question if there are a relation between the population growth and MSW generation?

It can be seen from Figure (10), that:

- In 2016 around 1.4 million persons in Bahrain generated around 1.8 million tons of the overall MSW streams (i.e. 1.3 tons per capita); while
- In 2005 around 888823 persons generated 1034921.1 tons (i.e. 1.16 tons per capita);

Assuming that people living in Bahrain directly and indirectly generate all MSW streams.

Figure (10), shows that there is a proportional trend between these two variables; this outcome is agreeing with what was reported by Al. Ansari (2012) in his published paper (Municipal solid waste management systems in the Kingdom of Bahrain), the same relation between the population growth and MSW generation in the Kingdom of Bahrain.

Other countries also reported that same relation between the population and the MSW generation (Sjöström and Östblom, 2010; Saeed, Hassan & Mujeebu, 2009; Manaf, Samah & Zukki, 2009; Alam et al., 2008).

And as concluded by Al. Ansari (2012): "it is expected more pressure will be put in Bahrain as the population size grows as a result of the proportional relationship between the two variables and specifically with regards to DWS"; this research also concludes the same.

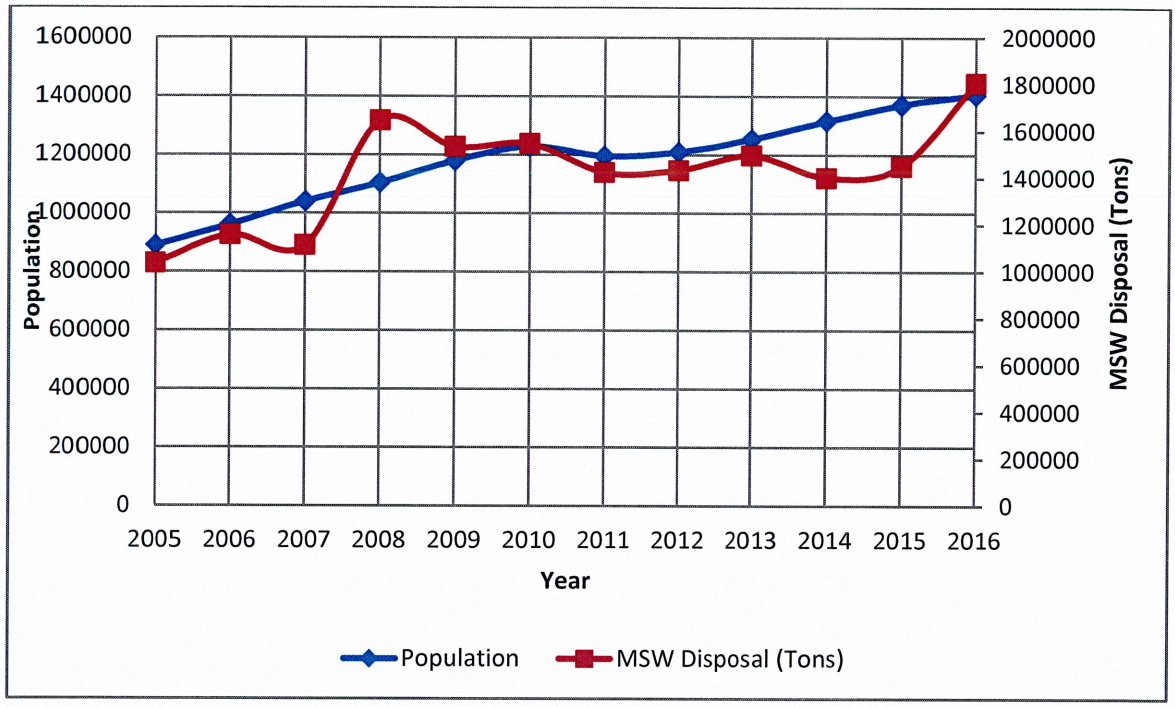


Figure (10)

MSW Disposal Quantities (tons) vs. Population Size (2005 - 2016)

(MoWMAUP, 2017; and CIO, 2015)

In studying the relationship between the population and the MSW generation, it's worth to study the population size and the DWS.

DWS is being analyzed because the generation of this waste stream is directly related to people activities, while the other waste streams - that are disposed at the landfill site - is indirectly generated by the people.

From the data provided by the MoWMAUP regarding MSW disposal quantities at Asker landfill site and the data taken from Bahrain CIO regarding Bahrain's population, it can be seen that:

- In 2005 with a population of around 888823, Bahrain generated around 306202.9 tons of DWS (nearly 839 tons per day); while
- In 2016 Bahrain's population has increased to 1370322 persons and as a consequence the domestic waste has increased to around 507349.9 tons (nearly 1389.999 tons per day for a 365 days a year).

As mentioned above, the increase in the disposal quantities of the DWS for the period from 2005 – 2016 is around 65.69%, and this increase was associated with an increase in the population for the same period of 54.17%.

Thus, it can be said that there exists a linear proportional correlation between the population increase and the domestic waste increase and hence increase in the MSW generation quantities.

Lack of regulations and their enforcements tools on imposing waste elimination, waste minimization, waste segregations, and putting the responsibilities on the waste generators for the management of their own wastes (i.e. the waste generated by themselves) and specifically the services providers, commercial and industrial generators; for example through imposing tariffs/charges, could be one of the other factors that contributed in the increase of the generation of the MSW including the DWS.

Figure (11) shows the correlation between the DWS disposal and the population size.

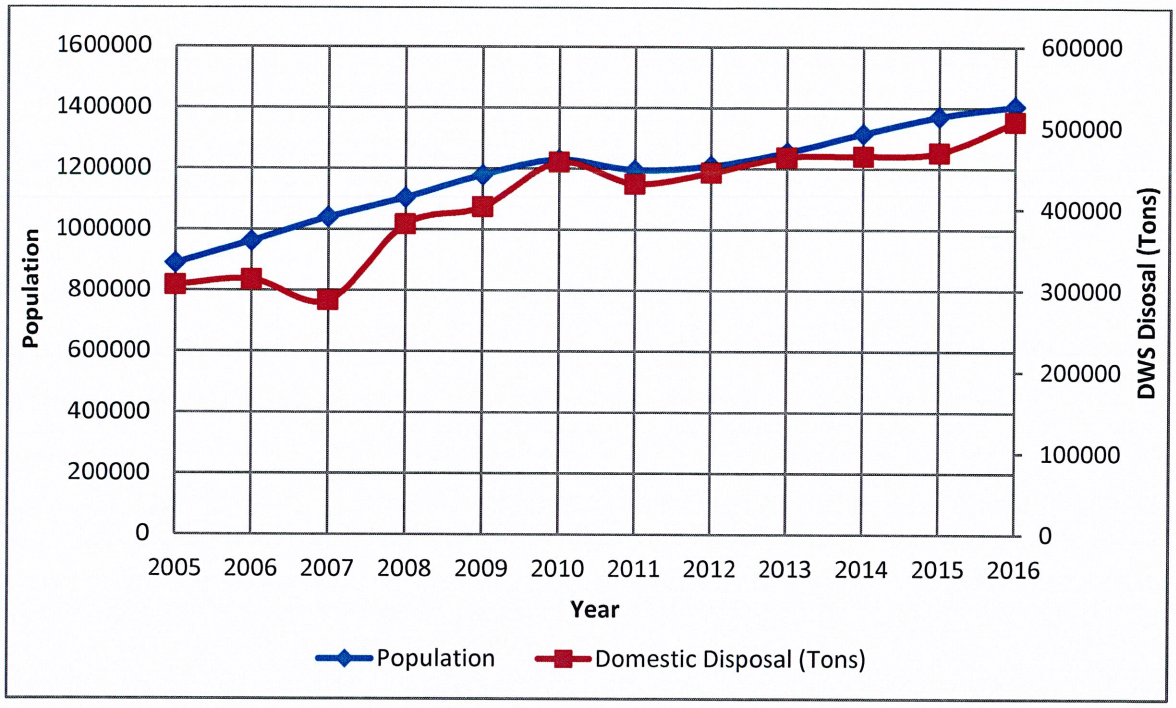


Figure (11)

Domestic Waste (tons) vs. Population Size (2005 - 2016)

(MoWMAUP, 2017; and CIO, 2015)

From the literature review, the per capita generation trend for the Kingdom of Bahrain ranged between 1.1 kg/capita/day for the DWS (Kawai and Tasaki, 2016; Al Sabbagh, 2012), to 1.4 kg/capita/day (Al. Ansari, 2012), to 2.7 kg/capita/day (GCC General Secretariat, 2004). However, the aforementioned references did not differentiate between the overall MSW streams and the DWS except for Al Sabbagh. Therefore, in this research, the waste per capita generation was calculated for both the MSW and the DWS.

In this research, it is assumed that the MSW landfilled in the country is equal to the generated quantity in order to facilitate the research work; and

based on this assumption, the per capita was calculated for both the MSW and the DWS.

The disposal of the DWS per capita is found ranging between 0.757 - 1.020 Kg/Capita/Day for the period from 2005 to 2016 with an average of 0.95 Kg/capita/day disposal quantity.

Although the population showed a linear relation to the DWS disposal, the per capita generation shows no correlation trend for the same period, as reflected in Figure (12). This can be related to other factors such as the GDP, population income, population lifestyle and awareness, in association with population size.

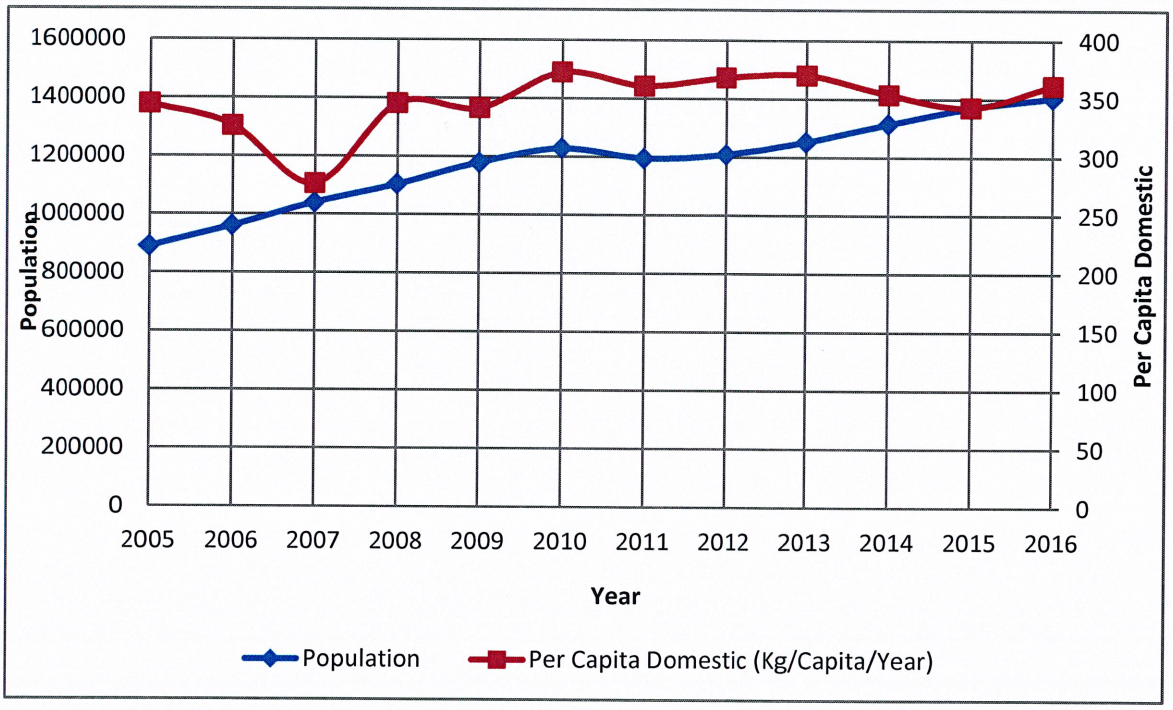


Figure (12)

Per Capita Domestic Waste vs. Population Size (2005 - 2016)

(MoWMAUP, 2017; and CIO, 2015)

On the other hand, the average overall MSW per capita generation is counted to be 3.3 kg/capita/year for the whole MSW streams received at Asker landfill site.

The DWS is the direct waste stream generated by the people living in Bahrain, while the overall MSW streams is indirectly related to the people activities, for example, the non-hazardous industrial waste stream that is being disposed at the Asker landfill site constitute of ashes from sewage and medical waste incinerators, filters and sludge's from seawater reverse osmosis desalination waste, sludge's from sewage treatment plants ...and so forth.

Table (5)

Bahrain Population, GDP, and MSW Generation

Year	Population	GDP (Billion US $)	Total MSW Streams Disposal Quantities (Tons)	MSW Kg Per Capita per Year	MSW Kg Per Capita Per Day
2005	888823	15.97	1034921.10	1164.37	3.19
2006	960425	18.51	1156464.08	1204.12	3.30
2007	1039297	21.73	1111030.90	1069.02	2.92
2008	1103496	25.71	1645505.06	1491.17	4.09
2009	1178415	22.94	1532525.60	1300.50	3.56
2010	1228543	25.71	1546325.52	1258.67	3.45
2011	1195020	28.78	1423279.93	1191.01	3.26
2012	1208964	30.75	1432029.94	1184.51	3.25
2013	1253191	32.54	1495548.69	1193.39	3.27
2014	1314562	33.39	1400963.13	1065.73	2.92

Year	Population	GDP (Billion US $)	Total MSW Streams Disposal Quantities (Tons)	MSW Kg Per Capita per Year	MSW Kg Per Capita Per Day
2015	1370322	31.13	1449392.79	1057.70	2.90
2016	1404000	-	1805124.23	1285.70	3.52

Generally, the increase in the country's GDP increases the income of the people and hence increase their power of purchasing and consequently their consumption of goods, which will impact the generation of the MSW. And this is clearly shown on the international reports where high-income countries generate more waste than low-income countries (Sharholy et al., 2007).

Bahrain's economy has been growing consistently over the last 11 years except for the years 2008 and 2015 as shown in Table (5); this increase is also associated with a general trend of increase in the MSW generation and the population growth.

Figure (10) and Figure (13) shows the correlation between the MSW and the population and with the Gross Domestic Product (GDP), where the quantity of MSW is moving in the same direction with the GDP and the increase in population.

