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COLLEGE OF ENGINEERING

SUSTAINABLE SOLUTIONS FOR DOMESTIC SOLID WASTE MANAGEMENT IN QATAR

BY

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Committee Page

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ABSTRACT

Due to the fact that Qatar has increased its investments and projects worldwide, Qatar has become one of the world's fastest growing economy and highest paid GDP. As a result, the population has increased in the last few years. This increase in population is associated with an increase in generated waste and accumulation of waste. Waste generation and accumulation is associated with hazards and is harmful to people and the environment. In line with Qatar National Vision 2030, it is important for Qatar to design and develop sustainable solutions for waste management. One of the major waste streams in Qatar is Domestic Solid Waste (DSW). This is waste produced by citizens at their homes. The current practice of domestic waste management in Qatar focuses on collecting all types of wastes from homes and sending the collected waste to landfills. This practice is associated with health and environmental problems, and therefore is not sustainable. In this project, new initiatives, directions and opportunities for sustainable domestic solid waste management and practices were investigated. Prospects for waste collection and waste recycling management system were discussed based on the fundamental principles of location allocation. A two tier sustainable waste management system in which waste from residential areas will be collected and transported to Waste Transfer Stations, sorted at these stations and then transported to dedicated Waste Recycling Plants was proposed. The feasible number and locations of Waste Transfer Stations and Waste Recycling Plants were determined through GIS modeling and simulation. Obtained results show that Qatar needs seven Waste Transfer Stations and three dedicated recycling plants (for paper,

plastic and metals) in order to deal with the issues of waste generation and waste accumulation in a sustainable manner.

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Dedication

A special gratitude to my parents and sisters for their support from the beginning of my master studies.

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Finally, to all my friends with whom I started and finished my master's degree. Lots of ups and downs throughout our studies, but the fun times we spent together and the hard work always helped us in achieving what we had in mind. Sara, Fatima, Mariam, and Alanoud, words can't describe how much fun I had with you before, and hopefully more to come.

1. Chapter 1 – Introduction

1.1 Background of the Study

Waste in general is any undesired and unwanted materials and substances referred to as garbage, trash, junk, or rubbish (US EPA, 2007). According to the EU Waste Framework Directive, even if the disposed material is given to someone who could recycle or reuse it, legally it is still considered as waste, as long as it is no longer required by the person who produced it in the first place.

The fact that waste is generated from different entities, be it consumers, manufacturers, industries or others, different chemical and physical properties will be produced. Therefore, the strategies to handle such wastes will be different depending on the generator type. Waste types or categories have been identified as follows (Bonomo and Higginson, 1988; Tchobanoglous et al., 1993; Pichtel, 2005; Reddy, 2011):

- Municipal
- Medical
- Industrial
- Radioactive
- Construction and demolition
- Hazardous

- Agriculture
- Mining
- E-waste

Domestic Solid Waste (DSW), or sometimes referred to as household waste, is one of the major streams in Municipal Solid Waste (MSW). DSW is the waste generated from residential homes, regardless of the location, type of residence, and the number of residents (Khatib, 2011).

Overall, MSW refers to unused and/or unwanted items thrown away and will no longer be used by households, schools, restaurants, and other public places, that includes food leftovers, plastic bags, plastic water bottles, cans, furniture, packaging, clothing, etc. Even though the sources of MSW might be different, however, types of waste can be similar to a great degree. Table (1) shows some of MSW sources and types (Pichtel, 2005).

Table 1: Sources and types of MSW

Source	Type
Households/Residential	Food leftovers, packaging, metals, appliances, plastic bottles, fabric, cans, boxes, yard waste, newspapers, magazines, napkins, bathroom waste
Commercial (restaurants, offices, grocery store, retail companies)	Papers, boxes, food leftovers, newspapers, napkins, wood, yard waste, packaging, plastic bottles, bathroom waste
Institutional (schools, hospitals)	Boxes, papers, yard waste, food leftovers, bathroom waste
Municipal	Abandoned automobiles, litter

The main factors that influence the generation rate and composition of domestic solid waste in any country are derived from the factors influenced by municipal solid waste, which include: population, seasonality, geographical conditions, and socio-cultural properties (Akinci et al., 2012; Chandrappa and Brown, 2012; Khatib, 2011; Magrinho et al., 2006). According to Khatib (2011), population growth in developed and least developed countries will increase waste generation. Particularly municipal waste discarded by households and waste from hotels and restaurants will have negative impacts on the environment and public health if not properly managed. Despite the fact that waste components are similar to some extent in different countries, the quantity generated is different depending on the economic status of the country. Research has already shown that waste generation rates range between 0.3 - 0.9 kg/capita/day in low income countries, whereas rates range between 1.4 - 2.0 kg/capita/day in high income countries (Chandrappa and Brown, 2012). Besides quantities, the percentage composition of MSW components is one of the elements that differentiate MSW generation rates. For example, people's lifestyle in low income countries generates organic waste that represents almost 50% of the total generated MSW. This is waste that can be decomposed and are biodegradable. On the other hand, the lifestyle in high income countries follows the trend of ordering food more than home cooking, and as a result, domestic waste will include more packing materials, which characterizes the highest percentage of waste generated, while organic waste represents less than 30% (Khatib, 2011).

The development and invention of products, services, and technologies come with environmental burdens **(**Chandrappa and Brown, 2012). The effects of MSW have been widely acknowledged by most governments, however, municipalities with high population growth make it difficult sometimes to even provide the basic waste collection services, due to poor strategy planning by the overwhelmed authorities. So, the uncollected waste would be dumped and left in the streets and drains, which will ultimately result in flooding, spread of insects and diseases. On the other hand, if waste is collected but disposed in uncontrolled landfills, this will increase the pollution of water resources and air (Zhu et al., 2008).

In general, the generation and accumulation of solid waste have many impacts on the well-being of humans, animals, and plants. Waste is disposed in either landfills, water, or is incinerated. If landfills are not controlled and do not follow the appropriate environment regulations and standards, then they will not only occupy the habitats of many animals and attract different insects, but also pollute water, air, and soil, which will eventually cause sicknesses and diseases that may spread over the community. In addition, waste accumulation results in an unpleasant view and bad smell of tons of waste piled up and dumped in large areas of land.

The standard surface water pH according to the U.S. EPA is 6.5 – 8.5, and for ground water is 6 – 8.5. If the pH level is not within this range, then it should be tested immediately as it could contain toxic metals, like: lead, copper, iron, zinc, and manganese (Fakayode, 2005).

Incineration is considered as an alternative to disposing solid waste in landfills (Emberton and Parker, 1987). Regardless of the fact that by incineration, a solid waste will be produced that requires a smaller land area compared to other unprocessed solid wastes dumped in landfills, however, it pollutes the air and harms the ozone layer. This solid waste, or ash, should be analyzed and tested to ensure that it is not hazard. Incineration plants should also be tested frequently to make sure that ash is contained securely and that no toxic leaks into the groundwater exist (U.S. EPA, 2013).

1.2 Solid Waste Management

Waste management is described by many as the collection of waste, transportation, treatment, recycling, resource recovery, composting, and finally the disposal of such waste (Schübeler et al., 1996; Khatib, 2011).

According to Rossel and Jorge (1999), solid waste management planning strategies should advocate avoiding waste generation, using cleaner technology, promoting waste recycling and recovery, using suitable treatment for generated waste and adequate waste final disposal.

The processes and activities related to solid waste management need a decision support system to help overcome issues of this matter. This support system should start by the governments who need to have sufficient planning and focus on the long-term view of this situation. A successful implementation of such a system needs the involvement and the collaboration of all stakeholders to consider the many aspects affecting it. The main stakeholders for the Domestic Solid Waste Management (DSWM) system, which is concerned with the household waste, are the general public, as their degree of awareness and participation affects the creation of either a successful or a failure system. This can be subject to the collection scheme followed by different countries, where the collection of waste from houses is appropriately done in cities with high income population, while the remaining cities rely on any open areas as dump sites. Other reasons are related to the inappropriate selection and design of new landfills and ignoring the opportunities of improving existing dump sites that can actually be used as sanitary landfills (Zhu et al., 2008).

The main goals of creating a DSWM system is to ensure the health and wellbeing of people, save the environment by controlling and monitoring pollution rates, support economic growth and development, create business opportunities and generate employment.

1.3 Solid Waste Management Practices

The United Nations Environment Program (UNEP) published "*Solid Waste Management*" book in 2005 to highlight on the management of MSW in different countries. The source book presented that waste reduction and separation of waste types at the original source are some of the main topics brought to the education of public in the high income East Asia/Pacific countries[1], in order to understand more about the objectives of SMW and the negative effects of waste on health and environment. Household waste in South Korea for example, should be separated and discharged in standard plastic bags bought from the government. As a result, domestic waste per person was reduced by 23% between 1994 and 2009, producing 1.33 kg/day to 1.03 kg/day, respectively. Japan has also noticed a reduction of

1 East Asia/Pacific countries are Australia, Hong Kong, Japan, Korea, and New Zealand

household waste produced. One of the main ideas taught to public is adapting the American concept of “garage sale”, which encourages the exchange of unwanted house supplies with others. In New Zealand, the Waste Minimization Act (WMA) 2008, which encourages waste minimization and disposal, allowed 95% of the population to have access to curbside recycling which helped in reducing MSW (ISWA, 2012).

The United States of America was also successful in promoting the advantages of recycling. As reported by U.S. EPA (2013), recycling rates reached 35% in 2012 compared to 10% in 1980.

In England, the Department for Environment Food and Rural Affairs (Defra) published the first Waste Prevention Program in 2013. The program focuses on the main waste areas that the government and the public should focus on to reduce waste, and the actions to do so. As part of all government departments’ support, implementation plans were developed to prevent food waste and to handle any waste already produced (Defra, 2013). Nevertheless, results show that waste from household has slightly increased to 44.2% in 2013, compared to 44.1% in 2012.

On the other hand, and even though countries of the Gulf Co-operation Council (GCC) are considered to be developed and luxurious nations, they lack the research regarding waste management and they use the large areas of deserts as landfills.

1.4 Sustainable Solid Waste Management

Having a solid waste management system to reduce waste and its effects will not help overcome the whole problems of such waste. Nevertheless, if a sustainable solid waste management system is integrated and adopted by governments, then the chance of not producing waste in the first place is even better.

While solid waste management focuses on the processes of collection through disposal of waste, sustainability focuses on the efficient use of resources in each process to motivate people first on the prevention of producing waste, then reusing and recycling of products and materials, to finally the disposal in landfills and/or incineration as the last and least favorite option.

Sustainable waste management activities was first introduced by the European Union's (1975/442/EEC) in 1975, and then modified in the European Waste Directive 2008/98/EC to include five levels of management, as illustrated in fig. (1)[2].

2 Source: The European Topic Centre on Sustainable Consumption and Production (ETC/SCP)

Figure 1: EU Waste Management Hierarchy

1.5 Problem Statement

Qatar has been considered as one of the highest producers of waste worldwide, as it has a rate of 1.8 kg per capita per day according to world bank figures. As outlined in the National Development Strategy 2011-2016, the strategies related to environmental management should help governmental and private sectors to start planning for more sustainable and eco-friendly systems, that will increase the efforts of recycling and reduce the amount of waste produced. The current waste management system in Qatar will not be able to cope with the amount of household waste produced daily, as the life style of living in Qatar has changed in the last few years, due to the fast growing economy of the country. If a sustainable system for an improved waste management system is not implemented, the negative effects of generated waste and waste accumulation on public's health and environment will increase. There is, therefore, an inherent and urgent need to for Qatar to move towards sustainable solutions for domestic solid waste management. This project investigates initiatives, opportunities and prospects for sustainable domestic solid waste management solutions in Qatar.