Figure (13), shows that Bahrain has gone through an economic development, and this has led to increasing the per capita income and the living standard of the population, which has also changed the consumption habits of the population. This change towards consumerism habits has led to increase in the MSW generation.

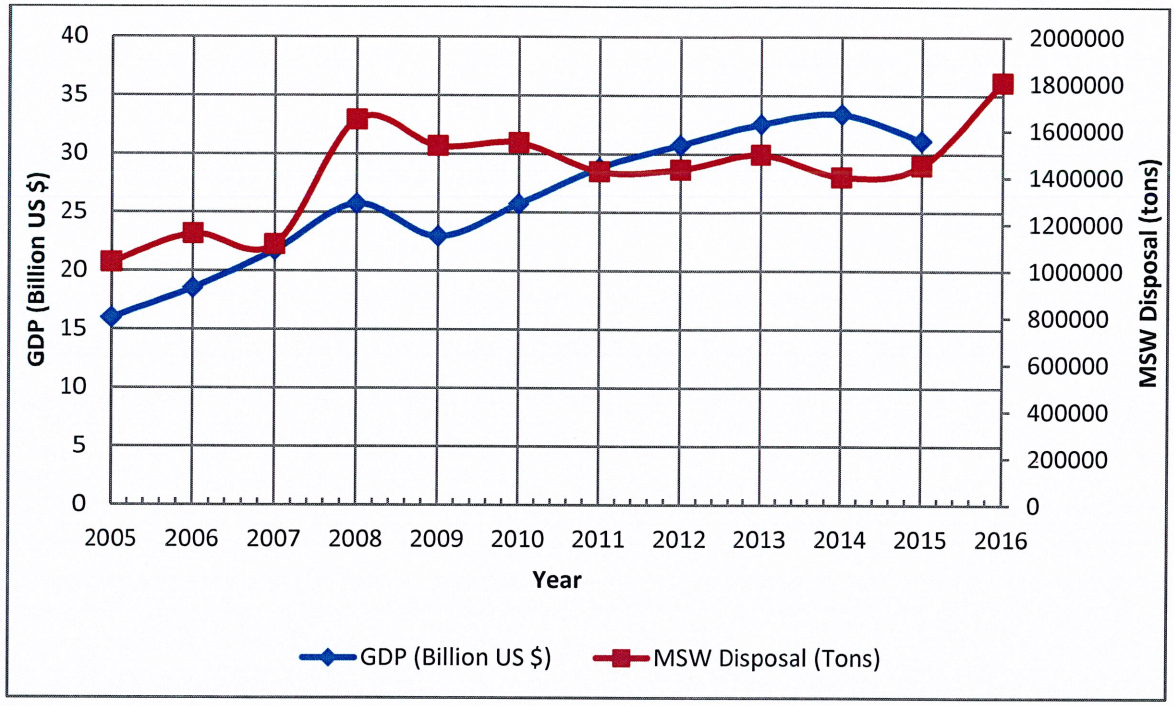


Figure (13)

MSW Disposal (tons) vs. GDP

4.2.4 MSW Management practices

An effective MSW system should comprise of activities that are associated with reduction of MSW generation, segregation, collection, transportation, reusing, recycling, and processing waste streams for resources recovery, and finally disposal in accordance with hygienic, environmental, aesthetic, and economical measures.

However, in Bahrain, the current MSWM activities are mostly shrunk into three formal, organized activities that are a collection, transportation, and landfilling/disposal. A variety of reasons from lack of proper regulation

that obligate the MSW generators to segregate and minimize their waste, to lack or even absence of recycling and processing infrastructure, and lack of awareness of the value of the waste streams in terms of economic, social and environmental incomes, can be the reasons for shrinking the MSWM system in Bahrain.

4.2.4.1 Segregation

Up to now, there is no organized MSW segregation at source system presented in Bahrain either at household level or at community bin and this is due to the absence of an official organized scheme for providing different bins for separating the rubbish; except:

- Few commercial initiatives by some private companies (no official data available) where they provided segregated bins for different waste (i.e. paper, cans, plastics) in some shopping malls, schools, few offices and some commercial areas,

- Some bins provided by Non-Governmental Organizations (NGOs) in some areas and for charity purposes (clothes, papers, used personal items)

- Unorganized segregation and collection practices by unofficial collectors/rubbish-pickers who practicing segregation under unsafe conditions where the efficiency of the segregation is low, because this unorganized sector segregates only valuable discarded constituents

from the waste stream that guarantees them a monetary price in the recycling/trading market.

Accordingly, MSW streams are dumped mixed into collection bins situated in neighborhoods and streets.

The practices of recycling activities in Bahrain are rare due to lack of regulations and enforcement mechanisms, lack of awareness of the waste values "as a resource for other products/service" and the lack of practicing segregation at source.

There is one composting facility in the country - as stated officially by SCE staff - located in Hafeera area - operated by a private company that is processing grass, chicken, and animal's manures to produce organic fertilizers.

Also, few companies are operated in Bahrain who deals with metals, cardboards, papers, and plastics, where these materials are collected from commercial sectors by making contracts with their generators directly, or by depending on the NGOs (voluntary waste recycling) and informal sectors (i.e. Scavengers) who are selling to these companies these materials for processing (e.g. extraction of metals, recycling of plastics) or pre-processing (e.g. shredding, compacting, packing) and exporting.

As said above "no official reliable" data is available on the segregation practices in Bahrain nor on the number of operating waste processing facilities (e.g. re-using, recycling and resources recovery facilities) in Bahrain is formally not available, and there is no official

monitoring by the government authorities in this sector; and this obstructs proper planning of future MSW management practices.

Generally, un-segregating waste makes the recovery of reusable resources difficult and results in requiring more space area/land for their disposal.

4.2.4.2 Collection and Transportation

A collection of MSW is an essential element of the waste management system. Generally, there are no bins for separating the MSW streams, only a few are presented - as mentioned in the previous section – for collecting beverage cans, plastic bottles, papers/cardboard, cloths, and metals, in some shopping malls, commercial areas, schools, few offices and few in residential areas for charity purposes.

With regards to the collection system of the MSW streams that have domestic waste streams characteristics from around Bahrain, currently, two private companies have been contracted/outsourced by the MSW responsible authority in the kingdom (i.e. MoWMAUP) for its collection. The outsourcing of the MSW collection and transportation started in Bahrain in the year 2001 (MoWMAUP, 2017). The fund is allocated from the government budget through the Ministry of Finance for the payment to the private companies for their collection and transportation services.

The two outsourced companies collect daily (365 days a year) the unsegregated trash from all over the four governorates, using its owned

fleets of vehicles and equipment that varies between small, medium, and heavy trucks, compactors, skid steer loaders, and sweepers, to remove the trashs.

The communal rubbish collection system is applied in the Kingdom of Bahrain (i.e. communal collection system). The Communal collection bins with a 1100 liters' capacity are provided at vantage points within the community area (one community bin for around 12 houses as per MoWMAUP) to allow for scheduled pickups and to enable the households to bring their domestic waste at suitable timings at locations that suit them. The collection service is provided for all around Bahrain 7 days per week.

Rubbish bins are also distributed in public areas such as schools, bus stops, markets, roads, walkways, and gardens. The private contractors provide movable bins in order to enable the waste collectors/workers easily move them to the collection vehicles/compactors; bins with a 1100 and 240 liters' capacity are provided in these areas.

The DWS of the MSW, that is mainly generated from houses is usually transferred by the families themselves in a plastic bags into communal bins (either plastic bins or metal bins), from where the domestic waste streams are then emptied into 4, 6, and 10 wheels' vehicles or compactors and then transported to the landfill site for disposal. These communal rubbish bins are also used by some small scale commercial and services establishments for the disposal of their waste commercial type waste along with household waste.

From a walk over observations, the condition of the communal bins found satisfactory throughout Bahrain and this conclusion has been reached

also by Al. Ansari in his 2012 paper titled "Municipal solid waste management systems in the Kingdom of Bahrain" where he showed an overall good and fair levels of satisfaction by the majority of surveyed residents (not excellent nor poor) and by Al Sabbagh et al. (2012) in her paper (Resource management performance in Bahrain: a systematic analysis of municipal waste management, secondary material flows and organizational aspects).

Although, it was observed from the field observations, that some communal container is associated with some problems such as an overflow of waste containers in some areas, ground dumping near the containers is also seen in some areas, open dumping that is associated with uncontrolled emissions, presence of insects, rodents and strong odor is seen in various areas due to leaving the rubbish bins un-closed.

The generators of garden, commercial, C& D building waste, and industrial non-hazardous waste streams are obliged to engage/contract private companies "with a fees to be paid directly to those companies" for the collection and transportation of their nondomestic's waste streams from their premises to the disposal site where a fee for disposal to be paid at the disposal site".

The generators of dead animals (e.g. farms, slaughterhouses, horses stables) are also obliged to engage private companies "with a fees" for the collection and transportation of their waste to the dead animals incinerator that is operated by the MoWMAUP.

In additions, sweeper – from the two companies contracted by the MoWMAUP – sweeps the internal roads manually within Alleys (i.e.

defined blocks) - clearly defined for the sweeper by the private contractors management - (i.e. each sweeper is assigned a specific area), then the sweepers uses the wheelbarrows to transfer the swept waste to domestic waste collection points (i.e. communal bins) where they mixed with another domestic waste stream; while automatic sweeping vehicle are used by the two companies for the sweeping of the main roads and highways and transport the waste that has been swept directly to Asker landfill site.

Finally, the collection efficiency in the Kingdom is considered satisfactory, this conclusion has been agreed upon from the walkover survey conducted by the researcher and through discussions between SCE waste control section staff.

The MSW streams transportation services are provided by the same private contractors that are responsible for their collection on a daily basis all over Bahrain, where they are responsible for transporting the MSW streams to Asker landfill site.

4.2.4.3 Landfilling

The collection and transportation of the domestic waste streams of the country non-hazardous waste streams – including street sweepning – are outsourced to two private companies – under the supervision of the MoWMAUP through their 4 administrative municipalities; where this waste is being transported directly (i.e. there is no transfer station for the MSW) to the landfill site dedicated for MSW in Bahrain (i.e. Asker landfill site).

As per MoWMAUP, the outsourcing does not mean privatization, as the two companies are only mandated to collect and transport the waste, and clean the streets, while the disposal at Asker landfill is till date under the responsibility of the MoWMAUP.

Currently, all the MSW streams are being disposed directly in the landfill without or with minor un-official and un-organized segregation practices, and this is could be due to the absence of rubbish classification mainly.

Asker landfill site receives all non-hazardous wastes generated in the country such as, C & D wastes, commercial wastes, household domestic wastes (although DWS contains some chemical materials, batteries, electronics ... and so forth), garden wastes, and industrial non-hazardous waste (after granting approval from SCE that the industrial waste stream does not contain hazardous materials).

The non-hazardous industrial waste streams include ashes from incinerators, sludge produced from sewage treatment plants operating in the country, textile sludge, where these waste streams are being dumped at the site after approval from SCE and without their supervision on the site.

Dead animals' bodies are also disposed at the landfill site; however, it should be not because it is a hazard material in its nature.

The site receives around 3888.8 tons of waste streams daily throughout the whole week (this average daily estimation have been calculated based on the average yearly MSW disposal quantities provided by the MoWMAUP for the period 2005 – 2016 divided by 365 days), and a ton

of waste (including the and coverage) requires around 1.7 m^3 of the Landfill space.

The Landfill utilizes heavy earth-moving trucks to compact the waste in order to reduce its volume and is used for leveling of the land after waste dumping.

An average of 500 deliveries is made per a day according to the landfill records.

A computerized weighbridge system has been installed at the site to record the delivered streams weight. Trucks delivering the MSW streams information (truck ID number), the origin/source of the waste, date and time of arrival are recorded in the site database; in addition, the category of the delivered waste stream is determined by the site gate staff according to the major constituent of the delivery (dead animal, C & D building waste, DWS, commercial, agriculture, non-hazardous industrial) are recorded in the database.

Although the "Cellular Tipping" disposal method have been practiced for long period of time at Asker landfill site, where the waste is tipped within a "Cell/hole", then compacted and covered with a sand fill material or by sand mixed with uncontaminated C & D building waste using heavy earth-moving trucks (heavy Crawlers); however, this coverage is not practiced on reliable continuous daily basis (although on reliable frequencies; this information is given by the site staff), and this could be due to the high amount of waste being received at the site and could be due to lack of sand available for the coverage.

4.3 Asker Landfill Site

The landfill is a site where unwanted materials (i.e. wastes) are disposed in by burial, and it is considered as the last preferred option for dealing with materials in the waste management hierarchy. Landfilling is still the dominated method for dealing with MSW in the Kingdom of Bahrain, where Asker landfill site is being used for landfilling.

Asker Landfill Site is the only MSW landfilling site in the Kingdom of Bahrain currently, however, not all waste streams entering Asker landfill site are classified as non-hazardous MSW; it presently receives on daily basis an average of 3888.8 tons of waste (this daily average estimation have been predicted based on the average yearly MSW disposal quantities provided by the MoWMAUP for the period 2005 – 2016 divided by 365 days).

Although, from the economical, social, and environmental point of views, the least preferred management method for MSW is landfilling; Landfills should be considered as the final disposal option for un-recovered waste (Tchobanoglous et al., 1993). However, Bahrain is still relying on landfilling of MSW at Asker landfill site, although various and advanced systems are now available for processing the MSW in order to recover resources from them.

Asker landfill site is in the stone quarry area in the southern governorate. The area consists of huge pits/holes; these pits have been excavated by private sector using blasting for the purpose of extraction of rocks which are used for various development works in the country

especially the construction sector. The depth of the pits/holes where the waste is disposed is ranging between 10 to 15 meters (MoWMAUP, 2017).

Currently, the excavated quarries are being filled with the MSW generated in the country. Reutilization of the pits/holes for landfilling purpose could be generally considered as kind of rehabilitating the sites and making benefits from it rather than leaving the holes open without any further investments; however, the site should be sanitary constructed (i.e. with engineered lining, leachate and landfill gases capturing systems) before utilizing it for landfilling purposes to minimize any negative consequences on the surrounding environmental sensitive receptors such as soil, air quality and groundwater or surface waters (if presented) and to protect the nearby residential areas and workforces.