1.6 Aims and Objectives

The aim of this project is to identify opportunities and solutions for sustainable domestic solid waste management in this Qatar. The goal is to use GIS modeling and simulation to design a waste management infrastructure that can alleviate problems associated with waste generation and waste accumulation in Qatar. In order to achieve this goal, ArcGIS software is used as a planning and designing tool for determining the feasible number and feasible locations of waste transfer stations that can cover the maximum demand of waste generated from houses. In addition, ArcGIS is used to determine the locations of dedicated recycling plants to ensure the sustainability of the new waste management system and practices in Qatar. The objectives of this project are:

- Study the current waste management system
- Quantify and characterize household waste

- Apply location-allocation models in ArcGIS to determine the feasible numbers and locations of waste transfer stations
- Develop sustainable solutions for domestic solid waste through application of recycling principles

1.7 Significance of the Study

Identifying sustainable solutions for domestic solid waste management is a key starting point towards achieving Qatar's vision 2030. Development and implementations of such solutions has a great impact on the natural environment in Qatar as well as the health and safety of the people of Qatar. Qatar is a rapidly growing nation that aspires to have smart cities in the future. Subsequent implementation of sustainable waste management solutions is amenable to smart cities in which visible waste and liter are not acceptable. Another significant issue of the project lies in the lack of adequate research on waste management in GCC in general, and in Qatar in particular. Therefore, this project can provide a reference for stakeholders interested in investing in waste management including the general public who can understand their roles in realizing sustainable solutions to domestic solid waste management in Qatar and the region beyond. This project also demonstrates that there is a need to increase the efforts of recycling, decrease the generation of household waste, decrease water, soil, and air pollutions, and design a sustainable waste management system to achieve a better and healthier environment.

1.8 Scope of the Study

The project will focus on: (a) quantification and characterization of household waste collected from houses, compounds, and residential towers. Whereas other types of waste are excluded, (b) assessment of the current waste management practice in Qatar; (c) studying the location allocation models using ArcGIS software, to propose new transfer stations and recycling plants in Qatar.

1.9 Limitation of the Study

Waste management studies usually require extensive historical data. One of the limitations of this study was unavailability of Qatar's waste generation data in public databases. For example, waste data for 2014 and 2015 was not available at the time of the study in the database of both Ministry of Municipality and Urban Planning and World Bank.

1.10 Organization of the Project

The project includes five chapters. Starting with an introduction in chapter 1, where a background of the study was presented and some highlights on solid waste management practices. The literature review is presented in chapter 2, with a deep research on the theoretical aspects of sustainability in solid waste management. Chapter 3 focuses on the methodologies used in this project to achieve its objectives, while the analysis and results are reflected in chapter 4. Finally, chapter 5 presents the conclusion and recommendations for future work.

2. Chapter 2 – Literature Review

2.1 History of Waste

Waste has been generated for thousands of years, but its quantities and characteristics have changed over these years based on the standards and lifestyle of living. In 10,000 BC, humans transformed their nomad lives into more civilized ones by moving to and living in the cities. As a result, solid waste mass production increased rapidly. In 2100 BC, the Island of Crete connected homes with trunk sewers. Jerusalem built sewers and water supply in 800 BC. However, it was in 500 BC when actions were taken towards waste, and not because of its effects on human health or the environment, but because it was threatening many countries in different aspects. For example, Athens passed a law requiring all waste to be disposed miles away from town, as rubbish piles next to the city walls gave opportunities for invaders to climb up and jump over the walls. The same problem was faced in Rome, where eventually a waste collection system was developed in 14 AD. In the Middle Ages, Europe was characterized as "unimaginable filth", as animals strayed around cities, and in 1300, the Black Death led to the decease of a large number of people, which was to a great degree the result of the filth existed (Vesilind et al., 2002).

In the 1840s, Edwin Chadwick, a lawyer and public health activist in England, claimed that there is a connection between diseases and filth, however, this theory was not accepted until John Snow, a health physician, suspected that water from the Broad Street bump was contaminated and the cause of the cholera epidemic. In the

19th century or “The Great Sanitary Awakening” as called by Charles Winslow, a public health figure and expert in the United States and the Western World, public became more aware of the relationships between the spread of diseases and sewage water, and how it is crucial to avoid drinking this contaminated water (Worrell and Vesilind, 2012).

In 1900, when the coastal cities of the United States became more urbanized, waste quantities increased and their disposal was practically done by loading large barges, which would dump all waste into the water. About 80 years later, the media started focusing on the hazards of waste refusal and its effects on the environment, especially after knowing that the current waste management system was not working properly, and the fact that there was no “away” for throwing waste away. One of the incidents that were alarming to Americans is the fact that barge Mobro was carrying medical wastes, and it could not discharge it into the ocean, as it became an illegal action to do so. Also, the captain of Mobro was unable to unload the barge in landfills as they were all full, and the barge was turned away by many states and countries forbidding it to dump its waste on their lands. Eventually, a municipal solid waste incinerator was developed to burn aged wastes. After this incident, reporters claimed that the United States will soon be covered with solid waste and people will be buried with garbage, unless something is done about this issue (Pitchel, 2005)

As stated in Singapore’s Environmental Public Health Act (EPHA) 1968, nowadays waste is considered to be: (a) materials with scrap substances or other undesirable substances arising as outputs from any process, (b) broken, contaminated, spoiled materials, and (c) anything that is considered to be surplus until it is proven to be other than that. Since then, a number of ways for defining MSW have been presented. For example, Schübeler et al. (1996) stated that MSW is any *"refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings"*. The Municipal Solid Wastes in India under the Management and Handling Rules (1999) referred to it as *"commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes"*. While the U.S. Environmental Protection Agency (EPA) (2008) defined MSW as *"the materials traditionally managed by municipalities, whether by burning, burying, recycling, or composting"*. The United States Environmental Protection Agency (2013), defined MSW as items *"used and then thrown away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries"* coming from "*homes, schools, hospitals, and businesses*".

By means of using and collecting official statistics and data available in governmental publications and provided by international agencies, the World Bank published "What A Waste: A Global Review of Solid Waste Management" report in 2012. The report revealed many data related to waste generation, and showed that the amount of waste generated had increased from 0.64 kg/capita/day (0.68 billion tons) in 2002, to 1.2 kg/capita/day (1.3 billion tons) in 2012, which was the result of population growth that was 2.9 billion people, increasing to 3 billion people, in 2002 and 2012, respectively. The report also covered in details the amount of waste generated, collected, and disposed for almost every country around the world.

As fig. (2)[3] illustrates, OECD countries produced nearly half of the total waste generated in 2012, about 572 million tons, whereas AFR and SAR produced the least.

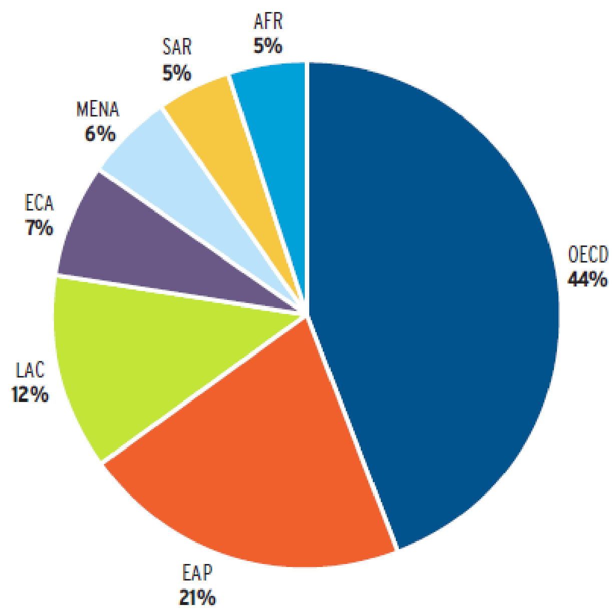

Figure 2: Waste Generation by Region, 2012

3 Source: What A Waste: A Global Review of Solid Waste Management

Data of waste generated was also presented based on country income. Countries were categorized as low income (LI), lower middle income (LMI), upper middle income (UMI), and high income (HIC) countries[4]. Figure (3)[5] is from the report and shows this category.

4 According to World Bank estimates of 2005 (High: $10,726 or above; Upper middle: $3,466-10,725; Lower middle: $876-3,465; and Lower: $875 or less)

5 Source: What A Waste: A Global Review of Solid Waste Management

Lower Income (LI)	Lower Middle Income (LMI)	Upper Middle Income (UMI)	High Income (HIC)
Chad	Bulgaria	Colombia	Barbados
Comoros	Cameroon	Costa Rica	Belgium
Congo, Dem. Rep.	Cape Verde	Cuba	Brunei Darussalam
Eritrea	China	Dominica	Canada
Ethiopia	Congo, Rep.	Dominican Republic	Croatia
Gambia	Cote d'Ivoire	Fiji	Cyprus
Ghana	Ecuador	Gabon	Czech Republic
Guinea	Egypt, Arab Rep.	Georgia	Denmark
Haiti	El Salvador	Grenada	Estonia
Kenya	Guatemala	Jamaica	Finland
Lao PDR	Guyana	Latvia	France
Liberia	Honduras	Lebanon	Germany
Madagascar	India	Lithuania	Greece
Malawi	Indonesia	Malaysia	Hong Kong, China
Mali	Iran, Islamic Rep.	Mauritius	Hungary
Mauritania	Iraq	Mexico	Iceland
Mongolia	Jordan	Myanmar	Ireland
Mozambique	Lesotho	Namibia	Israel
Nepal	Macedonia, FYR	Panama	Italy
Niger	Maldives	Peru	Japan
Rwanda	Marshall Islands	Poland	Korea, South
Senegal	Morocco	Romania	Kuwait
Serbia	Nicaragua	Russian Federation	Luxembourg
Sierra Leone	Nigeria	Seychelles	Macao, China
Tanzania	Pakistan	South Africa	Malta
Togo	Paraguay	St. Kitts and Nevis	Monaco
Uganda	Philippines	St. Lucia	Netherlands
Vanuatu	Sao Tome and Principe	St. Vincent and the Grenadines	New Zealand
Vietnam	Solomon Islands	Suriname	Norway
Zambia	Sri Lanka	Tajikistan	Oman
Zimbabwe	Sudan	Uruguay	Portugal
	Swaziland	Venezuela, RB	Qatar
	Syrian Arab Republic		Saudi Arabia
	Thailand		Singapore
	Tonga		Slovak Republic
	Tunisia		Slovenia
	Turkey		Spain
	Turkmenistan		Sweden
	West Bank and Gaza		Switzerland
			Trinidad and Tobago
			United Arab Emirates
			United Kingdom
			United States

Figure 3: Classification of Countries According to Income

As mentioned earlier, population growth and economic status of any country are main factors to affect waste generation. Figure (4)[6] demonstrates how urbanization changed between 1990 and 2013 based on the income level.

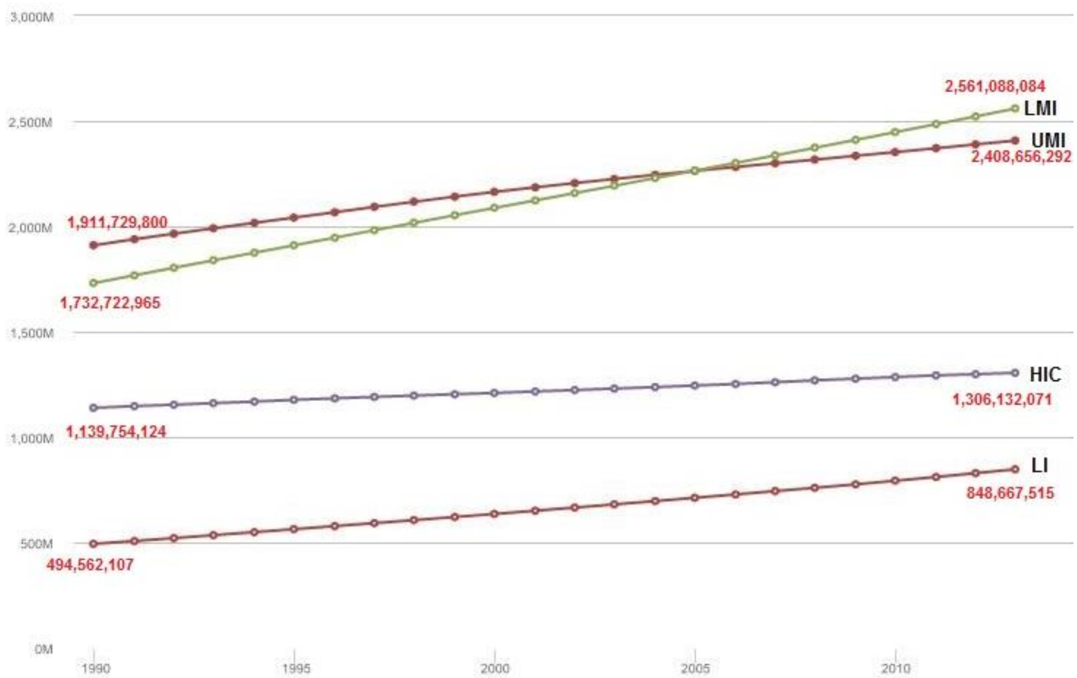

Figure 4: Population Growth Based on Income Level, 1990-2013

Statistics proved that high income countries generate the highest percentage of waste (46%), while low income countries generate the least (6%). The reason behind having

6 Source: What A Waste: A Global Review of Solid Waste Management

a higher generation rate in lower middle income than upper middle income countries as shown in fig. (5)[7], is because China is considered to be a LMI country, and its average waste generated per capita is relatively high in comparison to the economic status of the country.