The landfill site is being operated by the Municipalities Affairs of the MoWMAUP, and no treatment facilities of any kind exist at the site.

Asker Landfill site started receiving the MSW in Febreuary1986. The site has exceeded its operational capacity in June 2016; the surface area assigned for MSW disposal purpose were initially 2500000 (around 2.5 square kilometers) with depth ranged between 10 to 15 meters, now the government has extended the landfill surface area by additional 600000 square meters (0.6 square kilometers) with a depth of 15 m in July 2016.

As per MoWMAUP estimations, approximately 1.7 cubic meters is required for each ton of MSW (this 1.7 covers also the sand used for coverage).

Asker landfill site is approximately 25 kilometers from the capital city Manama, around 4 kilometers away from Asker village residential area. The nearness of the residential areas to a landfill that comprises of large quantities of heterogeneous MSW streams, makes these areas vulnerable to emissions of air pollutants, and nuisance such as odor pollution, in addition to nuisance from the passage of trucks delivering the wastes (Palmiotto et al., 2014).

The existing disposal method at Asker landfill site is "Cellular Tipping"; in this method, the MSW streams are tipped within existing holes in the stone quarry area, and then the waste streams are covered with sand.

The landfill sites in some published literature are described to as biological reactors, where the waste contents undergo physical, chemical, and biological change which results in generating gas and leachate as by-products (Regadío et al., 2015).

In Bahrain, The Criteria for sanitary landfills is not practiced at the Asker landfill site, as:

- No continuous sand coverage is applied for the waste at present (i.e. not on daily basis, but however on a continuous basis).
- No lining system.
- No leachate drainage system.
- No gas collection system.
- No groundwater monitoring boreholes provided at the site.
- The landfill gases are released and pose a fire hazard at the site.

Fire occurs occasionally at the dump site. However, the potential impacts of the emitted gases of the fires have never been quantified nor documented. Monitoring of the environmental and health risks at the landfill site is not assessed due to the lack of trained personnel according to the SCE officials. Table (6) summarizes Asker landfill site features, and Figure (14) shows its location.

Table (6)

Asker Landfill Site Features

Features	Description
Location	In the stone quarry area, in southern governorate.
Distance to nearest Residential Area	Around 4 kilometers to Asker Village.
Life of the Site	Around 31 years (since February 1986).
Operation Timings	Saturday to Thursday from 6:00 a.m. to 4:00 p.m. Friday from 6:00 a.m. to 12:00 p.m.
Climate	Desert climate with high humidity.
Area of the Site	In June 2016, it exceeded its operational capacity of around 2.5 square kilometers. The government has extended the landfill area by additional 0.6 square kilometers in July 2016.
Depth of the Filling Waste	Since 1986, the depth ranged between 10 to 15 meters, and since July 2016, the depth of the added area is 15 meters.
Waste Received	Around 3888.8 tons (this average daily estimation has been predicted based on the average yearly MSW disposal quantities provided by the MoWMAUP for the period 2005 – 2016 divided by 365 days) of mixed non-hazardous waste streams per day.

Features	Description
Waste Type	Dead Animals, C & D Building Waste, Commercial Waste, Domestic, Garden, and Non-Hazardous Industrial Wastes.
Waste Category	Non-hazardous Municipal Solid Waste "as classified by MoWMAUP"; although the site is receiving some hazardous waste in its nature (e.g. dead animals, electronics … and so forth).
Cell Planning	Cell by cell is developed, and MSW disposal is allowed only in the designated cells; however, un-contaminated C & D building wastes is stored in designated areas within the landfill site for the purpose of waste coverage at the site (i.e. not all C & D bulding waste are disposed along other MSW streams.
Site Preparation	No lining at the base and sides of the landfill site.
Leachate Management	No leachate management.
Landfill Gas Management	No gas collection nor treatment management system exists at the site.
Application of Soil Cover to the Waste Disposal	Covering of waste is implemented regularly, but not necessarily daily.
Compaction of the Waste	Compaction of waste is applied.
Fire Fighting Management	Around 14000 m^3 of desert sand is stored at the site (on permanent basis) for firefighting contingency plan in case of fire occurrences.
Environmental Monitoring System	No collection samples and analyses of air, groundwater, and soil within nor around the landfill site.
Environmental and Health Impacts	High potential for fires and environmental and health impacts

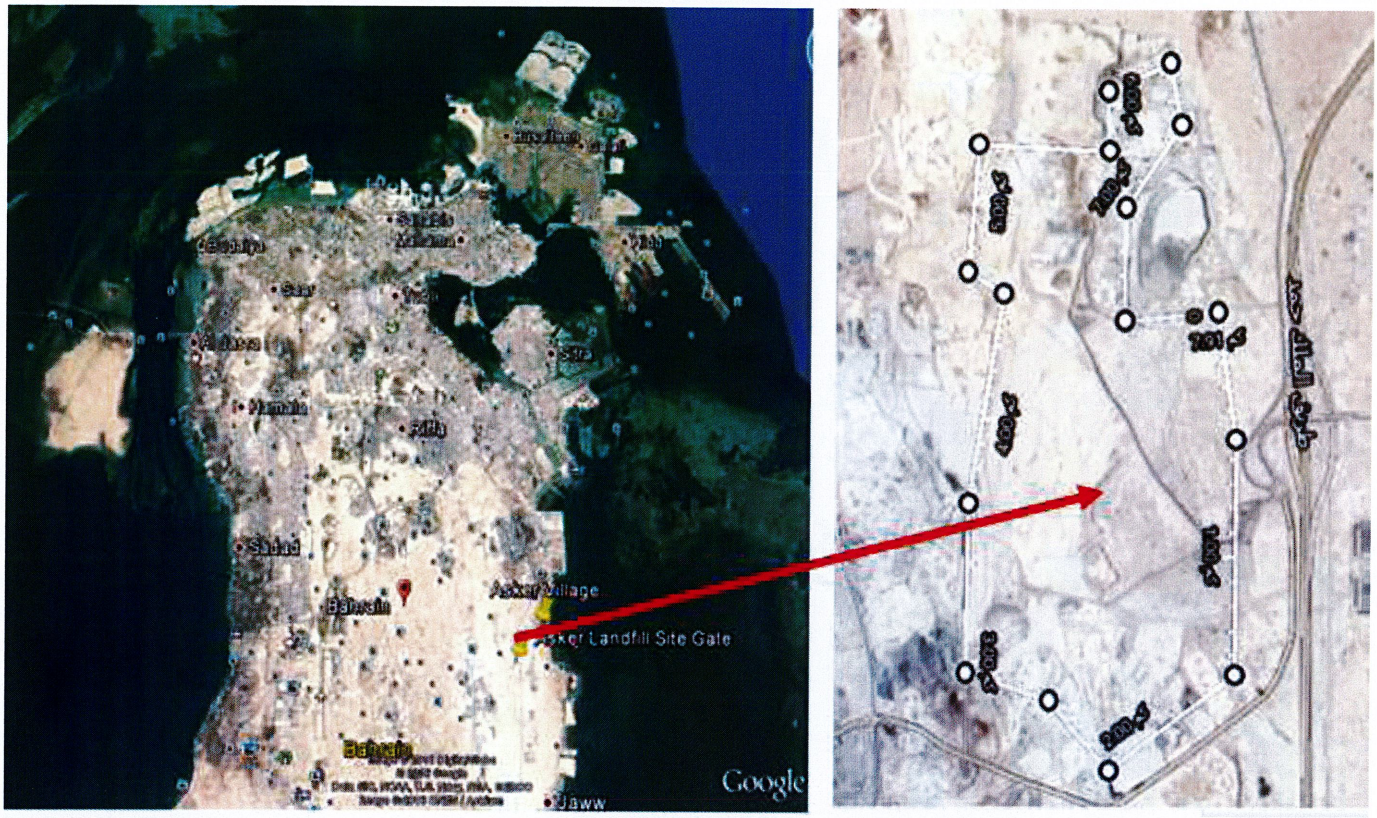


Figure (14)

MSW Asker Landfill (MoWMAUP & Google Earth, 2017)

4.4 Motivation for Changes

The following Table (7) summarizes the gaps in the existing MSW management practices.

MSWM has improved over the past years in Bahrain; however, the MSW generation keeps growing, and the final management practice in Bahrain (i.e. the end of pipe handling) is considered generally unscientific, where final MSW handling is unsanitary landfilling.

The municipality has strengthened its efforts in the collection, transportation, and disposal of MSW to the landfill site. Bahrain is still facing challenges with regard to the segregation of MSW streams and their final disposal.

Bahrain is facing growth in the population size, that is associated with a poor MSW reduction, reusing, recycling and recovery management system; leading to increasing MSW generation which has overwhelmed the saturated capacity of the only existing landfill site available for MSW streams in the country.

The MSWM should be developed in a way that can handle the increasing generation of the MSW.

One of the areas for future practices is to segregate the MSW streams in order to reduce the quantities of MSW that goes to the landfill.

In addition, the MSW can be reused, recycled, and processed for resources recovery, and thus reducing the need for new virgin materials, and at the same time, reducing the stress on the available land areas and avoiding environmental pollution associated with landfilling.

Table (7)

Summary of the Current MSWM Practice in Bahrain

MSWM	Gaps and Weaknesses	Concerns and Challenges
Regulations and Institutions	- Outdated regulation that focuses only on maintaining a clean, hygienic living environment for residents and ignores the enforcement of minimization, recycling, and resources recovery practice. - Absence of MSW strategy for the country - The absence of targets to be reached, in order to set a work plan for reaching those targets. - The absence of legal obligations imposed on generators that can be relied on to promote minimizing landfilling. - The absence of regulations and strategies that promote waste minimization, recycling, and recovery activities. - Lack of integration between the concerned authorities. - The absence of regular environmental monitoring program of MSWM system and specifically at the landfill site. - The absence of official recycling activities data. - Absence or lack of official awareness campaign that presents the importance of MSW minimization and recycling in the country sustainable development plans.	- The gaps led to missing the economical, social and environmental beneficial opportunities, and that has led Bahrain to be far from a sustainable MSWM system where a lot of MSW materials can be recycled and/or recovered and can ,in turn, derive economical benefits to the country and can create jobs in recycling business. - The absence of official recycling activities data in the country has led to missing the opportunities of presenting its importance to the economy and as consequence led to economical loss in terms of not benefiting from the waste and using new materials; it also led to stressing the existing landfill capacity and the associated impacts of using unsanitary landfilling.

MSWM	Gaps and Weaknesses	Concerns and Challenges
MSW Generation	- Increasing trend of the volumes of MSW that goes to the landfill indicates that the current system is unsustainable in terms of the quantities that need to be landfilled.	- Population and economic growth, associated with changing lifestyle increased the consumption patterns of goods which in turn increased the MSW generation. - The growth in MSW generation increased the pressure on the landfill capacity associated environmental impacts of using unsanitary criteria for landfilling in addition to the economic implications of continuous landfilling of resources available with MSW stream.

MSWM	Gaps and Weaknesses	Concerns and Challenges
Segregation	- Papers, cardboard, plastics, metals, and glass are already collected, shredded, packed and exported in Bahrain; however due to the absence of an official segregation system in the country, data on this regards are not available and hence a beneficial conclusion on this sector contribution towards Bahrain sustainable development elements (economy, environmental protection, and social benefits) is difficult to be delivered to the planners and decision makers in particular. - Lack of waste segregation at the source of generation and at the landfill site; leading to losing the opportunities for resource recovery. Recovering materials from MSW streams can: ▪ Provide new commercial/salable materials ▪ Avoid using of raw natural materials ▪ Create jobs in recycling, processing industries, and commercial business ▪ Avoid landfilling ▪ Save land areas ▪ Minimize pollution sources from landfilling practice ▪ Adds value to local economy	- The efficiency of the segregation practice is considered low because the unorganized sector tends to segregate the materials that have economic profit in the recovery business. - Scavengers are practicing segregation in unsafe conditions, due to the absence of official monitoring to this sector. - Segregation of DWS is not usually practiced neither at the source of generation nor at the landfill site, and this is primarily due to the fact that the waste collection system is common for the various wastes generated through communal rubbish bins. In the country, few informal waste pickers sort some reusable and recyclable wastes manually, such as beverage cans, plastic containers, cardboards from community bins. In addition, households sort some of their private things such as clothes and furniture items, where they give them to NGOs for reuse purposes by others either at the country or Abroad. - Dead animals, C & D, and agriculture streams, being collected and transported separately from their generation sources; however, these streams are landfilled mixed with other streams. - With regards to commercial and industrial wastes streams, it can be said that only a few commercial and industrial establishments are partially practicing segregation; where they typically segregate the waste generated into compostable, recyclable and hazardous wastes. The hazardous waste is managed according to the national regulations and signed conventions through coordination the SCE, while the non- hazardous recyclables and compostable waste is sold either to the traders or being sent to Asker landfill where they are again disposed mixed.

MSWM	Gaps and Weaknesses	Concerns and Challenges
Collection and Transportation	- Lack of segregation leads to a collection of huge quantities of waste streams, and this leads to maximizing the costs of waste delivery and traffic congestions in the country. - In addition, the increase in the waste deliveries leads to negative impacts on the environment from the transportation vehicles (i.e. Emissions of pollutants to the environment) and this is associated with negative impacts on human health, in addition, puts more pressure on the economy to offset its impacts on the environment and on the human.	- Domestic waste stream collection system is a communal system, where mostly unsegregated waste is collected. - With regards to dead animals, C & D building, agriculture and non-hazardous industrial wastes streams (i.e. non-domestic and non-hazardous waste streams); private companies that are being engaged/contracted are collecting this streams by their generators; however, this wastes streams are being disposed mixed at the landfill site together with all other waste streams. - From the observations in different commercial areas in the kingdom, it can be said that small-scale commercial establishments rely on the communal waste collection system, where their waste is disposed together with domestic wastes. While medium to large scale commercial establishments' contract private companies for the collection of their waste.