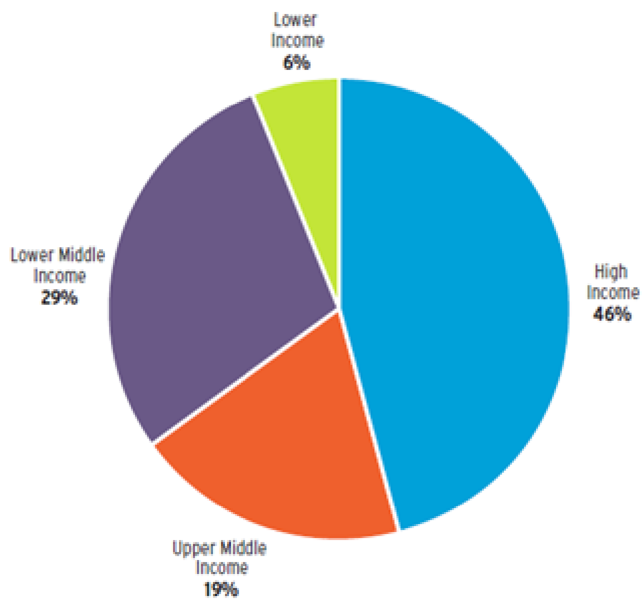

Figure 5: Waste Generation by Income, 2012

The World Bank used these current waste generation data to predict the generation in 2025 by "*factoring expected growth in population and GDP and estimated per capita*

[7] Source: What A Waste: A Global Review of Solid Waste Management

waste generation". Results show that waste will almost be doubled by 2025, reaching 6,069,705 tons/day compared to 3,532,256 tons/day. Figure (6)[8] demonstrates the predictions of 2025.

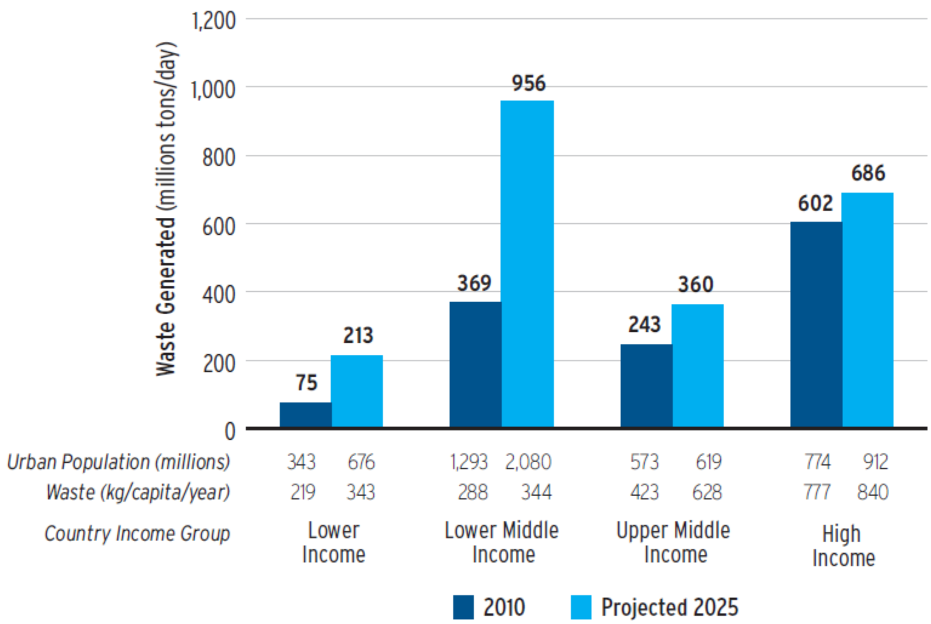

Figure 6: Urban Waste Generation by Income Level and Year

2.2 Background Theory

To transfer a solid waste management system into a sustainable system, different aspects should be taken into consideration, some of which are: social aspects, economic aspects, environmental aspects, legal aspects (Petts, 2000; Nilsson-Djerf

[8] Source: What A Waste: A Global Review of Solid Waste Management

2000; McDougall et al., 2001; Thomas and McDougall, 2005). Sustainability in solid waste management system should be socially acceptable by stakeholders, economically affordable, environmentally effective to reduce water, soil and air pollutions, and legally bonded and considered in current and newly established businesses.

2.2.1 Social Aspects

Researchers agree that if a waste management system ignores the social and cultural aspects of the society, then the system is "*doomed to failure*", and that it is as important as the other aspects (Joos et al., 1999; Petts, 2000; Morrissey and Browne, 2004; Henry et al., 2006).

It is very important to make sure that people, who are the main stakeholders for domestic waste, are aware and have the knowledge about waste management. Their participation in the decision making, planning and implementation of a solid waste management from the beginning, helps in changing their attitudes and behaviors about waste management, and as a result, helps the government in moving towards a more sustainable system (Morrissey and Browne, 2004; Henry et al., 2006). However, if local authorities choose to plan for a SWMS without the involvement of the society, then there will be resistance and difficulty in the implementation of such a system (Morrissey and Browne, 2004).

There are different means for society involvement; it can be through awareness programs that focus on health and environmental issues. Using different communication channels, like TV, radio, festivals, competitions to raise the awareness would be helpful. Society can also be involved by providing educational campaigns about MSWM, educational courses to be taught in schools and universities, and participation in local committees to discuss about collection of waste, separation at source, recycling, etc. (Schübeler et al., 1996).

2.2.2 Economic Aspects

Allocating an adequate budget for the collection and treatment of waste, and monitoring and evaluating the financial status of the country, help governments in the assessment of costs related to the establishment of a sustainable solid waste management system (Schübeler et al., 1996). This information can be used to compare it with the costs of doing nothing about waste, in order to have a clear picture on how it will affect the financial ability of the country. This comparison can then be shared with the public to increase their awareness of the amount of money spent monthly/quarterly/annually to clean their city and decrease the possibility of public health issues and pollutions.

However, if costs related to the operations of waste management system are inadequate, then it will be difficult to have a sufficient budgeting and cost accounting system (Schübeler et al., 1996).

There are different mechanisms to generate revenues from a municipal solid waste management system. Charging users on curbside collection is one option, where waste is collected from their doors to landfills. another method would be charging users based on the volume of waste generated at source, so the more they generate, the higher the cost will be (Skumatz et al., 2006). This option follows the concept of Polluter Pay Principle (PPP). From this concept, a system called Pay-As-You-Throw (PAYT), or sometimes referred to as User-Pay principle, and Unit or Variable Unit Pricing, has been followed by many countries to encourage users, especially house owners, to think twice about any solid waste generated at their homes (Skumatz and Freeman, 2006; Bilitewski, 2008). Many research papers have highlighted on the benefits of PAYT which resulted in reducing waste generated and increasing recycling rates (Canterbury, 1994; Van and Morris, 1999; Folz and Giles, 2002)

The analysis adopted by Kontogianni et al. (2014) regarding PAYT applications in Greece, showed that the benefits of applying this system covers all three aspects of sustainable solid waste management. It increases the participation of households, reduces waste quantities and increases the diversion of waste towards recycling and recovery, rather than landfills and incineration, and decreases service financial costs.

2.2.3 Environmental Aspects

Enforcing governmental legislation about waste collection, disposal, and treatment, especially for new residential areas and selection of landfills, will ensure the establishment of a sustainable solid waste management system.

Most organizations follow the standards of ISO 14001 to create an Environmental Management System (EMS). It leads to cleaner and better environmental products and services (Montiel et al., 2012).

On the other hand, for residents to help in this aspect, they need to be aware of the concepts of waste prevention, reduction and recovery, to live in a better and healthier environment, and to reduce the spread of diseases and pollution in their community.

2.2.4 Legal and Political Aspects

Many countries have adopted laws and policies to control the quantities of MSW generated. The issue of improper waste management and its negative impact on the environment has caught the attention of many governments around the world. As a result, governments have started to plan for a better and greener future. Going green is no longer a motto or slogan that people hear and pass by. In particular, affluent customers are more aware of environmental issues and global warming. As such, going green is now considered to be an integral part in many business strategies that aim to reduce costs, increase revenues, mitigate risks, and satisfy the requirements of their customers. In many countries, governmental policies have already been issued to make sure that all public and private sectors are taking the environment into consideration when it comes to project and production plans that may affect and harm the environment in any way. Consequently, organizations around the world have integrated environmental practices and programs in their operations as well as include several initiatives into their strategic plans (Bortoleto et al., 2012; Vector and Agamuthu, 2013).

Once a legal framework is established, with unambiguous and clear standards, bylaws, regulations and procedures, organizations will be able to implement strategic plans easily and effectively, satisfying their government and customers (Schübeler et al., 1996).

Other aspects that are considered to be affecting the sustainability of a solid waste management are:

2.2.5 Technical Aspects

Related to the technical skills of personnel in government authorities (Hazra and Goel, 2009), poor infrastructure (Henry et al., 2006; Moghadam et al., 2009), unavailability of inadequate technologies and consistent data (Mrayyan and Hamdi, 2006).

2.2.6 Institutional Aspects

Where waste management authorities lack professional knowledge, skills, experience and leadership to design and build the process, equipment, and technologies needed (Zurbrügg et al., 2012; Chung and Lo, 2008).

2.3 Sustainable Solid Waste Management Systems

A sustainable management approach should be implemented to deal with the domestic waste created by human activities, to help protect the environment and the wellbeing of society.

The concept of sustainable development was first introduced in a report called "Brundtland Report", published by the World Commission on Environment and Development (WCED) in 1987. The report defined sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

The concepts behind waste management system vary based on the country or region applying this system (Reddy, 2011). These concepts are:

2.3.1 Waste Hierarchy:

The idea of Waste Framework Directive was first introduced by the European Union’s (1975/442/EEC) in 1975. It focused on the importance of minimizing waste to protect human’s health and the environment. In 1989, the Commission of European Community published “A Community Strategy for Waste Management”, which included the actions that should be followed by the community to manage waste. The three strategies/actions are:

1. Waste prevention: this is the first strategy that should be taken into consideration before moving forward to the other two strategies. The EU Commission proposed that the prevention should be done on two levels. The first is prevention by technologies to have better manufacturing processes with little or no waste. The second is prevention by products, taking into consideration the whole life cycle of a product and its impacts on the environment. In this level, customers should be aware of the ecological characteristics of products by including the proper labelling.

2. Recycling and reuse: the community should be a great part of this strategy and should be motivated to recycle and/or reuse their waste to “*bring it back into the economic cycle proper*” (Commission of European Community, 1989). Some of the actions under this strategy that the EU Commission focused on is plastic waste and material packaging.

3. Safe disposal of non-recoverable residues: as a final resort, and after ensuring that waste cannot be prevented or recycled, waste can be dumped in appropriate dump sites or incinerated.

In 2006, the hierarchy was further modified in the European Waste Directive 2006/12/EC to introduce a waste hierarchy with three levels as stated in article 3 of the directive, which aims to propose the prioritization of waste management activities or options to be followed, in order to minimize the negative effects of waste. In 2008, the hierarchy was replaced by another one with five levels in the Directive 2008/98/EC. Ewijk and Stegemann (2014) described it as "*an influential philosophy in waste and resource management*". Both hierarchies are shown in fig. (7) and fig. (8)[9], respectively.