MSWM	Gaps and Weaknesses	Concerns and Challenges
Disposal / Landfilling	- Disposal of high mixed MSW leads to: - Losing the opportunities for resources recovery. - Losing the opportunities for other land development activities that could enhance the country economic and social developments; this associated with the fact that the country is facing a big challenge associated with the shortness in its land areas. - Difficulties regarding the scarcity of sand availability for covering the MSW stream on daily basis. In addition to the associated cost of acquiring the sand. - Generation of landfill gases that impacts the air quality and contributes to climate change, which leads also to impacts on human health. - Landfill gas is not utilized for energy generation purpose, which causes wasting its value as a resource. - Posing fire hazard that again impacts the air quality and contributes to climate change, which leads to impacts on human health. - Generation of leachate and its associated impact on the soil and groundwater, which are indirectly impacting human health. - Breeding of rodents and insects - Creation of traffic nuisance to the nearby residential area. - Generation of odor nuisance to the nearby residential area.	- All MSW streams end up mixed in the landfill site, where no daily sand coverage is applied for the landfilled MSW at present (however, regularly and continuously), no lining system, no leachate drainage system, no gas collection system and no groundwater monitoring boreholes provided at the site, in addition, fire is generated from time to time due to release of the landfill gases. In addition, the funding for the landfill site improvements (e.g. buying advanced compactors) are limited, therefore chances for expanding the lifespan of the landfill are reduced and challenged.

4.5 Asker Landfill Carrying Capacity

4.5.1 Projecting MSW and DWS Generation

In order to project MSW generation, it is assumed that the overall MSW streams generation in the country is, directly and indirectly, dependent on population, and specifically the DWS. It is also assumed that the MSW landfilled in the country is equal to the generated quantity in order to facilitate the research work, and based on this assumption, the per capita were calculated for both the MSW and the DWS, that is equal to the waste generated by a capita/person in the country in a given year.

The calculations were based on the data gathered for total MSW landfilled/generated in the country, for the period from 2005 – 2016. Based on this data, per capita, MSW generation with an average of 3.3 kg/capita/day generation for the last 11 years as mentioned previously were utilized to project the future MSW generation.

In order to project MSW generation, and in order to project how long Asker landfill site can last, the average per capita for the period 2005 – 2016 for MSW and the projected population size till the year 2030 that were obtained from CIO was used for the project. Equations used for the purpose of the calculations are described in section (3.3).

The projected MSW and DWS profile of the projected population are shown in Table (8) below.

Table (8)

Projected MSW and DWS Profile

Year	No. of Months	Projected Population	MSW (Kg)	DWS (Kg)
2016	6	1404000	853210105.4	244532531.7
2017	12	1451000	1749318345	501316490
2018	12	1496000	1803570120	516863865.6
2019	12	1544000	1861438680	533447732.9
2020	12	1593000	1920512835	550377097.5
2021	12	1644000	1981998180	567997456.6
2022	12	1670000	2013343650	576980384.7
2023	12	1747000	2106174465	603583671.9
2024	12	1800000	2170071000	621895025.5
2025	12	1854000	2235173130	640551876.2
2026	12	1910000	2302686450	659899721.5
2027	12	1968000	2372610960	679938561.2
2028	12	2022000	2437713090	698595411.9
2029	12	2078000	2505226410	717943257.2
2030	12	2136000	2575150920	737982096.9

4.5.2 Asker Landfill Carrying Capacity and Scenarios Analysis

This section describes the modelling exercise results of how long the current MSW landfill space can last, applying different scenarios. The methodology of developing the scenarios and the model was described in chapter three for this research. The identification of the problems was based on discussing: what is the main/key pressure on the county from the current MSWM system that needs to be enhanced?.

The enhancement needs of the current MSWM system were addressed based on the critical analysis/thinking on the subject related to the current management practices and the generation trends. The critical analysis/thinking was built on the data gathered from various sources (i.e. Interviews, field observations, discussions with this research supervisor, published an unpublished scientific papers, books, reports, and statistics).

From the critical review of the gathered data and visual observation of the current MSWM system; It was determined that the key issue that needs to be enhanced in an effective way is managing the continuous disposal of the mixed MSW streams at an unsanitary landfill site that is associated with possible pollution to the air, water and soil (practically not monitored in the Kingdom), that is also associated with the fact of a limited lands available in the kingdom.

The investigations of possible alternatives for appropriate an action plan for a sustainable waste management are essential, in order to ensure that MSW is minimized and diverted from Asker landfill site. On this basis scenarios were formulated based on the assessment of the current MSWM system weaknesses, taking into the consideration the past and the current trends, focusing on the critical issue that needs to be tackled as a priority (i.e. landfilling of mixed MSW streams in our case) in order to extend the lifespan of the landfill as a first step towards the system sustainability, by reducing the quantities of the MSW to be landfilled.

For projecting the landfill lifespan, data on current quantities of MSW landfilled was obtained from MoWMAUP. Because segregation and recycling data is not available and there were difficulties in estimating the

rates due to the size of this sector and the involvement of various authorities and the time limit for conducting this research, it was assumed that the MSW generation is the same as the quantities landfilled).

The projected population and the calculated average per capita generation were incorporated into the developed model (described in sections 3.2, 3.3 and 4.2). For the purpose of analyzing the proposed scenarios, The GDP was assumed to be stable, and the remained area from the total area that is already available since July 2016, with a total volume of ((600000 ((length (m) x width (m)) x 15 depth (m)) = 9000000 m^3).

Different scenarios were developed and were critically discussed with the aim of estimating to what degree the landfilling minimization can increase the landfill lifespan, taking into account the projected increases in MSW generation based on projected increase in Bahrain population size.

The results were expressed in terms of the years expected to which the MSW landfill lifespan exhaustion is likely to occur based on the developed scenarios and based on the total landfill space available since July 2016 as mentioned in the previous paragraph. The results also show the additional area required for the projected MSW generation. The results of modelling the scenarios were presented in figures and tables.

An appropriate model that suits Bahrain requirement for calculating landfill area future needs have been developed (chapter three; sections 3.2 and 3.6), and applied for analyzing the developed scenarios.

The modeled scenarios results and discussions are presented in the following subsections; where the developed scenarios were analyzed

through asking what are the implications of the scenarios on the aim that we need to reach (i.e. expanding the MSW landfill site lifespan)?; as answering this question will help in defining action plan options that need to be implemented.

Besides the baseline scenario that depends extensively on landfilling, recycling scenarios for different recycling percent's of DWS and MSW, and landfilling compaction enhancement were investigated, to realize their impact on extending the lifespan of the landfill site by minimizing the MSW that goes to the landfill site.

It's worth to mention that in addition to benefit related to expanding the landfill lifespan associated with recycling, other benefits of recycling were shown in literatures (although in some cases may be associated with other impacts on the environment and/or the economy), such as (but not necessary limited):

- The business investment inputs to the country's economy through investing in this sector.
- Provision of employment opportunities.
- Minimizing the dependence on virgin raw materials for producing new products.
- Positive impacts in saving the natural resources.
- Reducing the negative environmental impacts associated with excavating the virgin raw materials, its energy consumption, transportation, exporting and importing … and so forth.
- … and so forth.

4.5.2.1 Baseline Scenario (S 1)

The description of the baseline scenario is presented in **Table (9)**.

Table (9)

Baseline Scenario Description

Scenario	Description
S 1 (Baseline)	This scenario represents the continuation of the current MSWM system in the country, of transporting and mixed landfilling of the MSW streams at the unsanitary landfill site, without a considerable segregation or treatment (i.e. assuming no action plans towards implementing the waste management hierarchy preferences). The population growth projection was obtained CIO and used in the model; the per capita generation was remained as for the average of the last 11 years, at an average of 3.3 kg/capita/day for the MSW whole stream, and at an average of 0.95 kg/capita/day for the DWS. This scenario assumes 0% recycling of the MSW, where all waste generated in the country are landfilled.

The result of the baseline scenario (S1) presented in Table (10) and Figure (15), shows that if Bahrain continued with the current same system of landfilling the MSW streams, the remaining area of the landfill site will be depleted by the mid of next year (i.e. 2018) almost one year from now.

Therefore, securing additional areas is required now as an urgent action plan, to ensure sufficient handling of the continued generation of the MSW, however securing additional landfill area should be based on sanitary engineered criteria, to avoid the impacts associated with the unsanitary

landfilling, that have been discussed in several sections in this research work.

Table (10)

Baseline Scenario Result

ear	No. of Months	Total MSW (kg)	Domestic Waste (kg)	Total Used Volume (m^3)	Total Remaining Volume (m^3) (length x width x height)	Required Additional Surface Area (m^2)
16	6	853210105.4	244532531.7	1450457.18	7549542.82	0
17	12	1749318345	501316490	2973841.19	4575701.63	0
18	12	1803570120	516863865.6	3066069.20	1509632.43	0
19	12	1861438680	533447732.9	3164445.76	-1654813.33	110320.89
20	12	1920512835	550377097.5	3264871.82	-4919685.15	327979.01
21	12	1981998180	567997456.6	3369396.91	-8289082.05	552605.47
22	12	2013343650	576980384.7	3422684.21	-11711766.26	780784.42
23	12	2106174465	603583671.9	3580496.59	-15292262.85	1019484.19
24	12	2170071000	621895025.5	3689120.7	-18981383.55	1265425.57
25	12	2235173130	640551876.2	3799794.32	-22781177.87	1518745.19
26	12	2302686450	659899721.5	3914566.97	-26695744.83	1779716.32
27	12	2372610960	679938561.2	4033438.63	-30729183.46	2048612.23
28	12	2437713090	698595411.9	4144112.253	-34873295.72	2324886.381
29	12	2505226410	717943257.2	4258884.897	-39132180.61	2608812.041
30	12	2575150920	737982096.9	4377756.564	-43509937.18	2900662.479

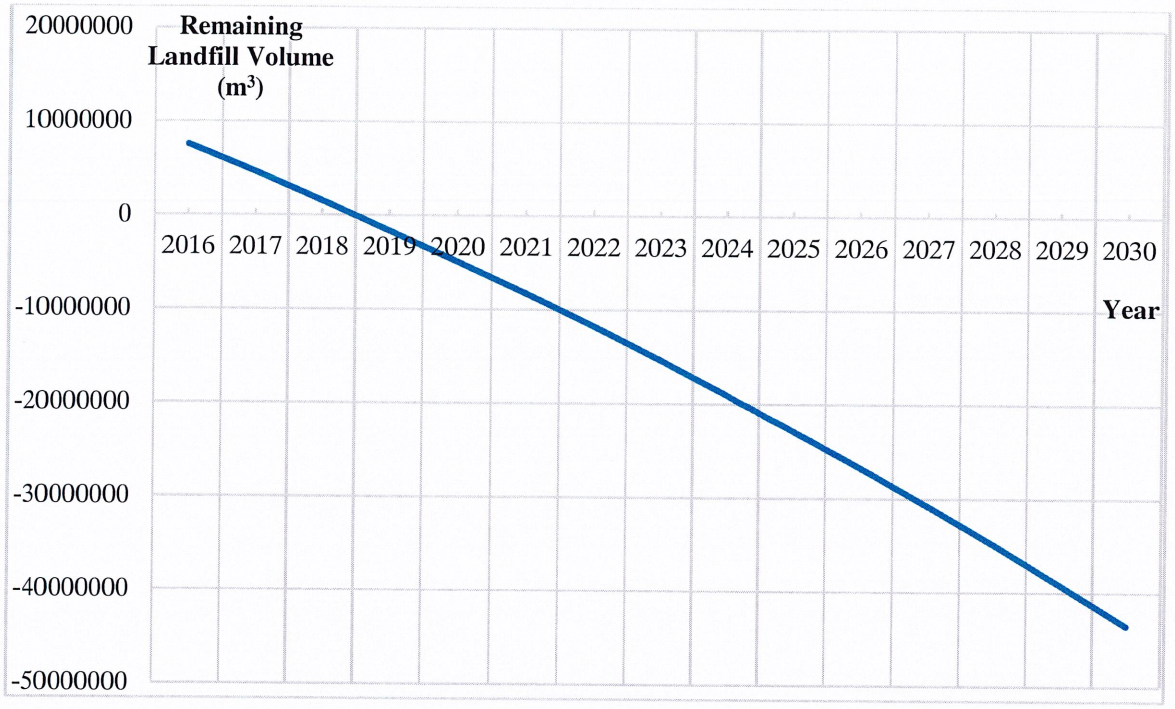


Figure (15)

Baseline Scenario result

Based on this scenario, the government will require an additional surface area of 2.9km^2 to cope with the MSW generation till the year 2030 (around 13 years from now). It's worth mentioning that Bahrain required from February 1986 to June 2016 around 2.5km^2 surface area for the MSW landfilling purpose (for around 30 years).

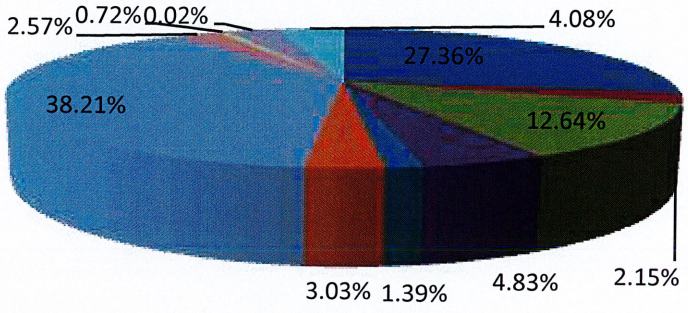
This finding means that less than half of the previous period will require more area for purpose of landfilling if the country continued with the same current system of handling the MSW, adding to this the fact of land scarcity, Bahrain are obligatory to work hard towards minimizing the landfilling to the minimum and that should be in a sanitary manner.

4.5.2.2 DWS Recycling Scenarios (S 2)

Table (11) presents DWS scenarios description, where recycling is proposed for the DWS fractions in sub-scenarios.

Table (11)

DWS Recycling Scenarios Description

Scenario	Description
S 2 Recycling of DWS Fractions only	This scenario represents recycling of the DWS fractions; where recycling of the only DWS is introduced to the current baseline scenario (S 1). In this scenario, the DWS composition that was modeled is based on thesis research submitted in the year 2016 by UoB student (Ms. Eman Ali Salman) described in the data collection section of chapter three. Figure (16) shows that the major constituents of DWS are plastics of 38.21%, and food waste of 27.36%. The population growth projection, the per capita generation, was remained unchanged as used in the baseline scenario (S 1). This scenario has been proposed in order to investigate how an appropriate DWS recycling can improve the current MSW pressure on the existing landfill site and extend its lifespan. Recycling rate of 0%, 60%, 80% and 100% is proposed for overall DWS fractions not for a single fraction within the DWS, although the developed model can take each fraction of the overall DWS fractions and test its impact on extending the landfill lifespan, however, in order to visualize the holistic figure of the DWS recycling impact, the recycling rate mentioned above is used for the overall DWS and not for its fractions for the purpose of this research. * For the years 2016 - 2017 no action plan has been implemented, therefore no recycling values have been placed (the baseline continues the same). ○ 27.36% Food ○ 2.15% Garden ○ 12.64% Paper ○ 4.83% Textile ○ 1.39% Wood ○ 3.03% Glass ○ 38.21% Plastics ○ 2.57% Metal ○ 0.72% C & D ○ 0.02% Diapers ○ 4.08% Others  **Figure (16)** **Domestic Waste Composition (2016)** **(Salman, 2016)**

In DWS scenarios, sub-scenarios were tested to visualize the impact of practicing DWS recycling in extending the Asker landfill site lifespan over the baseline scenario. Those sub-scenarios are 0%, 60%, 80% and 100% recycling of the DWS composition.

As shown in Table (12) and Figure (17), the option of going to DWS recycling will not extend Asker Landfill site lifespan to more than the end of the year 2019 (almost 1 and a half year from now), considering a maximum recycling rate option for this scenario of a 100% recycling for all DWS composition, and not more than the 2018 for other recycling options.

In simplest wording, the landfill lifespan will be extended a one and a half year more than the baseline scenario for a 100% recycling of DWS.

This minimum impact of this scenario could be due to the fact that, the DWS represents only 28.96% of the total MSW streams (i.e. not a huge fraction that could make a huge impact in saving the land space and thus extending its lifespan). Till the government starts implementing this option either by enforcing the segregation at the source of generation or by providing a segregation system at the landfill site, the year 2019 will be reached.

Therefore, it is more effective for the government to focus its action plans – as an urgent need for extending the lifespan of the landfill - to more viable option rather than concentrating on the recycling the DWS fractions of the MSW, as this waste stream is the complex one, because of its heterogeneous constituents of mixed household hazardous and non-hazardous waste.

It is not concluded to ignore the recycling option, but, for the short period action plan, other urgent options for the case of the Kingdom of Bahrain that lacks land areas should be considered. On other hand, recycling DWS will have more impact of the landfill on the environment in general.

One of the options that might be considered by the government for this sector is going for energy recovery by incinerating this waste stream; however, this option could be struggling with the fact that this waste constitute hazardous materials (e.g. batteries, medicines, electronics, light tubes ... and so forth) that are generated mainly by households and are dumped in the rubbish bins without segregation.

Therefore, it is recommended that waste to energy feasibility studies is conducted, so that the government does benefit from this waste in terms of recovering energy and reducing the environmental impacts associated with the DWS landfilling practices. The feasibility study should concentrate on all aspects related to economical sustainability, social profitability, acceptability, and environmental viability and specifically with regards to its constituents of some hazardous materials.

Table (12)

DWS Recycling Scenarios Results

Total Remaining Volume of the Landfill Space After Implementing DWS Recycling (m^3)				
	100%	**80%**	**60%**	**0%**
2016	7549542.821	7549542.821	7549542.821	7549542.821
2017	4575701.634	4575701.634	4575701.634	4575701.634
2018	2388301.002	2212567.288	2036833.573	1509632.43
2019	130716.3919	-226389.5516	-583495.4951	-1654813.326

Total Remaining Volume of the Landfill Space After Implementing DWS Recycling (m^3)				
	100%	**80%**	**60%**	**0%**
2020	-2198514.362	-2742748.518	-3286982.675	-4919685.145
2021	-4602315.592	-5339668.884	-6077022.175	-8289082.051
2022	-7044133.143	-7977659.765	-8911186.388	-11711766.26
2023	-9598537.491	-10737282.56	-11876027.63	-15292262.85
2024	-12230436.65	-13580626.03	-14930815.41	-18981383.55
2025	-14941292.78	-16509269.8	-18077246.81	-22781177.87
2026	-17734030.22	-19526373.14	-21318716.06	-26695744.83
2027	-20611573.3	-22635095.33	-24658617.36	-30729183.46
2028	-23568073.35	-25829117.82	-28090162.3	-34873295.72
2029	-26606454.71	-29111599.89	-31616745.07	-39132180.61
2030	-29729641.71	-32485700.8	-35241759.9	-43509937.18

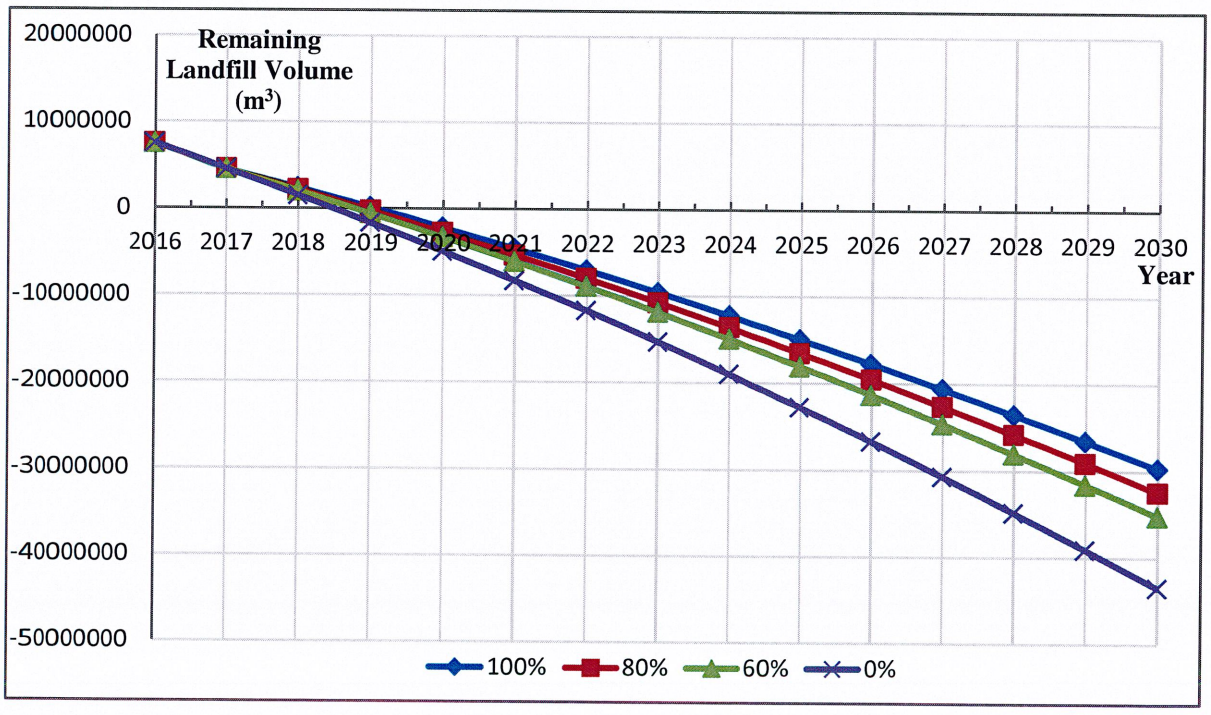


Figure (17)

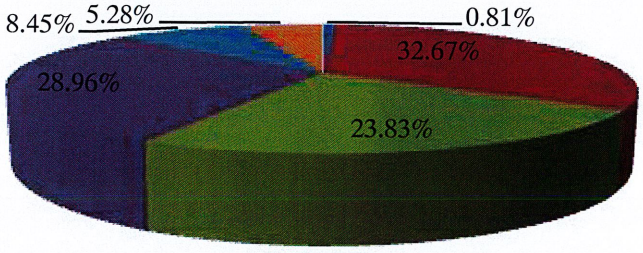
DWS Scenarios Results

4.5.2.3 MSW Recycling Scenarios (S 3)

Table (13) presents the MSW streams recycling scenarios description.

Table (13)

MSW Recycling Scenarios Description

Scenario	Description
S 3 Recycling of MSW Streams, except DWS	This scenario represents the recycling of the MSW streams; where wastes recycling of MSW streams – except for DWS - are proposed to be introduced to the current MSWM baseline scenario (S 1). In this scenario, the MSW streams that were modeled is (based on actual disposal quantities data for the period 2005 – 2016 as an average). The population growth projections, the per capita generation, were remained unchanged as used in the baseline scenario (S 1). This scenario investigates how an appropriate MSW streams recycling can improve the current MSWM and decrease its pressure on the existing landfill site and extend its lifespan. Recycling rate of 0%, 60%, 80% and 100% is proposed for MSW streams except for the DWS that were included in different scenario analysis described in the previous sub-section; although the developed model can take each stream of the overall MSW streams and test its impact on extending the landfill lifespan, however in order to visualize the holistic figure of the MSW recycling impact, the recycling rate mentioned above is used for the overall MSW and not for its individual streams for the purpose of this research. * For the years 2016 - 2017 no action plan have been implemented, therefore no recycling values have been placed (the baseline continues the same). * * The aim of excluding the DWS is that the impact of this waste stream has been tested separately although it could be included, and this stream is considered the most heterogeneous waste type as it is the most unsegregated waste generated mostly by households and constitute of some hazardous constituents such as batteries, medicines, light, electronics … and so forth. ○ 0.81% Dead animals ○ 32.67% C & D ○ 23.83% Commercial ○ 28.96% Domestic ○ 8.45% Garden ○ 5.28% Non-Hazardous Industrial  **Figure (18)** **MSW Average Composition (2005 - 2016)**

Recycling MSW streams – except DWS – will help in extending the life span of Asker landfill site from approximately the mid of the year 2018 (0% recycling - i.e. the baseline scenario) as follows to:

- Mid of the year 2019 for the 60% recycling,
- Beginning of the year 2020 for 80% recycling,
- Year 2022 for the 100% recycling of MSW streams except DWS.

As presented in Table (14) and Figure (19); after these years the given space at Asker landfill site will not be able to serve MSW generation. The results indicate the potential of MSW recycling to extend the existing landfill site lifespan by a few counted years and this is due to the fact that the available area is not huge (only $0.6km^2$ x 0.015km).

Results indicate that by maintaining a 100% recycling of MSW stream additional 3 years from baseline scenario will be extended, in addition to the benefits associated with recycling other than space savings like saving natural resources, providing employment opportunities, supporting country economy, minimizing pollution associated with landfilling … and so forth.

Table (14)

MSW Recycling Scenarios Results

Total Remaining Volume of the Landfill Space After Implementing MSW Recycling (m^3)				
	100%	**80%**	**60%**	**0%**
2016	7549542.821	7549542.821	7549542.821	7549542.821
2017	4575701.634	4575701.634	4575701.634	4575701.634
2018	3687798.654	3252140.88	2816513.768	1509632.43
2019	2771406.807	1886112.936	1000881.371	-1654813.326

Total Remaining Volume of the Landfill Space After Implementing MSW Recycling (m^3)				
	100%	80%	60%	0%
2020	1825932.577	476733.0694	-872371.4843	-4919685.145
2021	850188.9269	-977768.187	-2805596.653	-8289082.051
2022	-140986.1921	-2455272.505	-4769395.943	-11711766.26
2023	-1177862.2	-4000901.273	-6823741.666	-15292262.85
2024	-2246194.663	-5593420.897	-8940411.559	-18981383.55
2025	-3346577.101	-7233716.109	-11120581.55	-22781177.87
2026	-4480196.548	-8923556.377	-13366603.49	-26695744.83
2027	-5648240.041	-10664711.17	-15680829.24	-30729183.46
2028	-6848333.509	-12453641.54	-18058555.09	-34873295.72
2029	-8081663.986	-14292116.97	-20502132.88	-39132180.61
2030	-9349418.51	-16181906.93	-23013914.49	-43509937.18

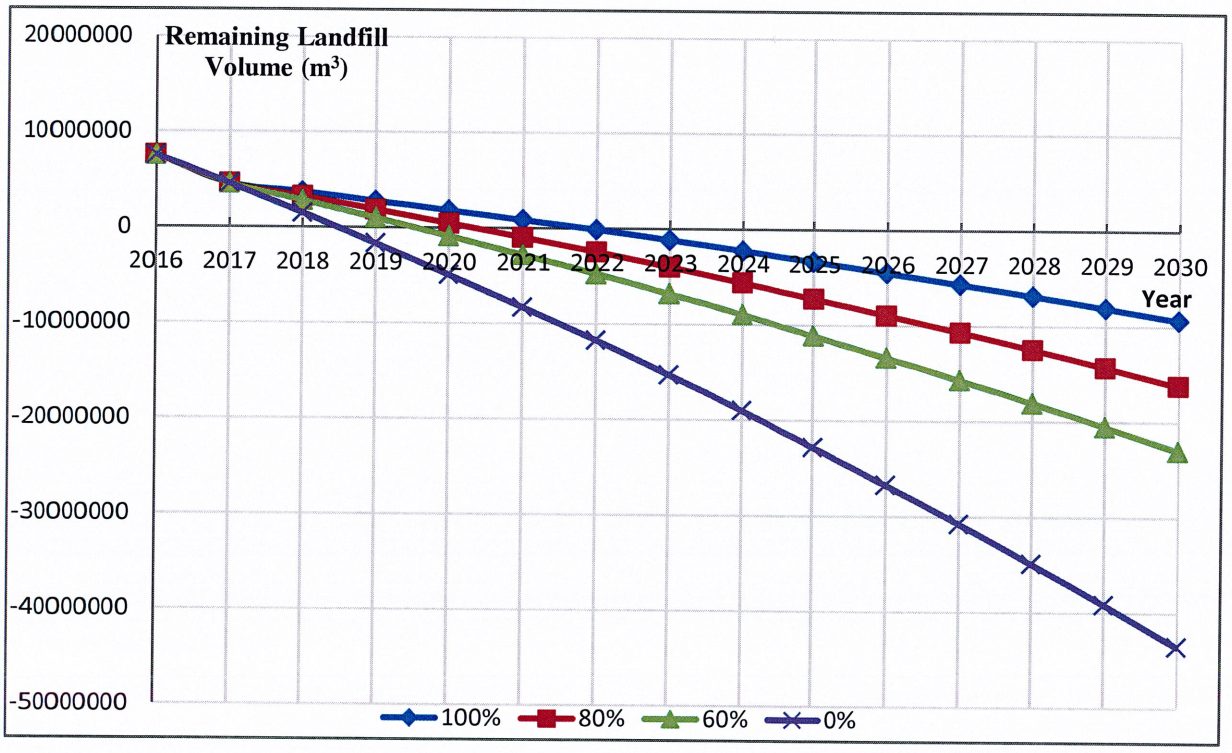


Figure (19)

MSW Recycling Scenarios Results

With the fact that till date no action plan has been announced by the government towards minimizing the landfilling practice, Bahrain will struggle by mid of next year with no spaces at the Asker landfill site for landfilling the MSW; the government – now – should look at a possible logic MSW stream management, that can help in minimizing the pressure on the existing capacity of the existing landfill as a short-term action plan, and this could be starting with working on stream by stream, or could be by working on the compaction factor of the landfilling practice as discussed in below sub-sections.