[9] Source: Adapted from European Parliament Council, 2006

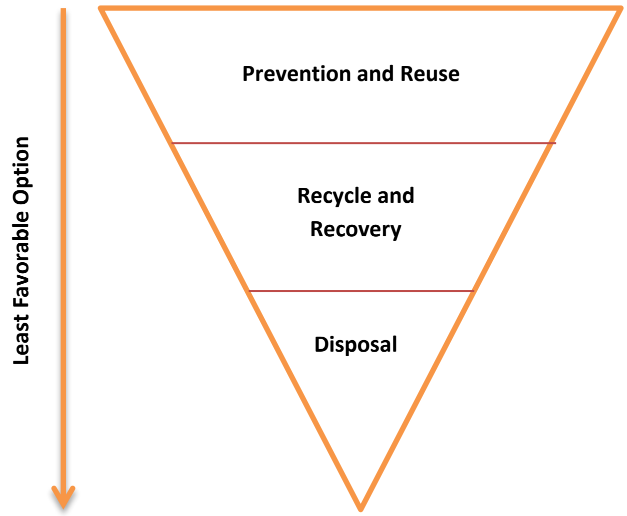

Figure 7: Waste Hierarchy, 2006

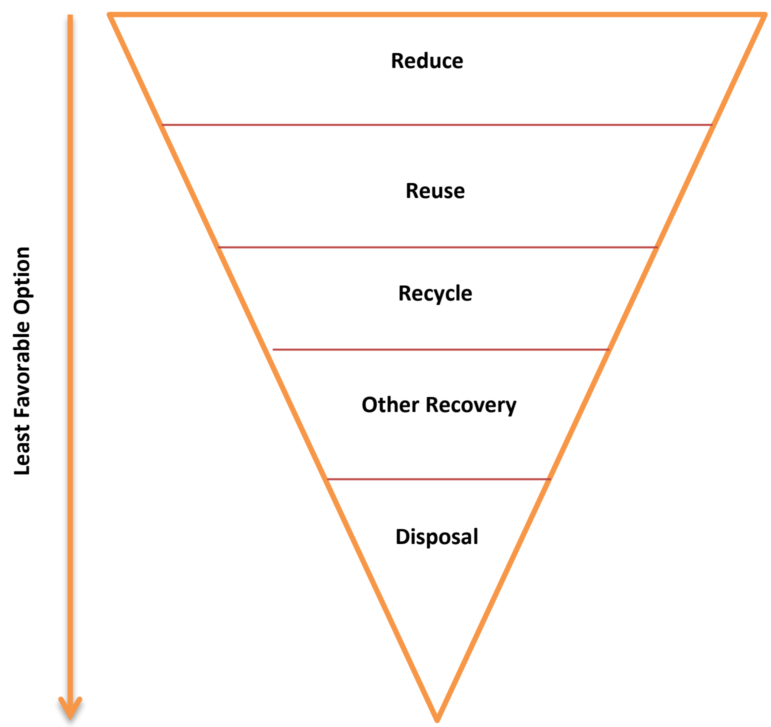

Figure 8: Waste Hierarchy, 2008

2.3.2 Polluter Pay Principle (PPP)

The second concept was first presented as an international principle in 1972 by the Organization for Economic Cooperation and Development (OECD). The principle stated that "the polluter should bear the expenses of carrying out the (pollution prevention and control) measures decided by public authorities to ensure that the environment is in an acceptable state". The idea behind it requires that if anyone harms the environment, then the person/corporation/firm, or the polluter in general, should pay for and bear the cost of any damages caused (Luppi et al., 2012). However, this principle was already well known years before that in the history of Western legal. Plato talked about it in his book in 1953 "*The Dialogues of Plato: The Laws*", where he mentioned that "*If anyone intentionally spoils the water of another…let him not only pay damages, but purify the stream or cistern which contains the water*".

In the public literature, there is no specific definition for sustainable solid waste management system. However, sustainable domestic waste management system is described by many as the collection of household waste, transportation, treatment, recycling, resource recovery and compost, and finally the disposal of such waste (Schübeler, 1996; Annepu, 2012)

For the purpose of this project, the following working definition will be used: Sustainable Solid Waste Management System refers to the implementation of the 4Rs

(Reduce, Re-use, Recycle, Recovery), to achieve and maintain continual sustainability in a solid waste system.

In 2009, the US EPA published a list of definitions for different terms used in the waste industry, including the 3Rs. It described Reduce as minimizing generation waste rates. Re-use as a second-hand use of the same waste without any additional manufacturing. Recycling is transforming waste into useful materials and/or products. The output of this process can be used as an input in the same product system, where this is referred to as "*Closed Loop Recycling*", or it can be used as an input in another product system, which is called "*Open Loop Recycling*". While Recovery means extracting energy from the waste stream, which follows the life cycle of waste from its production till disposal.

The same waste hierarchy will be used to describe the approaches and priorities to sustainable domestic solid waste management. The first approach and priority is Prevention, which includes Reduce and Re-use. Prevention aims to minimize the amount of waste generated by encouraging stakeholders to at least:

- select items that need the lowest amount of resources to be produced
- select items that have the least packaging
- purchase recyclable, biodegradable, and eco-friendly products
- re-use food leftovers instead of throwing them

When avoiding and re-using waste is not possible, then the second approach and priority becomes Resource Recovery. It focuses on recycling waste and recovering energy from it. Minghua et al. (2009) stated that governments must develop plans to encourage markets for using recycled materials and increase the productivity of recycling companies by increasing the professionalism of its personnel. Financial support for recycling plants (Nissim et al., 2005), and responsibilities of recycling enterprises (Henry et al., 2006) are other important factors to affect recycling rates in any country.

The last resort in the waste hierarchy is Disposal. Waste is disposed in either landfills, water, or is incinerated. Regardless of the constraints set by environmental agencies to control waste disposal, many disposal sites are uncontrolled, and the rules imposed for proper landfill management are ignored (Mondelli et al., 2007).

If landfills are not properly controlled and do not follow the appropriate environment regulations and standards, then they will not only occupy the habitats of many animals and attract different insects, but also pollute water, air, and soil, which will eventually cause sicknesses and diseases that may spread over the community. In addition, waste accumulation results in an unpleasant view and bad smell of tons of waste piled up and dumped in large areas of land.

Landfills can also help in the formation of ozone, as NOx and organic compounds react with the sunlight, causing nervous system damage. Ozone can also decrease the growth rate of plants and crops. Moreover, when rain mixes with organic waste, a liquid with different pollutants will be formed, called leachate, which leaks into the soil, and eventually to surface and ground water. Leachate causes the spread of bacteria and many diseases. In developing countries, typhoid fever is commonly spread among people because of this contamination. When leachate pollutes ground water, levels of nutrients will increase causing excessive growth of plants. This excess is called eutrophication. The National Academy of Sciences (1969) defined it as follows: "*The term 'eutrophic' means well-nourished; thus, 'eutrophication' refers to natural or artificial addition of nutrients to bodies of water and to the effects of the added nutrients….When the effects are undesirable, eutrophication may be considered a form of pollution*."

Moreover, landfills increase the chances of global warming as waste in uncontrolled landfills and open dumps results in emissions of greenhouse gases, especially methane that impacts climate change (Neal and Schubel, 1987; Daskalopoulos et al., 1998; Reddy, 2011). Greenhouse gases are responsible for regulating the temperature of the earth; however, the decomposition and incineration of solid waste produce more greenhouse gases, resulting in an increase in the global temperature (U.S. EPA, 2002). The Environmental Protection Agency (EPA) in the United States also reported that "*Countries in Asia, Latin America, and Africa account for nearly 40 percent of annual methane emissions from landfills, which is equal to 37 million metric tons of carbon dioxide equivalent (*$MtCO_2e$*) or the amount of air emissions from more than 102 million automobiles*".

Based on the latest publication of U.S. EPA facts and figures, recycling rates increased from under 10% in 1980 to almost 35% in 2012, as shown in fig. (9)[10]. While disposal in landfills decreased from 89% in 1980 to below 54% in 2012. These rates can be the consequence of awareness campaigns on the positive impacts of recycling and negative effects of landfills on all creatures. Advanced technology has also helped a lot in this regard.

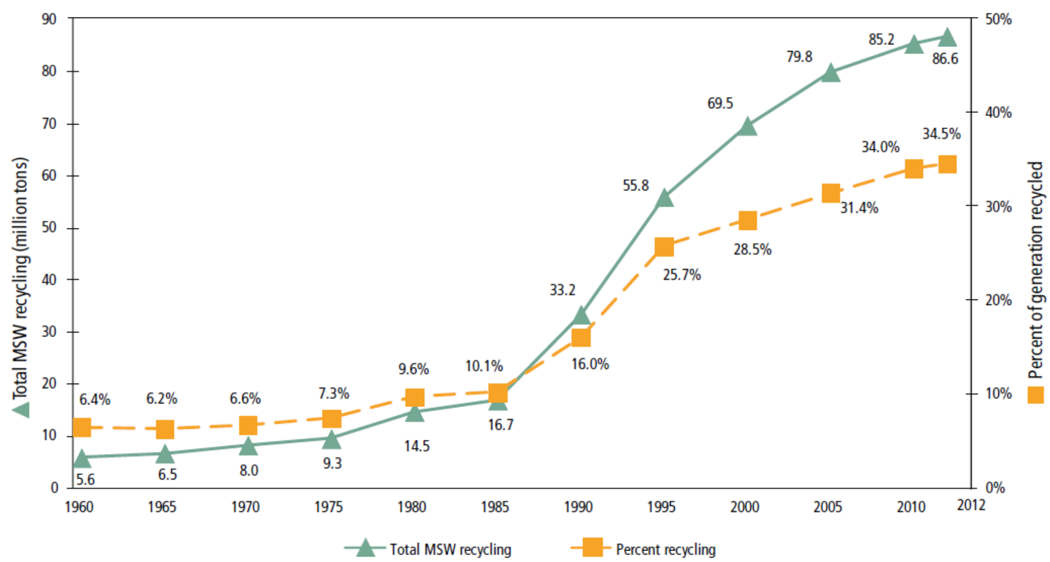

Figure 9: MSW Recycling Rates, 1960 – 2012

Water is an important natural resource, yet, it is one of the most poorly managed natural resources (Fakayode, 2005). The standard surface water pH according to the

[10] United States Environmental Protection Agency

U.S. EPA is 6.5 – 8.5, and for ground water is 6 – 8.5. If pH level is not within this range, then it should be tested immediately as it could contain toxic metals, like: lead, copper, iron, zinc, and manganese.

Incineration is considered as an alternative to disposing solid waste in landfills (Emberton and Parker, 1987). Regardless of the fact that by incineration, a solid waste will be produced that requires a smaller land area compared to other unprocessed solid wastes dumped in landfills, however, it pollutes air and harms the ozone layer. This solid waste, or ash, should be analyzed and tested to ensure that it is not hazard. Incineration plants should also be tested frequently to make sure that ash is contained securely and that no toxic leaks into the groundwater exist (U.S. EPA, 2013).

Despite the fact that these approaches are well known and defined, nevertheless, to design an effective municipal solid waste management system and implement it might be difficult.

The aforementioned aspects are key factors to establish a sustainable solid waste management system, however, they are also considered to be the barriers and challenges to the sustainability needed, if not properly considered.

According to de Oliveira and Borenstein (2007), the implementation of a domestic waste management system should take into consideration the following three factors: 1. awareness campaigns to the society to increase their contribution to recycling, 2. development of waste collection plans, starting from containers in the streets and ending up with unloading waste vehicles in treatment plants, 3. location of waste treatment plants as it affects several factors, such as: fuel consumption, distance driven, driving pattern, and vehicle load.

Troschinetz & Mihelcic (2009) focused in one of their studies on finding the barriers and incentives of recycling, and how it will affect sustainable solid waste management. An analysis of twenty three case studies in different developing countries was conducted, and twelve factors were identified as influencers to sustainable solid waste management. But the most important barriers to this sustainability were found to be education, waste collection and segregation, and finances.

Chung and Lo (2008) conducted a survey in China with three waste management authorities; Environmental Sanitation Bureaus (ESBs) that are responsible for the planning of MSW and the implementation of policies related to it, Environmental Sanitation Stations (ESSs) that are in charge with the collection of MSW, and Guangzhou Environmental Sanitation Research Institute, which is the only MSW research institute in Southern China. The results of this survey showed that the main factor affecting waste in this area is the lack of administrator's knowledge about waste treatment systems.