4.5.2.4 Short Term Action Plans Scenarios

The recycling scenario for the MSW streams discussed below are considered because these streams are brought to the landfill separately (i.e. segregated) therefore, it is assumed that their handling will be easier for any short term future management plans.

4.5.2.4.1 C & D Building Waste Recycling Scenario (S 4)

As a short action plan, the government may work on C & D building waste stream as a startup step, since this stream represents the dominant MSW stream for the recent years, and this waste stream being received at the landfill site separately.

C & D building waste in the case of the Kingdom of Bahrain has been considered as the major MSW constituents with an average of 32.67% for the past 11 years, and this could be due to huge construction works conducted during those years in the country as part of its development process.

This waste stream is generated from construction, renovation, demolition of buildings, house, bridges, roads, and comprise of concrete, tiles, cement, aggregate, clay, soil, asphalt, wood, steel, gypsum. Although landfilling of the C & D building waste is not considered as a preferable management option for this waste stream, in Bahrain, this practice is considered as the primary handling practice for this waste. C & D building waste consume a considerable volume of the landfill space.

Therefore, if we test the impact of recycling of this waste stream only, through running the developed model, it can be seen that the lifespan of the landfill can be expanded another few months from the baseline (i.e. till approximately the beginning of the year 2019) for a 100% recycling (Figure (20) and Figure (21)), and this will give a chance for the government to work on formulating a longer-term action plan, through conducting a comprehensive concentrated fast track study before the year 2019.

Thus, as part of enhancing the MSWM system in the country, short-term measures are encouraged with regards to MSWM system through diverting C & D building waste from the MSW landfill site in order to mainly save the land space and to make benefits from this stream in the construction sector of the country, after conducting specialized safety and

economical research works regarding the feasibility of processing C & D building waste for the purpose of reutilization.

The feasibility study is encouraged to be conducted to make sure the sustainability of the investment in C & D building waste sector for the investors, as the generation of this waste stream, may not be guaranteed in the future.

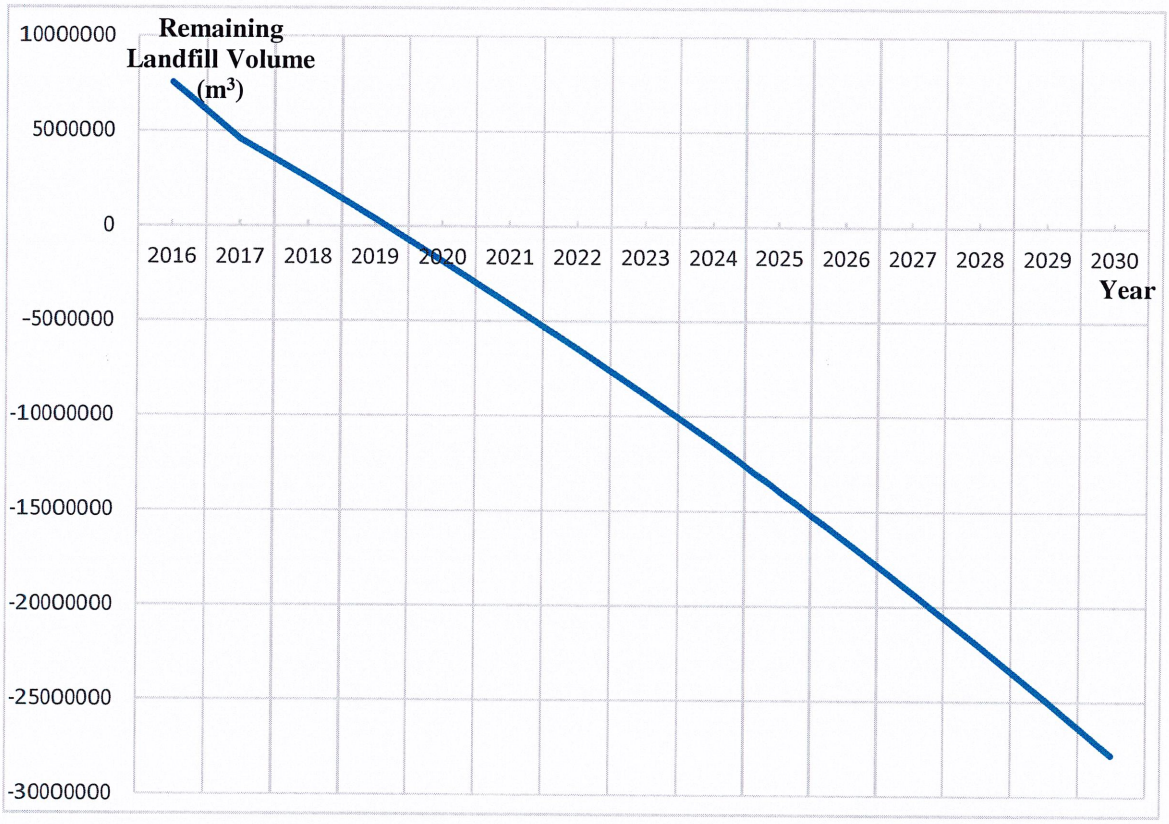


Figure (20)

C & D Building Waste 100% Recycling Scenario Result

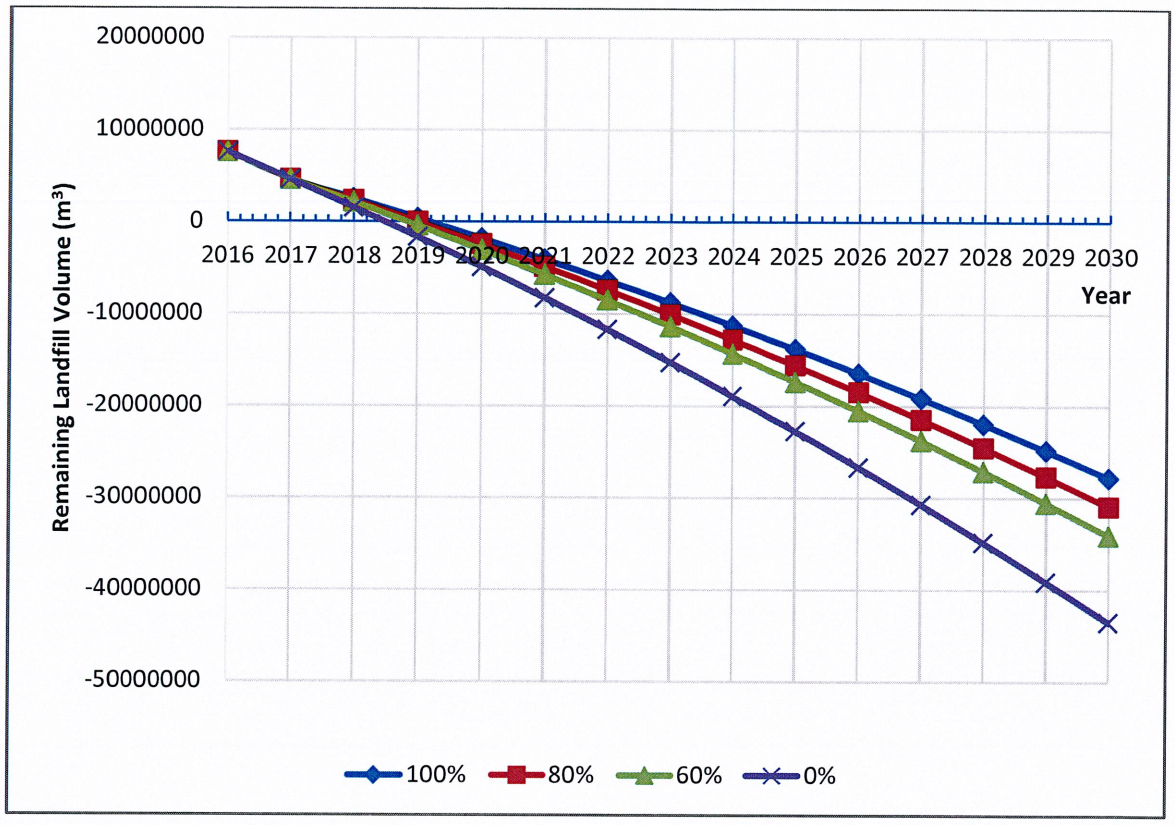


Figure (21)

C & D Building Waste Recycling Scenarios Result

4.5.2.4.2 WT Management Scenario (S 5)

Another short term action plan that the government may consider is the WT processing facility. This type of waste, represents a minor fraction of the total non-hazardous industrial waste landfill at Asker landfill site, less than 0.5% of the overall MSW streams being disposed at the Asker landfill site as presented in Table (15).

The typical content/composition of a tyre as reported by the World Business Council for Sustainable Development (WBCSD) are synthetic

rubber, natural rubbers, carbon black, steel and additives to make the rubber soft and resilient (World Business Council for Sustainable Development, 2008); These materials – at tyre end of life use - can be recovered to produce other materials, fuel, and energy.

WT present a challenge due to their size, shape, and chemical properties that make it hard to degrade fast, in addition to the fact related to Bahrain's small area associated with a large number of vehicles being used in the country. Private passengers' car (i.e. Private vehicles) is the primary transport method for the majority of the nearly 1.3 million residents of the Kingdom of Bahrain, even with the existence of the public transportation system. It can be said that the number of cars being used is linked to the growing number of passenger cars that is linked to the continuous generation of WT which are - till date –disposed at the MSW landfill.

Other challenges associated with WT landfilling are several risks if not managed properly, due to:

- Landfilling of WT means loss of resources that can be recycled.
- The bulky nature of the WT causes problems associated with space required for its disposal, due to the fact that tyres are un-compressed "unless they are shredded or grounded".
- Whole tyres have a tendency to drift/migrate to the top of the landfill as they (tyres) trap air within their structure; this results in collapse between the disposal layers (i.e. Damage the landfill ground structure) causing the instability of the sites ground (Van Beukering & Janssen, 2001).

- Pose fire hazard when stored or disposed accumulated and the difficulties associated with fire extinguishing. In addition, fire emits/discharges pollutants to ambient air, soil and water resources (UNEP, 2002), thus affecting public health and causing economic losses.

- Serve as a breeding ground for mosquitoes and rats when water traps in it (Jang et al., 1998).

MoWMAUP, decided in 2016 to landfill the WT along with all other MSW streams, previously they were landfilled separately, and the reason for that is that to avoid any huge fire caught in case it occur; Although no pre-study was found for this practice for Bahrain. Therefore, it is recommended that the MoWMAUP re-evaluate the decision based on all factors associated with this waste stream such as economic loss that may be encountered in the future due to losing the opportunities for investing in processing this waste for recovery purposes.

Due to the risks associated with WT landfilling practice, this waste stream is no longer being landfilled in European Union countries, this waste stream is totally being recovered for material and for energy (Reschner, 2008), thus Bahrain can benefit from the experience of other countries giving the different practices and their suitability for Bahrain.

However, for short-term urgent plan, the government may start with shredding the tyres to minimize their size and thus minimize space used for their disposal. However, the financial implication of shredding method must be evaluated to ensure securing its finance in future; but again the

government should re-evaluate its decision about not landfilling the WT separately.

Table (15)

Waste Tyre Disposal Fraction

	MSW landfilled (tons)	WT Landfilled (tons)	%
2009	1532525.6	3169	0.21
2010	1546325.515	4460	0.29
2011	1423279.926	3810	0.27
2012	1432029.94	5038	0.35
2013	1495548.686	4718	0.32
2014	1400963.127	4695	0.34
2015	1449392.791	5929	0.41
2016	1805124.228	6730	0.37

4.5.2.4.3 Dead Animals Management Scenario (S 6)

Also, other short-term action plans that are logic are to discontinue landfilling the dead animals with other MSW streams, although it again represents a small fraction of the overall MSW (around 0.81%), this stream is mainly considered hazardous due to its consistency of blood and other organs that may spread bacteria's that may pose health risks in long term period.

A facility is available in the country for incinerating the dead animals, and it is under the responsibility of the ministry itself, however, its capacity is limited. The government should enhance its capacity to receive all the

dead animal waste streams generated in the country. It should be emphasized that the enhancement of the facility capacity should be in an environmentally friendly that does not pose risks to the environmental elements such as air quality.

4.5.2.4.4 Compaction Scenario (S 7)

Ineffective compaction is one of the factors that cause lowering the lifespan of the landfills. Better compaction can add more operation years to the landfills. Therefore, as a short action plan, compaction rate can be considered by MoWMAUP, provided that a suitable financing mechanism to be secured in order to allow for purchasing new compactors, or increase the rate of usage of the available machines (by increasing the number of passages).

From the conversation with SCE waste section staff, it can be said that the waste compaction efficiency depends on the type and weight of compactor, number of passages, the composition of waste streams being compacted, waste moisture content, waste thickness. An attempt has been made to collect this information, however, no reliable data have been found.

Increasing the compaction from 1.7 m^3 for a ton of MSW to 1.3 m^3 for the same waste streams landfilling (including the sand coverage) will expand the lifespan of the landfill to approximately a year more, which will give more chance for the government to prepare for a long-term action plans Figure (22). Therefore, it is recommended to increase the compaction efficiency at the landfill site as a short-term action plan.

Also, another combined scenario of both a 100% recycling of MSW except the DWS with increasing the compaction from 1.7m^3 for a ton of MSW to 1.3m^3 (including the sand coverage) has been tested in the developed model, and it has given an amazing result of expanding the landfill lifespan to approximately mid of the year 2024, an additional 6 years to the baseline scenario Figure (23).

Therefore the government is encouraged to start thinking of increasing the compaction rate and start from now in implementing the short-term action plans for C & D building waste, WT, dead animals as mentioned in the above sections.

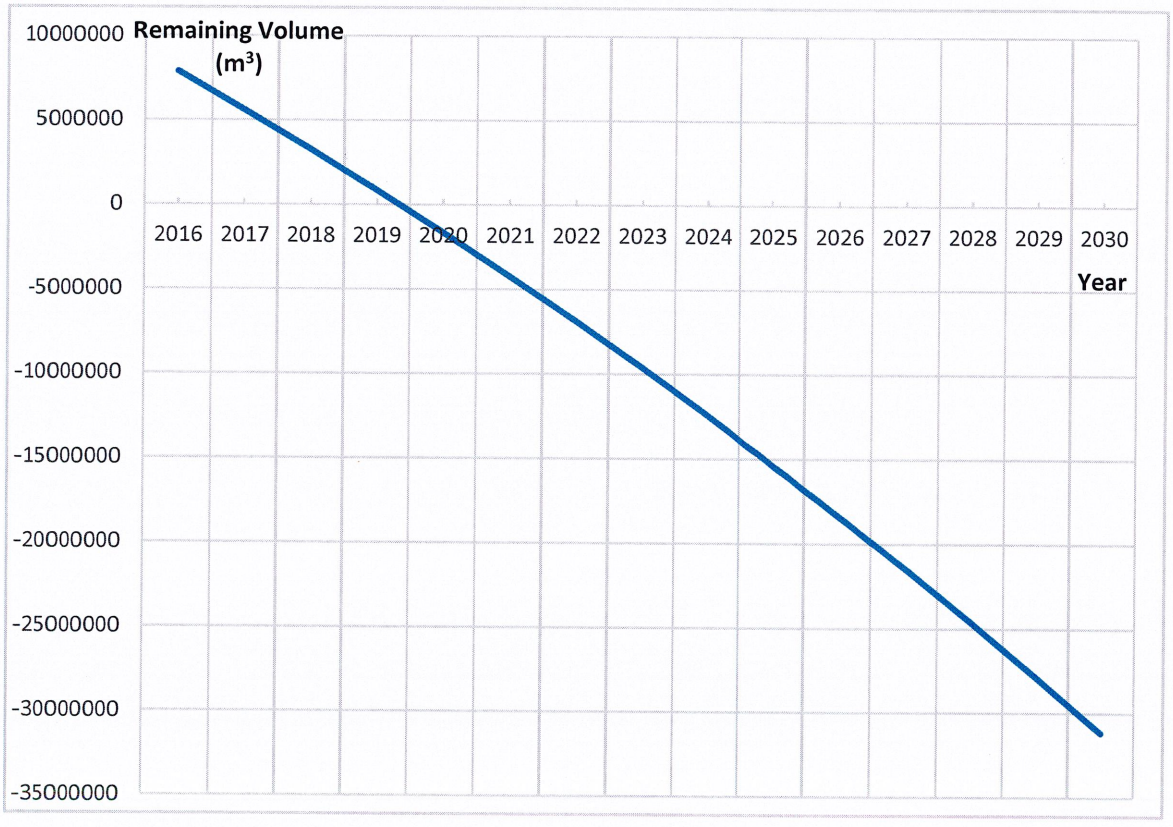


Figure (22)

Baseline Scenario, Combined with Increasing the MSW Compaction to 1.3 m^3/ton

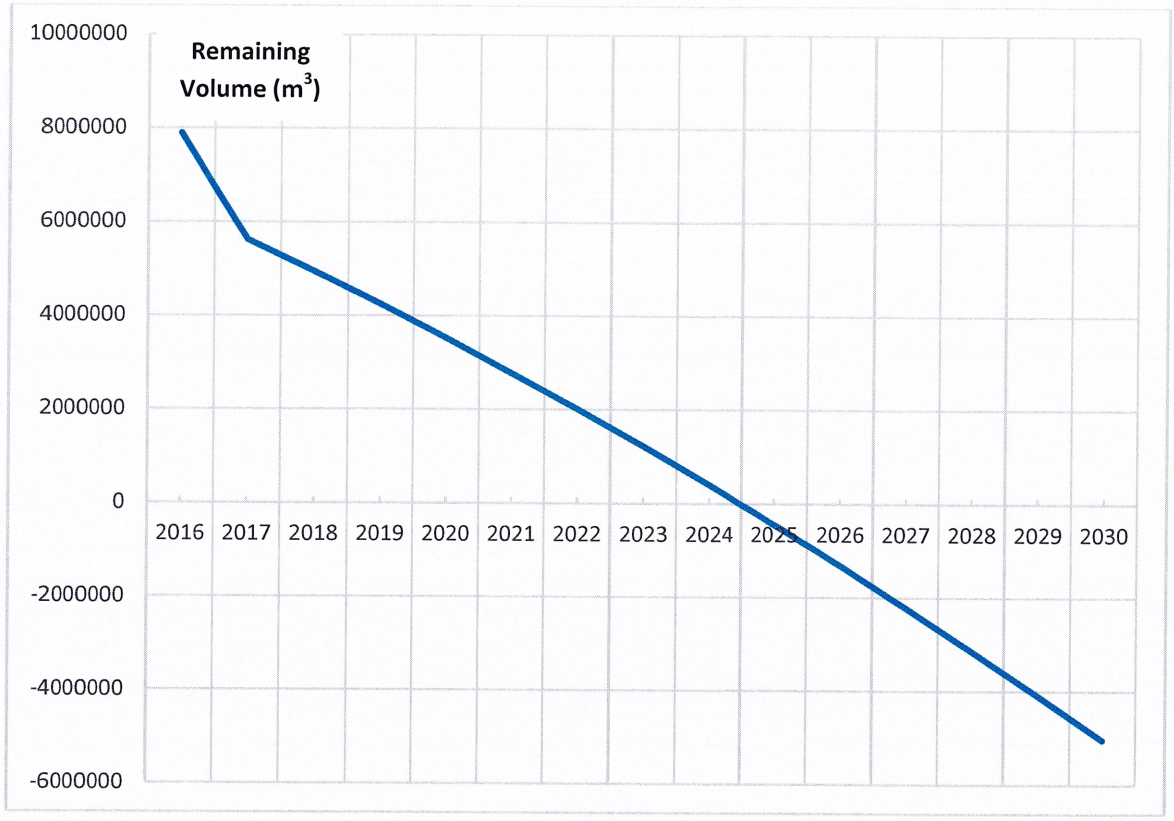


Figure (23)

100% MSW Recycling Scenario except for DWS, Combined with Increasing the MSW Compaction to 1.3 m^3/ton

4.5.2.5 Sanitary landfill as an Urgent Short Term Action Plan

As the 100% recycling is not an easy short-term action plan that could be reached, and as some waste cannot be avoided and no option for handling them the other than landfilling, and as landfill will be required for the waste streams that cannot be treated nor recovered/reused/recycled, therefore a sanitary landfills will always be required for Bahrain.

One of the MSW challenges facing Bahrain government is that there is an urgent need for them to provide a sanitary final disposal method to handle the increasing heterogeneous MSW generation. The current landfilling practice is not environmentally friendly as discussed in chapters one and two.

As landfilling cannot be avoided, and as it is realized by the baseline scenario, Asker landfill site will be able to handle the MSW generated in the country till mid of 2018; Thus, the government should consider establishing sanitary landfill, as a first short term action plan towards enhancing the MSWM system in the country. Sanitary landfills will provide healthier and environmental system for handling the MSW and In order to eliminate the environmental impacts of the current landfilling practice, the sanitary landfill will be the proper solution.

4.6 Long Term Action Plans

The following are summarizing Bahrain needs in order to improve its MSWM system in order to support its overall development processes, and to start developing the country long-term action plan, which will be achieved through the following:

- Enacting regulations that enforce MSW segregation and resources recovery.
- Enacting policies that discourage the production and consumption of products containing needless packaging materials, and encourages the use of reusable and recyclable products.

- Setting up goals oriented with a measurable indicators strategies for the MSWM in the Kingdom with a time framework for achievement, as a step towards setting up program and action plans to achieve those goals.

- Establishing a monitoring system that is governed by ministers' cabinet in order to ensure the implementation of the related regulations and ensures that the concerned authorities are implementing their roles.

- Developing institutional capacity building programs for the institutions working in MSW sector, that enable the workforce to develop and implement appropriate policies towards MSW minimization, reuse, recycling and processing for resources recovery.

- Coordinating the efforts between the concerned parties (i.e. Authorities, the private sector, and public representative) to enhance the MSWM system.

- Setting up a comprehensive reliable database for MSW characterization and quantification and its management system that are managed by a specified national authority (e.g., CIO or MoWMAUP), that can support the effective planning of this sector and to enable the assessment of recycling and recovery opportunities and hence ease the decision making.

- Developing an environmental management system for the landfill site to avoid any pollution consequences of implementing the unsanitary landfilling practice.

- Enhancing the awareness campaigns for public and private sectors.
- Incorporating private sector for establishing environmental friendly MSW recycling and resources recovery (material and energy) facilities, under the supervision of the government.
- Re-evaluating the waste to energy facility and overcome the weakness of the previous concept, especially the concept of incinerating the whole streams (hazardous constituents (batteries, lights, electronics, medicines ... and so forth, in addition to non-hazardous constituents) without considering the recovery possibilities of the recoverable resources.
- Conducting feasibility studies on rehabilitating the existing landfill for the same purpose, however with sanitary measures, or for another purpose, that supports the country development.

4.7 Conclusion

This study contributed to having a good baseline information and data regarding the MSWM system and the landfill site in Bahrain, for supporting its management planning in the future. Improving MSWM is vital for Bahrain. Improper MSW landfilling poses risks to the environment, public health, and the economy.

The weakness and gap analysis revealed that there exist gaps in the regulations, policies, institutions framework, and awareness, MSW processing facilities and landfilling.

The government - though committed to maintaining a hygienic living environment - is struggling with the management of the continuous MSW generation in a sustainable manner, due to its association (i.e. the MSWM) with:

- The population growth.
- Economic development.
- Land scarcity.
- Lack of regulations and policies that enforces segregation and recovery practices.
- Absence of strategies with targets to be achieved with regards to waste minimization.
- Lack of awareness on the value of resources that are presented in the waste streams.
- The unreliable recycling facilities within the country.
- The dependence on unsanitary landfill for MSW landfilling purpose - the only one existing landfill site available in the country for the MSW disposal - that are also associated with environmental, social and economical concerns that are discussed in this research.

The MSW landfill is almost reaching its full capacity by next year (2018) if the current system continued with same practices.

The issue of limited carrying capacity of the existing landfill associated with the continuous generation of MSW that are also associated with the country land scarcity fact, are adding pressure on the government towards solving the problem of landfilling.

The results of scenarios model showed that recycling of MSW streams will make the available space feasible;

- Till the year 2021 at maximum 100% recycling of all MSW streams except the DWS with 1.7 m^3/ton compaction; and
- Till the mid of the year 2024 at maximum 100% recycling of all MSW streams except the DWS with 1.3 m^3/ton compaction.

Current landfill capacity will not be able to keep pace with MSW generation; setting up a segregation for the MSW streams at the source of generation, establishing recycling facilities and constructing a sanitary landfill for unrecoverable waste streams ... and so forth, will enable the government providing better services for the population, the environment, and the economy; however, the segregation and recycling facilities must be linked with the available markets for the recovered materials through conducting feasibility studies.

Although a 100%, recycling is difficult to be achieved especially for mixed streams that contains also hazardous elements, and needs a detailed environmental, technical, social and economical feasibility studies and needs huge investment and to ensure the sustainability of recycling in the country. International standards are encouraged to be benefited from in this regards.

With the fact that recycling requires a considerable investment, infrastructure, and thorough feasibility studies (socially, economically, and environmentally); therefore, the government may work on a short-term action plans such as starting with (this is subject to further specialized feasibility studies as mentioned the sections related to these scenarios):

- Establishing a sanitary landfill (as an urgent action plan). Additional space for MSW landfilling will always be needed, for any waste streams that cannot be processed, due to unavailability of suitable technologies or unavailability for marketing opportunities. Landfills cannot be avoided; however, it should be constructed in well sanitary engineered scheme and for a minimum use.

- Improving the compaction efficiency of the existing landfill.

- Recycling the C & D building waste.

- Shredding the WT.

- Incinerating the whole dead animals waste streams generated in the country.

- Segregation of hazardous materials that presents in the DWS, to reduce the environmental concerns of unsanitary landfilling of this type of waste, and this could be done at the landfill site till the regulations for enforcing households to segregated their waste is enacted ad enforced in the country; however, segregation at the landfill site will require an investment that needs to be secured from the government for maximizing the workforce and to provide the needed equipments.

In addition to short-term action plans; the government is encouraged to focus its plans - from now - towards working on long-term action plan; For example re-evaluating the waste to energy facility concept/project that were proposed previously, and try to overcome the missing from the failed previous concept, which was incinerating the whole streams without

segregating the usable materials and thus missing their value as a raw materials for producing other products (i.e. missing the sustainability of materials consumption), and at the same time emitting dangerous pollutant to the air due to incinerating all types of mixed waste (hazardous and non-hazardous) that include batteries, electronics, light tubes, plastics, rubber, medicines ... and so forth.

Bahrain government has to set up policies and action plans towards minimizing generation before the waste is generated, which could be achieved by minimizing the consumerism habits; therefore, the government should enforce and encourage the use of secondary raw materials rather than virgin raw materials, at both public and industrial sectors; the government should develop capacity building programs of its institutions, and also should enhance the awareness campaigns on MSW sector.

MSW facilities for materials and energy recovery, as long-term action plan, is an essential part for improving MSWM system in Bahrain; It will not only add a value to MSW streams, and to the economy and the public sector, though, for example providing employment opportunities, but it will also help in diverting the MSW from landfills and especially from unsanitary landfills.

4.8 Recommendations

The research aimed at evaluating the current MSWM system in the Kingdom of Bahrain, accompanied by evaluating the factors that have led to gaps and weakness of the system. Moreover, it sought to evaluate the current

landfilling practice in the country along with evaluating the opportunities for expanding the lifetime of the existing landfill site that accommodates the generation of the MSW.