Challenges are also caused by insufficient financial resources which limits the safe disposal of waste in engineered landfills (Pokhrel and Viraraghavan, 2005), and the inadequate supply of waste facilities and containers for households, where sometimes they need to travel for a long distance to drop their wastes, increase the potential of dumping waste in open areas and along the streets (Tadesse et al., 2008)

The efficient use of the hierarchy has been successful in some countries; some continue to face problems with different sustainability aspects, while others keep ignoring the importance of designing a sustainable system.

The European Topic Centre on Sustainable Consumption and Production (ETC/SCP), in collaboration with the European Environment Agency (EEA), conducted a study on "*Managing Municipal Solid Waste*" to review the achievements attained between 2001-2010 by 32 European countries; the EU-27, Iceland, Norway, Switzerland, Turkey, and Croatia. All countries involved should change their waste management system and move up the waste hierarchy by prioritizing and promoting waste prevention, focusing on recycling, reuse, and recovery, while disposal, and mainly landfilling, should be minimized and given the lowest priority. The European environmental policy incorporated these goals and assigned targets for each, in order to ensure the successful implementation of such important objectives.

The study reported that landfilling decreased by almost 40 million tonnes and recycling increased by 29 million tonnes. Figure (10)[11] shows the development of MSW management between 2001-2010.

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[11] Source: Eurostat, 2012a, 2012c; ETC/SCP, 2013a, 2013b, 2013d, 2013e,2013f

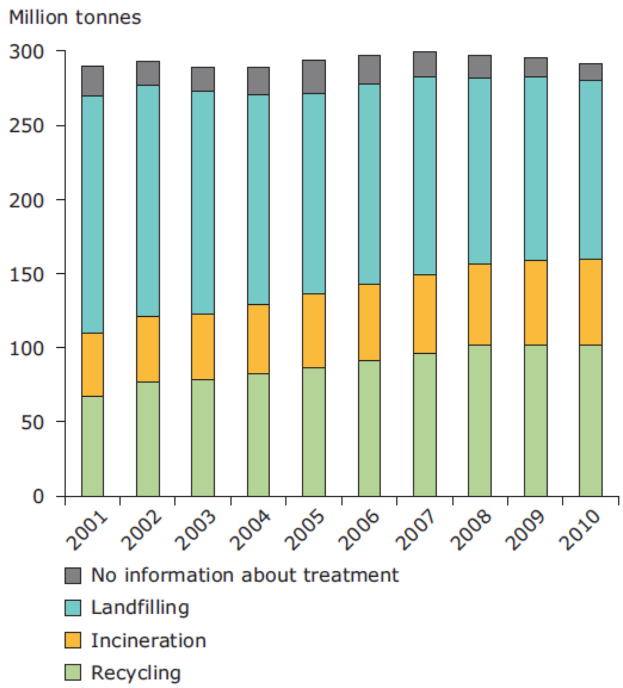

Figure 10: Development of MSW Management System between 2001-2010

In addition, shifting municipal waste management up the hierarchy did not only help in reducing waste problems and finding better and more efficient use of resources, but also reduced the emissions of greenhouse gas (GHG). Methane emissions declined significantly between 2001-2010, and due to the fact that virgin materials were replaced by recycled materials, GHG emissions caused by primary production were reduced (EEA, 2013).

Research shows that waste management policies related to recycling had affected the rates of MSW generation. The Department for Environment Food and Rural Affairs in England (Defra) showed that in 2010, the Waste Prevention Program has led to a

13% reduction in household solid waste, and as part of all government departments support, implementation plans are being developed to prevent food waste and to handle any waste already produced (Defra, 2013). In New Zealand, the Waste Minimization Act (WMA) 2008, which encourages waste minimization and disposal, allowed 95% of the population to have access to curbside recycling which helped in reducing MSW (ISWA, 2012).

The Kingdom of Saudi Arabia is the largest oil producer worldwide, however, it currently follows a simple solid waste management system. The system is to collect waste and discharge it in open dump areas (Ouda et al., 2013). The Saudi government is aware of the problems facing the Kingdom as a result of producing about 14 Mt/year of MSW, and so, new regulations have been approved early 2015 for the management of such waste.

Sultanate of Oman is also facing the same problems regarding its MSW, as currently there isn't any solid waste management system available. The data on the generation and composition of waste is also not available (Taha et al., 2004).

The State of Qatar has made it clear in the Qatar National Development Strategy (QNDS) 2011-2016 that environmental sustainability is one of the most important goals that should be considered by all institutions and companies in the country. In addition, Qatar National Research Strategy (QNRS) includes an objective under the Energy and Environment Pillar to "*Develop improved approaches for solid waste* *management in Qatar, to include reducing waste generation, increasing waste recycling, and mitigating the adverse impacts of waste disposal*".

Very little has been done in terms of sustainable solid waste management in Qatar and the Gulf region. However, it is expected that some of the challenges that have been experienced in other parts of the world, still remain to be addressed in GCC, some of which will be addressed in this project.

2.4 Location Allocation Methods and Models for Domestic Solid Waste Management

2.4.1 Location-Allocation

The location allocation method is known as an optimization method in order to select the feasible number and location of facilities to serve the demand required (Fotheringham et al., 1995). There are many location allocation models that can be used to help achieving the objectives of this project. But the most common are:

2.4.1.1 Covering Problem

This problem uses a coverage distance or a coverage radius to allocate demand points to facilities, where the distance between them is less than or equal to that coverage distance (Fallah et al., 2009; Eiselt and Sandblom, 2010; Farahani et al., 2012). Covering problems are categorized into Location Set Covering Problem (LSCP) and Maximal Covering Location Problem (MCLP). Toregas et al. (1971) were the first to apply this model to locate emergency facilities. The model aimed to minimize the cost of these facilities while ensuring that demand is covered by at least one facility. On the other hand, taking into consideration the size and location of demand points (Jia, et al., 2006), Church and ReVelle (1974) used MCLP to maximize the coverage within a predefined coverage distance/radius. This method is mostly used when there are limitations to cover all demand (Farahani et al., 2012).

This model can be applied to problems related to the location allocation problems of fire stations, ambulances, warehouses, and products distribution (Fallah et al., 2009; Eiselt and Sandblom, 2010).

2.4.1.2 P-Centered Problem

Rather than focusing on minimizing the number of facilities, p-centered problem uses a set of predefined number of facilities and focuses on minimizing the maximum distance between demand points and facilities (Biazaran and Seyedi Nezhad, 2009). This model can be applied to hotels, parks, warehouses, and bus stops.

2.4.1.3 P-Median Problem

Whereas demand points in coverage and p-centered models are either covered or not covered by facilities, p-median model objective is to minimize the average and or total distance travelled. The fixed cost of facilities in this model is not considered, and so, the total cost will be minimized (Jamshidi, 2009).

This model can be used for public services, such as: schools, hospitals, and firefighting stations.

Even though these models can help in selecting the best location of different facilities, however, when the problem includes a very large number of demand points, then it would be better to use another method to help solving the problem. ArcGIS is one of the main systems that can help in the location allocation problems.

2.4.2 Geographical Information System (GIS)

GIS is a database system that organizes geographic objects as different layers. These layers are: features (objects with shape and dimension), points (houses), lines (streets), and polygons (districts). GIS is used to manage, analyse, and display all information that is connected to a spatial location.

In Qatar, the Ministry of Development Planning and Statistics refers to GIS as “a computer based-tool for mapping and analyzing things that exist and events that happen on Earth". MDPS also listed some of GIS applications that governmental and non-governmental organizations can use it for. These applications are:

- "Utilities- Planning and Monitoring
- Master Planning- Site Selection
- Map Making - Automated Map Production
- Public Facilities Determining- Hospital, School, Car park
- Environmental Management- Waste Dump Sites
- Emergency Response Planning- Route and time to attend
- Agriculture Planning- Land use, Crop Management
- Municipal GIS - for administering and planning
- and many more areas such as in Statistical Operations"

In order to solve the problems related to location allocation, GIS includes the following models:

2.4.2.1 Minimize Impedance (P-Median)

This model, or as it is called in ArcGIS "Minimize Weighted Impedance", minimizes the total sum of weighted impedances. By multiplying the demand allocated to a certain facility by the impedance to that facility, the total is minimized. This model is mostly used to locate public facilities, because it minimizes the distance travelled by the public to the facility needed, such as libraries and health clinics. It is also used to locate warehouses, because it reduces the transportation costs between warehouses and outlets.

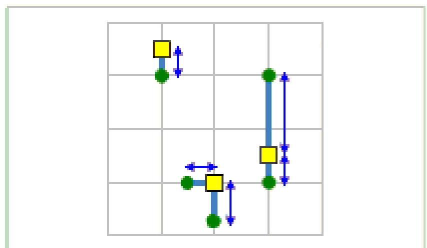

Figure 11: Minimize Impedance (P-Median)

2.4.2.2 Maximize Coverage

Problems related to allocating as much demand as possible to facilities within a specified impedance cutoff can be solved using this model. Maximize coverage is used to locate emergency room service centers, fire stations and even the delivery business followed by restaurants. In all cases, the location of the facility should serve a wide range of demand.

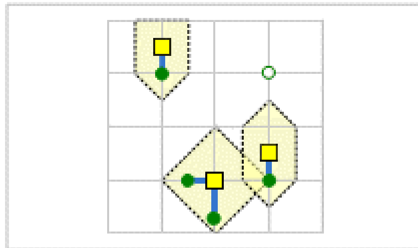

Figure 12: Maximize Coverage

2.4.2.3 Maximize Capacitated Coverage

This model solves problems that are similar to Minimize Impedance or Maximize Coverage problems, however, with a constraint. When facilities have a limited capacity, then this model should be used. The location of facilities is chosen where all or most of the demand can be served, without exceeding the capacity of the facility. Also, it takes into consideration that the total weighted impedance should be minimized. Medical centers with limited number of beds can use this model to allocate the best location of the facility.

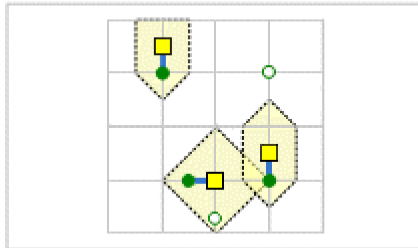

Figure 13: Maximize Capacitated Coverage

2.4.2.4 Minimize Facilities

The minimum number of facilities needed to cover all or most of the demand within an impedance cutoff is located by this model. This type is similar to maximize coverage; however, the number of facilities is predetermined. The location of a fire station can be solved by this problem type.

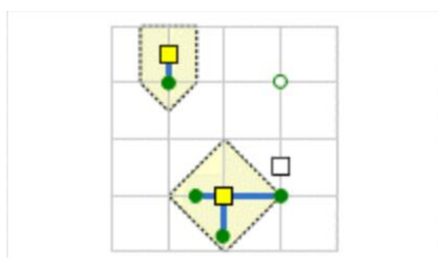

Figure 14: Minimize Facilities

2.4.2.5 Maximize Attendance

This model works with the assumption that the demand weight decreases as the distance between the demand and the facility increases. So the location of facilities is chosen so that as much demand as possible is allocated to facilities. The facilities that can benefit from this model are coffee shops and restaurants that do not enough data on competitors. Otherwise, the following problem type can be used.

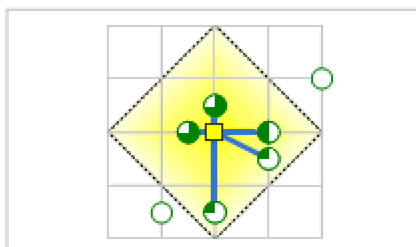

Figure 15: Maximize Attendance

2.4.2.6 Maximize Market Share

When comprehensive information is available about the owner's and competitor's facility weight, then, a specific number of facilities is chosen where the demand is maximized. Large discount stores can benefit from this problem type to locate a number of new stores.