And through the conclusions that have been revealed in the previous section (Section 4.12), the researcher, highly recommends continually addressing the MSWM needs to be based on updated data related to MSW (e.g. generation rates, factors affecting the generation, handling carrying ... and so forth), from social, environmental, economical, technical ... and so forth point of view; as the issues of MSW are a live one, as waste will continue to be generated as long as life on earth is continued.

Sustainable development of the country with regards to the issues related with MSW is reliant on the ability of the management system to accommodate its generation in a sustainable manner, through waste (including MSW) prevention, reduction, reuse, recycling, recovery, and sanitary landfilling of unavoided waste streams. Accordingly, Kingdom of Bahrain should consider the sustainability elements in planning its waste management sector in order to be able to cope with continuous generation of the waste that are associated with land scarcity in the kingdom.

Scenario planning and critical thinking methodologies were used in this research work to recognize the current situation of the MSWM system in the kingdom and to predict how the future may be developed. The application of these methodologies allowed for thinking of possible alternatives to the current system, as they provide the opportunity to visualize and think about multiple situations on how the future might look to allow for preparation for them.

One of the recommendations of this research is to apply scenarios planning and critical thinking methodologies, for strategic planning for various issues in the country, not only the MSW, but also water, energy, transportation, urban planning … and so forth.

Developing an improved database management system, that should be managed by a specified regulated authority in the kingdom, are highly recommended, so that any planning for the MSWM sector in the future will be based on reliable data.

Currently, the significant concern regarding the MSWM system is reducing the demand for land area requirements for MSW landfilling, and this can be achieved by maximizing appropriate processing for recovery purposes of different MSW streams, in order to reduce waste volumes requiring landfilling. The gaps in this aspect can be met by involving the private sector investment in this sector.

MSW legal framework is to be updated to governing various aspects of MSWM, such as giving a specific waste streams definitions, classifications, and responsible management authority with specified roles. Regulations that enforce segregation and recovery activities should be enacted in the country and enforced.

A Formal institutional framework for MSW collection and recycling activities needs to be established to enhance the current informal practices. The formal institution should enhance segregation practices, by providing separate bins for different types of MSW (e.g. plastics, paper, glass, metals, organics … and so forth) in different areas such as public parks, streets, schools, universities, malls … and so forth.

In order to minimize landfill space requirement for C & D building waste; processing and re-utilization of this waste stream should be investigated thoroughly from an economic feasibility point of view mainly not just environmental and resources conservation possibilities.

The WT should be segregated to allow for its possible utilization in future.

The dead animals' waste streams should not be accepted at the municipal waste landfill site, as this waste stream is considered hazardous and could create health issues with time and by accumulation.

Planning for sanitary landfill should be started as an urgent measure for the Kingdom of Bahrain for the MSW streams that are unrecoverable, through establishing a lined ground and installing leachate and gases capturing systems; so that pollution to air, groundwater and soil will be mitigated and energy production infrastructure can be planned and established.

Institutions capacity building programs are encouraged for the institutions working in MSW field.

Awareness programs must be conducted with the focus on the subjects related to the value of the waste streams (i.e. the waste should be managed as a resource rather than a rubbish), and the subjects of environmental degradation concerns. The society and the business sector should be educated regarding the importance of source segregation at the point of generation (e.g. compostable, hazardous, recoverable, and inert) for proper MSW management.

The government should encourage universities, research institution to include waste management in their courses specifically the research projects, as their contribution may help an establishing a database that will help in further enhancement of MSWM sector.

Environmental monitoring programs should be conducted at the landfill site on a periodic basis, to ensure that the ambient environmental quality is within acceptable standards or take a corrective action if deemed necessary at an appropriate time before any incident occurrence.

4.9 Further Surveys and Research Works Encouraged to be Conducted Regarding MSW Sector in Bahrain

Bahrain is still in short of research works related to MSW sector; therefore, there is a need to enhance the researches in this field.

Following are some proposals that are encouraged to be investigated:

- A comprehensive survey should be conducted on the MSW generation and characterization from the sources, in order to build a reliable database for further research work in the MSW field, for example for energy recovery feasibility for the Kingdom of Bahrain, as no updated comprehensive survey have been conducted to characterize MSW generated and landfilled.

- As MSW is heterogeneous in nature, a reliable number of samples (i.e. based on recognized scientific approaches in this field) have to be collected and analyzed to build reliable results for further research work in MSWM sector.

- MSW treatment options conducted worldwide for different recovery options, in terms of their feasibility for the Kingdom of Bahrain from economical and social, beneficiary, acceptability, and feasibility, and in accordance with environmental protection standards.

- Landfill site investigations, to assess the opportunities of rehabilitating the site for purposes such re-utilizing the used pits again for the same purpose (i.e. MSW landfilling) or in construction public parks …and so forth.

- Environmental Assessment studies at the landfill site and its surroundings to ensure its healthiness. The assessment should cover, but not necessarily, the health effects on the public, air, water resources and soil, noise, and vibration effects on surrounding areas and environmental features.

- Waste transportation traveling distances and their contribution to environmental pollution and greenhouse gases emission and climate change; and crowds resulting from trucks traffic on the traveling passage areas.

- Social acceptance of the MSW collection points and collection timings.

- Social ethics contribution to MSW generation.

- The impact of social behavior changes towards sustainable consumption on minimizing the MSW generation.
- Public and private sectors contribution in MSW segregation and recycling industry.
- Private sector role in Municipal Waste Management in Bahrain, and the risks associated with their withdrawal.
- MSW regulatory framework enhancement requirements.
- MSW Institutional framework enhancement requirements.
- Feasibility of landfill gases capturing and re-utilization.
- MSW leachate impact on the groundwater.
- Bahrain MSW generation and the economical factors.
- WT diversion impact on saving landfill space.

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Appendix (2)

Municipal Solid Waste Disposal Quantities

(2005 – 2016)

Table (A)

Bahrain MSW Streams Disposal Quantities at Asker Landfill Site (2005 – 2016) (MoWMAUP, 2017)

Year	Dead Animal	C& D Waste	Commercial Waste	Domestic Waste	Garden Waste	Non-Hazardous Industrial Waste	Total (Tons)
2005	9857.5	298503.8	351971.9	306202.9	34220.8	34164.2	**1034921.1**
2006	11409.0	350217.2	372786.5	312983.5	51014.1	58053.8	**1156464.1**
2007	10912.9	224647.0	479372.7	287205.2	63071.5	45821.6	**1111030.9**
2008	15329.3	617951.2	445508.2	380871.2	120189.1	65656.0	**1645505.1**
2009	16570.5	570455.8	320432.4	402241.2	149153.1	73672.6	**1532525.6**
2010	11643.4	528712.5	287511.1	457335.5	173128.4	87994.7	**1546325.5**
2011	9777.2	534473.5	247013.1	430836.1	117613.1	83566.9	**1423279.9**
2012	10585.0	476163.1	271245.9	444801.2	133999.7	95235.1	**1432029.9**
2013	9063.9	518919.4	268594.3	463859.7	151094.7	84016.8	**1495548.7**
2014	11051.7	416880.4	265420.5	465079.2	153495.4	89036.0	**1400963.1**
2015	13102.0	423174.1	276224.1	469489.4	171415.4	95987.8	**1449392.8**
2016	5971.7	708632.1	320239.1	507349.9	168069.0	94862.4	**1805124.2**

Year	Population	GDP (Billion US $)	MSW Disposal (tons)	MSW Disposal (kg)	Per Capita MSW (tons/capita/year)	Per Capita MSW (kg/capita/year)	Per Capita MSW (kg/Capita/day)
2005	888823	15.97	1034921.1	1034921100	1.164372547	1164.372547	3.190061772
2006	960425	18.51	1156464.08	1156464080	1.204117011	1204.117011	3.298950714
2007	1039297	21.73	1111030.9	1111030900	1.06902156	1069.02156	2.928826191
2008	1103496	25.71	1645505.062	1645505062	1.491174469	1491.174469	4.085409504
2009	1178415	22.94	1532525.6	1532525600	1.300497363	1300.497363	3.563006474
2010	1228543	25.71	1546325.515	1546325515	1.258666172	1258.666172	3.448400471
2011	1195020	28.78	1423279.926	1423279926	1.191009294	1191.009294	3.26303916
2012	1208964	30.75	1432029.94	1432029940	1.184509994	1184.509994	3.245232859
2013	1253191	32.54	1495548.686	1495548686	1.193392457	1193.392457	3.269568374
2014	1314562	33.39	1400963.127	1400963127	1.065726171	1065.726171	2.919797729
2015	1370322	31.13	1449392.791	1449392791	1.057702344	1057.702344	2.89781464
2016	1404000	/	1805124.228	1805124228	1.285701017	1285.701017	3.52246854
						Average	3.302714703

Year	Population	Domestic Disposal (tons)	Domestic Disposal (kg)	Per Capita Domestic (tons/capita/year)	Per Capita Domestic (kg/capita/year)	Per Capita Domestic (kg/capita/day)
2005	888823	306202.9	306202900	0.344503799	344.5037988	0.943846024
2006	960425	312983.48	312983480	0.325880188	325.8801885	0.892822434
2007	1039297	287205.2	287205200	0.276345645	276.3456452	0.757111357
2008	1103496	380871.21	380871210	0.345149606	345.1496063	0.94561536
2009	1178415	402241.2	402241200	0.341340869	341.3408689	0.935180463
2010	1228543	457335.471	457335471	0.372258416	372.2584159	1.019886071
2011	1195020	430836.056	430836056	0.360526231	360.5262305	0.987743097
2012	1208964	444801.18	444801180	0.367919293	367.9192929	1.007998063
2013	1253191	463859.694	463859694	0.370142855	370.1428545	1.014090012
2014	1314562	465079.224	465079224	0.353790254	353.7902541	0.969288367
2015	1370322	469489.369	469489369	0.342612444	342.6124436	0.938664229
2016	1404000	507349.879	507349879	0.361360313	361.3603127	0.990028254
					Average	0.950189478

نموذج رقم (2)

صفحة الاعتماد من قبل لجنة التحكيم

جامعة البحرين

كلية : العلوم

قسم_____

برنامج الماجستير في البيئة والتنمية المستدامة

ناقشت الطالبة/ : مريم محمد عبد الله الأنصاري الرقم الجامعي: 19981612

الأطروحة الذي استكمل بها متطلبات الحصول على درجة الماجستير في : البيئة والتنمية المستدامة

والمعنونة:

Municipal Solid Waste Management in the Kingdom of Bahrain:

Practices and Way for Sustainable Performance

وذلك يوم : الثلاثاء – 6 يونيو 2017

وتوصي اللجنة بمنحها درجة الماجستير بتقدير : A

(لجنة المناقشة)

الدكتورة حنان مبارك البوفلاسه	مشرف	
الدكتور محمد الأنصاري	ممتحن داخلي	
الأستاذ الدكتور أحمد الخولي	ممتحن خارجي	

الخلاصة

قدم هذا البحث تقييمًا شاملًا لنظام إدارة النفايات البلدية الصلبة في مملكة البحرين لتحديد نقاط ضعفه وثغراته. كما قدم البحث تصورًا عن كمية إنتاج النفايات الصلبة البلدية الحالية والمستقبلية بناءًا على ما ينتجه الفرد من هذه النفايات. وقد قدم البحث تقييمًا كميًا لحجم المساحة المتاحة والعمر الافتراضي المتبقي لمدفن النفايات البلدية بناءًا على سيناريوهات مختلفة لخيارات إعادة تدوير وضغط النفايات.

وبين البحث أن كميات التخلص من النفايات البلدية الصلبة في مدفن عسكر للنفايات البلدية قد زادت بنسبة قدرها 74.421٪ من 1034921.1 طن خلال الفترة من عام 2005 إلى 1805124.2 طن في عام 2016 (خلال 11 عام) بمعدل نمو 6.77٪؛ وقد ارتبطت هذه الزيادة أيضًا بزيادة قدرها 65.69٪ في كميات التخلص من النفايات المنزلية لنفس الفترة، التي ارتبطت بدورها بزيادة قدرها 54.17٪ في حجم السكان.

وباستخدام البيانات المتاحة والنمذجة الرياضية، تم تقدير العمر الافتراضي المتبقي للمدفن لسيناريوهات مختلفة. وقد تبين أنه بحلول منتصف عام 2018، سيصل مدفن عسكر للنفايات البلدية إلى طاقته الاستيعابية لسيناريو خط الأساس الحالي، وبالتالي يمكن اعتبار أن الممارسة الحالية تعتبر غير مستدامة بالنسبة للإنتاج المستقبلي المتوقع للنفايات البلدية الصلبة في مملكة البحرين.

وخلص البحث إلى أن توفير مدفن صحي للنفايات البلدية الصلبة يجب أن يكون من أولويات خطط العمل العاجلة لمملكة البحرين للتعامل مع إنتاج النفايات البلدية الصلبة في المستقبل القريب، وبالإضافة إلى ذلك، يمكن الاعتماد على إدارة تيارات النفايات البلدية الصلبة التي تصل للمدفن مفصولة بالأساس ضمن الإمكانات الحالية للبلد (مثال: نفايات الهدم والبناء، نفايات الحيوانات النافقة، نفايات إطارات النفايات) كخطة عمل قصيرة يمكن البدء بها كخطوة أولى نحو الإدارة الشاملة لهذا القطاع. وأظهر البحث أيضا أن تحسين كفاءة ضغط النفايات البلدية بمدفن النفايات كخطة عمل قصيرة المدى من شأنه أن يؤدي إلى توسيع عمرها بنتيجة ملحوظة.

وأشار البحث إلى أن التخلص من النفايات البلدية الصلبة لا ينبغي أن يعتمد فقط على التخلص منها في مدفن صحي مخصص لهذه النوعية من النفايات، ولكن يجب أن تلعب مبادئ خفض النفايات وإعادة استخدامها وتدويرها واستردادها دورًا رئيسيًا في إدارة هذا القطاع ضمن خطط العمل طويلة الأجل.

جامعة البحرين

كلية العلوم

برنامج ماجستير البيئة والتنمية المستدامة

إدارة النفايات البلدية الصلبة في مملكة البحرين: الممارسات والطريق لتحقيق الأداء المستدام

بحث مقدم استكمالاً لمتطلبات الحصول على درجة الماجستير في البيئة والتنمية المستدامة

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19981612

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جامعة البحرين

مملكة البحرين

مايو 2017