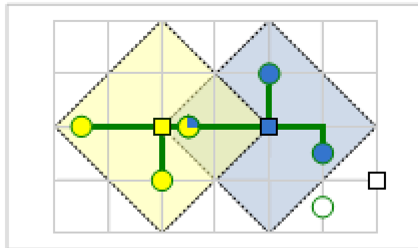

Figure 16: Maximize Market Share

2.4.2.7 Target Market Share

If budgets of large discount stores were a concern, then maximize market share option should be followed. On the other hand, if there were no concerns regarding the budget, then target market share is the model to be chosen. This model locates the minimum number of facilities to serve a predetermined percentage of a market share. As the previous model, comprehensive data should be collected regarding the owner's and competitor's facilities.

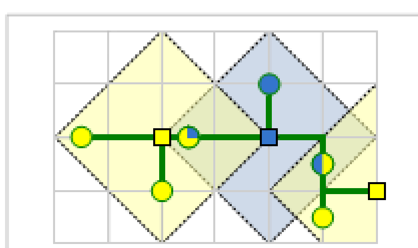

Figure 17: Target Market Share

2.4.3 Applications of GIS in Domestic Solid Waste Management

As this project focuses on the selection of the best location of recycling and waste transfer stations, different research papers covering the same concept were studied. For example, Vatalis and Manoliadis (2002) used GIS to find the most suitable landfill sites in Western Macedonia, Greece. Kontos et al. (2005) used a spatial multiple criteria analysis methodology. Chang et al. (2008) and Akbari et al. (2008) used GIS and a multi criteria decision-making, while Wang et al. (2009) used spatial information technology and analytical hierarchy process (AHP) to find the optimal landfill site in Beijing, China. Ghobadi et al. (2013) also focused on using AHP to site MSW landfills in Hamedan Province, Western Iran. Kara and Doratli (2012) used the applications of GOS and AHP to site sanitary landfills in Northern Cyprus.

Şener et al. (2010) focused in their study on combining GIS and AHP to select a landfill site for Lake Beyşehir in Konya, Turkey, since it is one of the developing cities that lacks proper planning for waste management, due to inadequate information regarding its restrictions (Tinmaz and Demir, 2006). The analysis of this study showed four suitability classes for this area, which were: high, moderate, low, and very low suitability. Results helped in choosing two out of four sites as the most suitable landfills.

Chatzouridis and Komilis (2011) used GIS and binary programming for the purpose of developing a methodology to design municipal solid waste transfer stations, in the case of not having the exact number and location of waste transfer stations.

Zamorano et al. (2009) used GIS as an optimization methodology to the Region of Eastern Macedonia and Thrace (REMATH) in North Greece, and it focused on the following:

1. Locating waste transfer stations (WTS) by excluding any zones that are close to residential areas and water resources, because of the impacts of these stations on the environment, as they exert noise, odors, litter, and dust. For the location of these stations, GIS was used to develop suitability maps, and areas near road networks were considered to be suitable.
2. The notion of the optimization model was to ensure that each initial node transfers its waste to only one transfer station using waste collection vehicles, or directly to a landfill using semitrailers. So after the exclusion of all unsuitable areas for WTS, the remaining areas were considered to be appropriate for such locations.

In the early sixties, the discovery of oil in GCC countries led to rapid development in different fields. To cope with this development, expatriates from different countries migrated to work in GCC. This migration happens annually, due to ending and termination of contracts. As a result, new immigrants come to live and work instead. This continuous change keeps the rate of solid waste generated high and continuous (Alhumoud, 2005). Recently, GCC countries have been taken considerations reducing the amounts of waste generated by focusing on different methods, one of which is recycling.

The Arab Forum for Environment and Development stated in the report of 2008 that construction waste has the largest rate among GCC countries, whiles municipal waste is the second. Most of the waste coming from households has organic materials, which means that most of it has materials that can be recycled, like papers, plastic, glass, and metals.

The State of Qatar has made it clear in Qatar National Vision (QNV) 2030 and Qatar National Development Strategy (QNDS) (2011-2016), that one of the main pillars is to protect the environment by encouraging all public and private sectors to decrease their waste generated, and increase the efforts of recycling.

However, research shows that there are many gaps missing about this topic. Only few research papers are dedicated to the solid waste generated in Qatar, and so, it is still not covered properly as there aren’t many papers referring to the solutions and methodologies that can be approached to solve the issues related to municipal and household waste generated.

This project will contribute to the knowledge of municipal solid waste management in Qatar, as it will propose solutions to the sustainability of this type of waste. This sustainability can be achieved by ensuring that waste transfer stations are available to cover most of the household’s demands. Also, as there are currently no recycling plants, the project will also propose the location of these plants, so that the benefits of recyclable materials can be used in energy and sustainability.

3. Chapter 3 – Methodology

3.1 General Approach

In order to propose a sustainable solid waste management in Qatar:

- A study of different research papers with similar scope was conducted, in order to be more familiar with the problem type, and to understand the gaps in the area of household waste management
- Quantitative and qualitative studies were conducted. The study was done by collecting data from different stakeholders. The main stakeholders in this project; from where the primary data was collected, are households. The secondary data was gathered from Keppel Seghers Company, Ministry of Municipality and Environment, and Ministry of Development Planning and Statistics
- Study of the current DSWM system followed in Qatar, to understand the existing issues with the current system and recommend better solutions for a more sustainable system
- Based on the suggestions from the previous studies, ArcGIS was used to achieve the objectives of this project, which mainly focused on proposing the location of new waste transfer stations and recycling plants.

3.2 Research Process Flow Chart

Figure (18) shows the process chart that was followed during the study of this project:

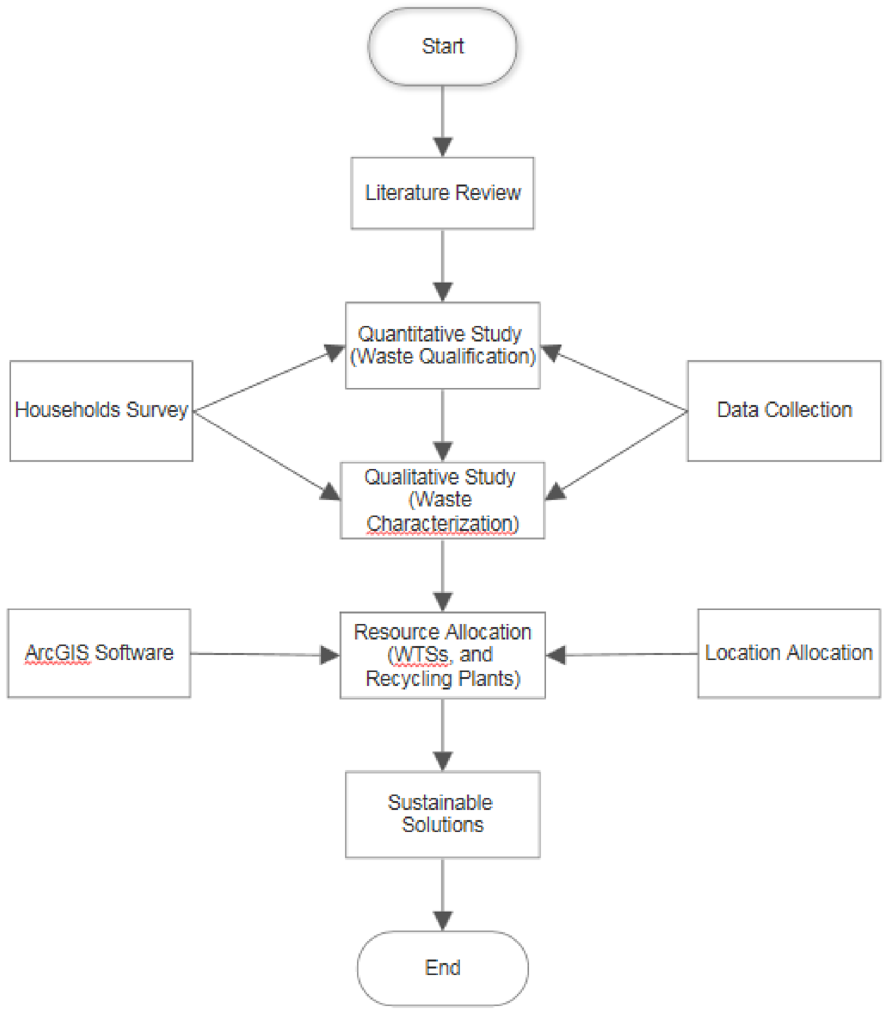

Figure 18: Project Process Flow Chart

3.3 Quantification of Domestic Solid Waste

A previous study was conducted and collected data during the period between February and April 2015, where 84 houses located at different municipalities in Qatar where involved.

To get data as precise as possible, households were instructed to follow the following steps:

1. Wastes should be divided in different waste bins as per the category list provided.
2. At the end of each day, each type of waste should be weighed by a scale
3. Enter the weights in the excel sheet provided
4. Calculate the total weight
5. Divide the weight of each category by the total weight

The template that was used by the households to fill the information needed is provided in Appendix (A).

The data collected from houses helped in getting familiar with the quantities and types of waste generated per day. Also, since the data was collected during almost 3 months, this will give an indication of the pattern of waste generated.

The secondary data gathered through meetings and discussions with the Ministry of Municipality and Environment, Ministry of Development Planning and Statistics, and Keppel Seghers Company. Keppel Seghers is a leading company in providing the solutions for solid waste and water problems. It was awarded by the Ministry of Municipality and Environment, previously known as Ministry of Municipality and

Urban Planning, to construct one Domestic Solid Waste Management Centre (DSWMC), and four transfer stations located in different areas around the State of Qatar.

According to the data provided by those stakeholders, it was found that the quantity of DSW is 1.6-1.8 kg/capita/day. However, this quantity covers domestic waste coming from different entities in Qatar, and not only households.

Therefore, in order to calculate the total waste generated in Qatar per year, the total weight of waste per house per capita will be calculated to find the total DSW for the whole population in Qatar.

3.4 Characterization of Domestic Solid Waste

Based on different research papers, the following list represents most of waste types generated by households (Al-Khatib et al., 2010, Dangi et al., 2013). The following list was provided as part of the survey conducted by the 84 houses, in order to register the weights of each type:

a. Organic waste/food waste
b. Clean paper
c. Plastic and polythene bags
d. Glass and ceramic scrap
e. Cardboards
f. Metallic items

g. Cans
h. Rubber
i. Textile and leather
j. Soiled paper
k. Wood and saw dust
l. Leaf litter, garden pruning
m. Other materials

The steps followed in quantitative and qualitative approaches were chosen carefully after studying different research papers about characterization and quantification methods of DSW. As there are many approaches to collect the data of both based on the given situation, it was decided that the method followed in this project is the most suitable method to be implemented in Qatar.

As per the latest research papers, the method followed by Al-Khatib et al., (2010) was to collect waste from different areas around Nablus, Palestine, and place them in a tank. Afterwards, a sample of waste will be taken from the tank and sorted. Another paper by Sun (2010) focused on quantifying and characterizing waste at landfills. While Eisted and Christensen (2011) suggested sorting and quantifying waste at recycling plants, after the collection from different houses in Greenland.

For this project, the method followed is similar to the one adopted by Dangi et al., (2013) in Tulsipur, Nepal. The sorting of waste was done by households at the source of generation. In addition, an older research paper by Ojeda-Benitez et al., (2003), showed that the same method was applied in Mexicali, Mexico, where waste was collected and sorted from 84 houses.

3.5 Case Study

The case of Qatar will be used as a case study in this project.

Surrounded by the Persian Gulf and a land border from the south by Kingdom of Saudi Arabia, the State of Qatar is a peninsula that has a strategic geographic location filled with petroleum and natural gas. With a total area of 11606.8 km^2, Qatar has 7 municipalities shown in figure (19), 94 zones, and 755 districts. By February 28, 2016, the number of population in Qatar reached 2,545,603, where most of them live in its capital Doha, also known for its skyscrapers, and Al-Rayyan. Qatar has had a fast growing economy that led to vast changes in its population rate. The population increased between 2010 and 2015 by 67.6%. By 2030, the World Bank expects the number will increase to 2,781,000, as shown in figure (20).

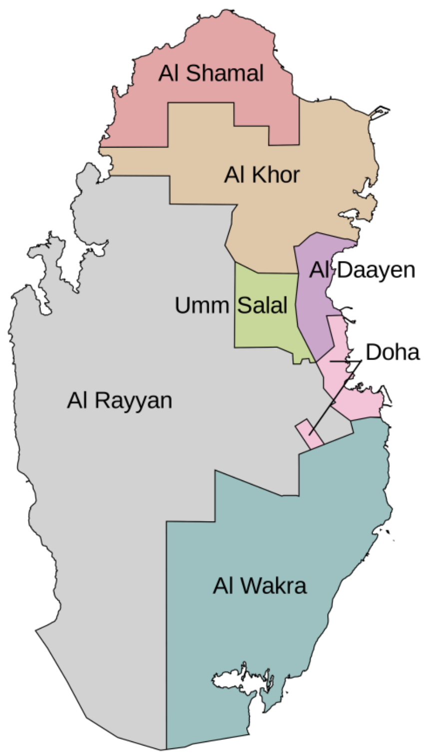

Figure 19: Municipalities of Qatar

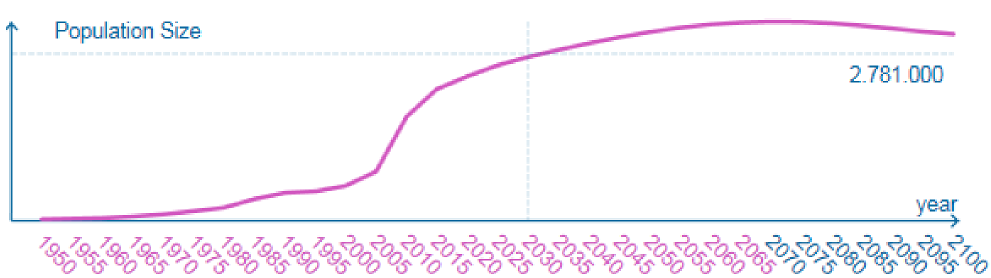

Figure 20: Expected Number of Population in 2030

3.5.1 Domestic Waste Management in Qatar

As explained before, the generation of waste is linked to the number of population in an area, and their lifestyle of living. As the number of population in Qatar is increasing, so does waste generation and accumulation.

The management of domestic waste in Qatar is represented by four main sub-systems:

1- Domestic waste generators
2- Waste bins
3- Waste transporting vehicles or trucks
4- Waste transfer stations
5- Domestic Solid Waste Management Center (DSWMC) or landfill

3.5.1.1 Current System

Domestic waste is collected in each municipality and transported to one of the four current waste transfer stations. After that, waste is transported to the Domestic Solid Waste Management Center (DSWMC) located in Mesaieed, and run by Keppel Seghers Company.

In a sustainable system, more information should be shared between those sub-systems in order to act in harmony.

According to fig. (20), which shows the domestic solid waste statistics 2013-2014, a total of 7,569 tons of solid waste was produced daily in Qatar, of which 2,700 tons was domestic waste. This represents 6,866,481.3 kg/day and 2,449,398.8 kg/day, respectively. As reported by Ministry of Municipality and Environment, Qatar produces 1.6 – 1.8 kg/capita/day of domestic solid waste. Taking into consideration that domestic means waste generated from all sectors, excluding hospitals and construction sites. Out of the 2,700 tons produced, 55% are sent to DSWMC, 34% are composted, and 15% are sent to landfill.

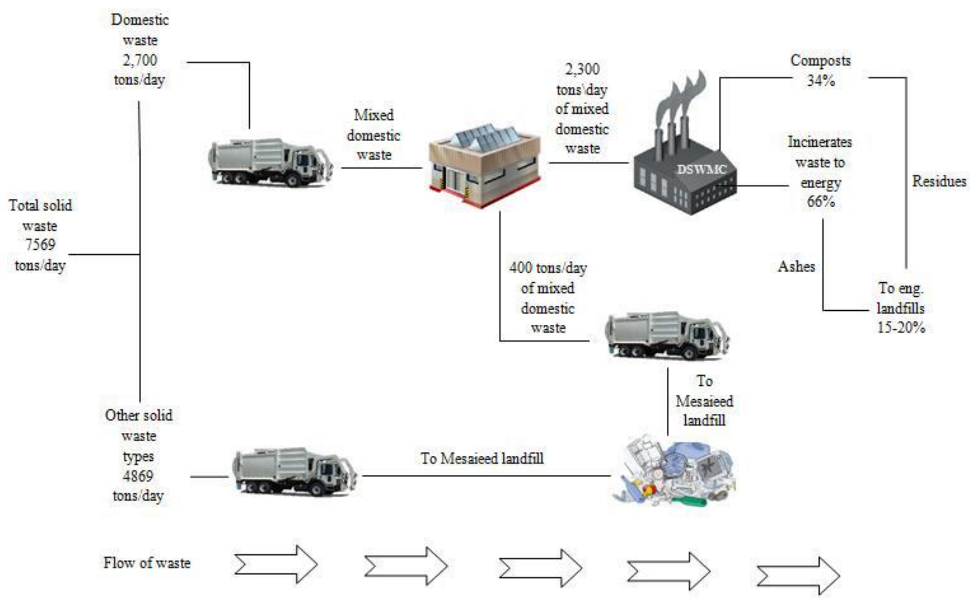

Figure 21: Domestic Solid Waste Statistics 2013-2014

Waste generation has different trends due to seasonality and holidays. For example, household waste reaches its low level during the summer, as many leave for summer vacation. On the other hand, during winter, people tend to stay at home and eat more. Therefore, waste generated is higher. Also, during the holy month of Ramadan, where families gather during the whole week, large amounts of food are unfortunately thrown as waste. Besides, it was also noticed by Keppel Seghers Company that it would be better to collect waste at the beginning of the week, as many family gatherings and celebrations are held during the weekend.

Under the supervision of the Ministry of Municipality and Environment, Q-Kleen is a free of charge private company that is responsible for the collection of waste from houses to waste transfer stations.

The contract between Ministry of Municipality and Environment and Keppel Seghers was signed in 2006 to design and build four waste transfer stations and a domestic solid waste center that can receive all the waste generated in Qatar. While designing the center, four main concepts were considered: integration, sustainability, environmental friendly, and flexibility (Clarke & Almannai, 2014).

The problem with the current system is that each sub-system act in isolation. According to the meetings with the stakeholders, the fleet of vehicles that collect domestic waste from houses does not follow an interrelated time sheet between its travel time and the waste generated at source. This means, the truck can go to pick up the waste, but waste bins can be empty, or not fully packed. So waste of time and fuel is already associated in the current system. Also, there isn't any integrated system between the amount of waste already collected in the WTSs and the trucks that will collect more waste and need extra space for disposal. If the level of waste at one WTS has reached is maximum, waste collection trucks should be informed in order to transfer waste to another station.

In addition to that, it was reported that one of the failures of the current system is the unawareness of recyclable materials collected. It might take months to realize that some waste can be recycled. Due to the miscommunication between WTSs and DSWMC, and unavailability of recycling plants, these materials will be deteriorated to waste.

3.5.1.2 DSWMC

Located near Mesaieed, with an area of 3 km^2, the Domestic Solid Waste Management Center started its operations in 2011. The center includes a state-of-the-art sorting and recycling facilities, engineered landfill, composting plant, and an incineration plant (Keppel Seghers, 2015). DSWMC operates daily with a maximum capacity of 2,300 tons/day (2,086,524.9 kg/day), of which 800 tons/day (725,747.792 kg/day) are sent to recycling plant, 1500 tons/day (1,360,777.11 kg/day) sent to the engineered landfill for incineration. The remaining 400 tons/day (362,873.896

kg/day) are sent to the already existed landfill near Measieed. The first landfill located in Umm Al-Afai was closed in 2012 as it reached its maximum capacity.

The waste is separated at the center and organic materials are composted and the residue incinerated. Nevertheless, the DSWMC does not currently recycle any paper, plastics or metals, but just composts in-organic waste. The process flow diagram for Domestic Solid Waste Management Center in Qatar is shown in the following diagram.

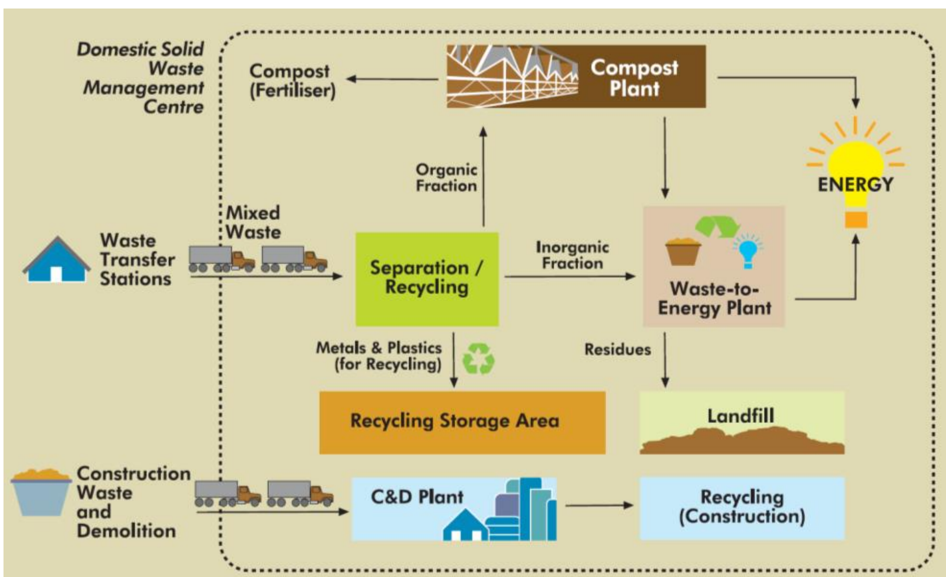

Figure 22: Process Flow of DSWMC

The diagram describes the processes for municipal solid waste and construction and demolition waste. The latter is out of the scope of this project.

For MSW, and based on the category that the waste belongs to, five areas are available:

1. Incoming waste management: the initial separation starts at this area by four drums. Magnets are used to separate the metals. Plastics are separated by Near Infra-Red (NIR) and are then kept in the storage
2. Waste-to-energy plant: by incineration, heat recovery boilers, and flue gas cleaning, materials that can't be recycled or re-used are sent to this plant and will be transferred to energy
3. Energy recovery: a steam turbine generator will produce 50 MVA. After using the power needed by the plant, approximately 30 MVA is exported to Kahramaa network
4. Power station composting: the incoming organic waste will be sent to compost plant
5. Landfill: an engineered landfill will take any incinerators ash and street sweepings

Needless to mention that even though the center produces energy and exports some to the national grid, however, compared to the generation capacity required by Qatar, which is 800 MVA, the amount produced is very small. Also, the amount of recycled or incinerated waste is extremely low compared to the amount of waste generated by day. Currently, Qatar recycles only 10% of the waste generated.

3.5.1.3 Waste Transfer Stations in Qatar

The transfer stations are located in South Doha, West Doha, Mesaimeer, and Dukhan. These stations were designed based on European standards. Once collection trucks reach WTS, waste will be compacted within hours and then loaded to transfer trailers that have a capacity four times larger than the previous ones. Transfer trailers will then transport waste to DSWMC or landfill. Waste can be stored at the station for 3-5 days before their transportation.

The locations of current WTS, DSWMC and landfill in Qatar are shown in the figure below. WTSs are represented by green circles, while the center and the landfill are the blue squares.

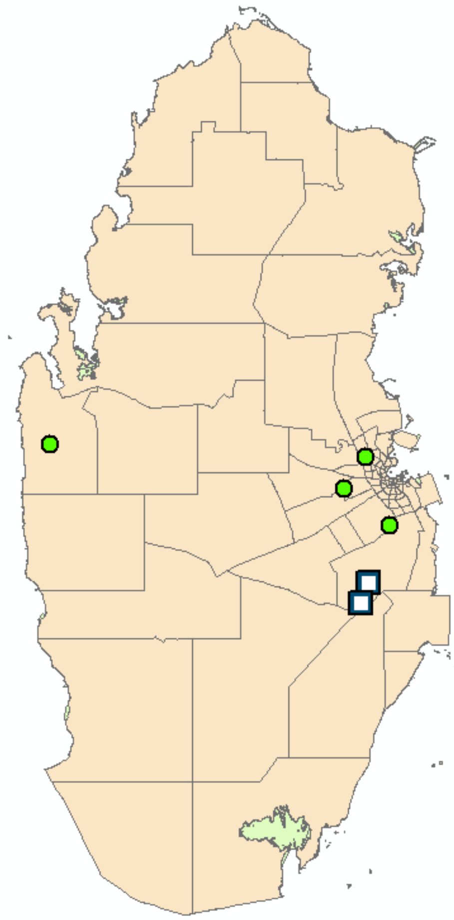

Figure 23: Qatar Map Showing Current WTS, Landfill, and DSWMC

3.6 Location-Allocation Models in ArcGIS

In addition to the current waste transfer stations in Qatar, a previous study was conducted aimed to propose the location of new waste transfer stations to cover the demand of households. The study used minimize impedance model to solve the problem. Results showed that with 10 km impedance cut-off, 6 stations are needed to cover the demand (Bsaisu et al., 2015).

As explained in chapter 2, there are 7 location allocation models in ArcGIS. The previous study focused on minimize impedance for the case of Qatar in 2015, however, because the rate of population has increased, the generation and accumulation of waste increased as well. Therefore, it is necessary to cover as much waste generation and accumulation as possible to prevent the side effects of both. So, in the design of waste transfer stations, it was found that it is necessary to use maximize coverage model. Geo database used in this project for location allocation was based on research in (Enas, 2014).

3.6.1 Mathematical Model

This model covers the maximum number of demand points that can be served by a limited number of waste transfer stations within a stated distance. The mathematical model was first introduced by Church and Revelle (1974) to describe the Maximal Coverage Location Problem (MCLP). The mathematical model shows that a demand point is covered if the distance between the demand and the facility is less than or equal to the specified impedance. Otherwise, the demand is not covered.

$$Maximize\ z = \sum_{i \in I} a_i y_i$$

S.T

$$\sum_{j \in N_i} x_i \geq y_i \qquad for\ all\ i \in I \qquad (1)$$

$$\sum_{j \in J} x_j = P \qquad (2)$$

$$x_i = (0,1) \qquad for\ all\ j \in J \qquad (3)$$

$$y_i = (0,1) \qquad\qquad for\ all\ i \in I \qquad\qquad (4)$$

Where

$I = set\ of\ demand\ nodes$

$J = set\ of\ facility\ sites$

$S = distance\ where\ a\ demand\ point\ is\ not\ covered$

$d_{ij} = shortest\ distance\ from\ i\ to\ j$

$$x_j = \begin{cases} 1\ if\ a\ facility\ is\ allocated\ to\ site\ j \\ 0\ otherwise \end{cases}$$

$N_i = set\ of\ facility\ sites\ to\ cover\ demand\ i\ when\ it\ is\ at\ a\ distance$

$less\ than\ or\ equal\ to\ S\ = \{j \in J \mid d_{ij} \leq S\}$

$a_i = population\ to\ be\ served\ at\ demand\ i$

$p = number\ of\ facilities\ to\ be\ located$

They also mentioned that "*Constraints of type (1) allow y_i to equal 1 only when one or more facilities are established at sites in the set N_i (that is, one or more facilities are located within S distance units of demand point i). The number of facilities allocated is restricted to equal p in constraint (2)*".

3.6.2 Analysis of Proposed DSWM System

3.6.2.1 Application of Minimize Facilities Model

The analysis started by using minimize facilities model to specify the minimum number of WTSs needed in Qatar. To solve the problem, the steps followed were:

1. Activate the layers needed to start the analysis; zones layer, districts layer, road network layer
2. Use Create Network Location Tool to add a candidate WTS at the center of each zone
3. From Network Analyst list, choose New Location-Allocation
4. Under Network Analyst window, right click on Facilities to choose Load Locations, which represents WTSs
5. Under Network Analyst window, right click on Demand Points to choose Load Locations, which represents population
6. Press Location-Allocation Properties button and choose Analysis Settings tab:
    a. Impedance: Length (Meters)
    b. Travel From: Demand to Facility
    c. U-Turns at Junctions: Allowed
7. In Advanced Settings tab:
    a. Problem Type: Minimize Facilities
    b. Impedance Cutoff: 10000
8. Press Apply then Ok
9. Press Solve button to run the current analysis

The same model will be used for locating recycling plants. The steps will be the same with few changes:

- Step 2: Use Create Network Location Tool to add two candidates recycling plants at each of the industrial areas in Qatar
- Step 4: Under Network Analyst window, right click on Facilities to choose Load Locations, which represents the recycling plants
- Step 5: Under Network Analyst window, right click on Demand Points to choose Load Locations, which represents the feasible WTSs
- Step 7.b.: Impedance Cutoff: 82000 km

3.6.2.2 Application of Maximize Coverage Model

Using the results of the previous model, maximize coverage model was used several times until the feasible number of facilities is found. To solve this problem type:

1. Activate the layers needed to start the analysis; zones layer, districts layer, road network layer
2. Use Create Network Location Tool to add a candidate WTS at the center of each zone. However, for the zones where the current transfer stations exist, use their xy-coordinates to locate them
3. Double click on the current WTS under Maximize Coverage, change Facility Type to “Required”.
4. From Network Analyst list, choose New Location-Allocation

5. Under Network Analyst window, right click on Facilities to choose Load Locations, which represents WTSs
6. Under Network Analyst window, right click on Demand Points to choose Load Locations, which represents population
7. Press Location-Allocation Properties button and choose Analysis Settings tab:
    a. Impedance: Length (Meters)
    b. Travel From: Demand to Facility
    c. U-Turns at Junctions: Allowed
8. In Advanced Settings tab:
    a. Problem Type: Maximize Coverage
    b. Facilities to Choose: 7
    c. Impedance Cutoff: 10000
9. Press Apply then Ok
10. Press Solve button to run the current analysis

After recording the data of the first iteration, more iterations will be done and the only step that will change is 7.b. Facilities to Choose. Here, the number of facilities was changed based on the suitability of the obtained results.

3.6.2.3 Application of Service Area Analysis

This analysis will be conducted to study the feasible solution. So, once the number of WTS is optimized, follow these steps to analyze this optimization:

1. Activate the layers needed to start the analysis; zones layer, districts layer, road network layer
2. Use Create Network Location Tool to add a candidate WTS at the center of each zone
3. From Network Analyst list, choose New Service Area
4. Under Network Analyst window, right click on Facilities to choose Load Locations, which represents WTSs. Here, facilities will represent the required stations only, which can be exported from the previous model
5. Press Service Area Properties button and choose Analysis Settings tab:
    a. Impedance: Length (Meters)
    b. Default Breaks: 10000 15000 20000
    c. Direction: Towards Facility
    d. U-Turns at Junctions: Allowed
6. In Polygon Generation tab:
    a. Polygon Type: Generalized
    b. Multiple Facilities Option: Overlapping
    c. Overlap Type: Rings
7. Press Apply then Ok
8. Press Solve button to run the current analysis

3.6.2.4 Application of OD Cost Matrix Analysis

This analysis is also done for the feasible number of stations found in order to find the cost of the analysis in terms of distance.

1. Activate the layers needed to start the analysis; zones layer, districts layer, road network layer
2. Use Create Network Location Tool to add a candidate WTS at the center of each zone
3. From Network Analyst list, choose New OD Cost Matrix
4. Under Network Analyst window, right click on Origins to choose Load Locations, which represent population
5. Press OD Cost Matrix Properties button and choose Analysis Settings tab:
    a. Impedance: Length (Meters)
6. Press Apply then Ok
7. Press Solve button to run the current analysis

3.7 Constraints

There were a number of constraints considered during the application of the models mentioned earlier. These constraints are:

- U-turns at junctions were allowed
- Unpaved roads to be avoided

3.8 Assumptions

- Waste transfer stations have the same capacity
- Vehicles for transferring waste are available
- Vehicles for transferring waste have the same capacity

3.9 Sustainability in DSWM System

As mentioned in chapter 3, Waste Management Hierarchy was developed to focus on the 3Rs (Reduce, Re-use, Recycle) before sending waste to landfill or incineration. It described Reduce as minimizing generation waste rates. Re-use as a second-hand use of the same waste without any additional manufacturing. Recycling is transforming waste into useful materials and/or products. However, this hierarchy was further developed in the last years to increase the opportunities of sustainability in waste management.

As shown in fig (23), the hierarchy was transformed from 3Rs to 6Rs. Designers are the first link of the production chain that should consider using this hierarchy. Their designs should aim to reduce the negative environmental impacts.

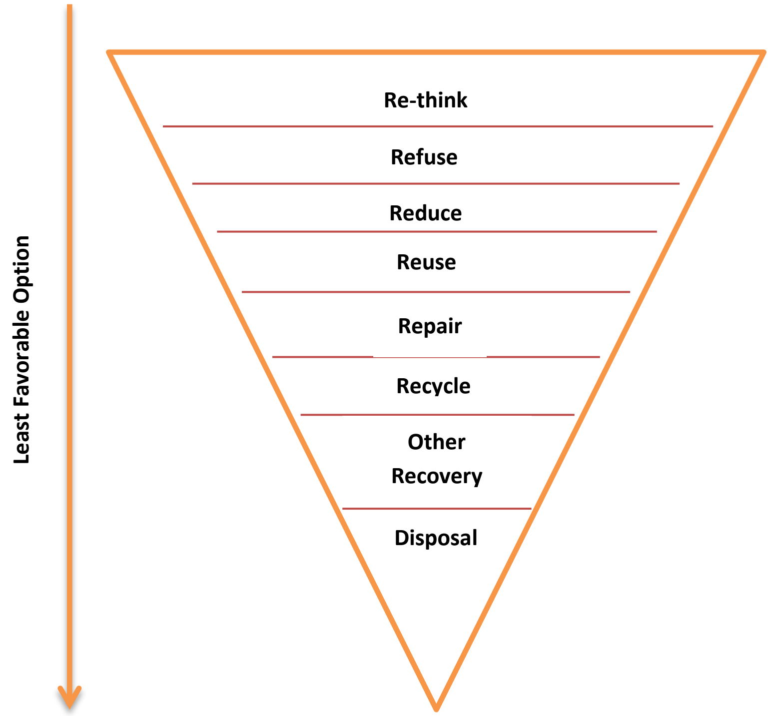

Figure 24: Waste Management Hierarchy with 6Rs

The hierarchy starts with Re-think, as to reconsider the lifestyle people follow to think how our attitudes impact the environment. Refuse to buy and consume products and materials that are unsustainable and difficult to be recycled. Reduce the amount of energy and materials used to manufacture a product. Reuse the product in a different way instead of throwing it to increase its life cycle. Repair any broken products to avoid considering them as waste and throwing them away. Then, categorize waste and place each type in a different bin to be recycled and converted to another product. This project focused on recycling only.

4. Chapter 4 – Results, Analysis, and Discussion

In this chapter, the findings of quantitative and qualitative approaches will be presented, in addition to the results of all network analyst models used in ArcGIS. The main findings in this project will describe the rate of waste generated, number of waste transfer stations to be located, and number of recycling plants to operate in Qatar.

4.1 Waste Quantification

Based on the results that were collected in spring 2015 from 84 houses, the figures below show the amount of waste generated and waste generation pattern between February 2015 to April 2015.

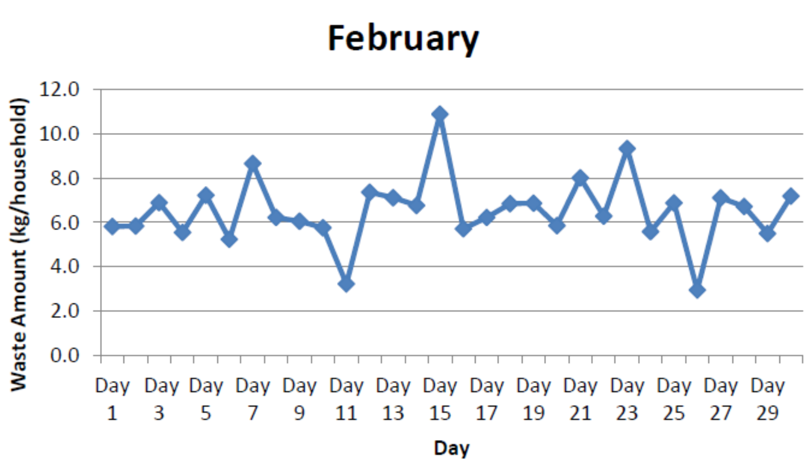

Figure 25: Household Waste Generated in February 2015

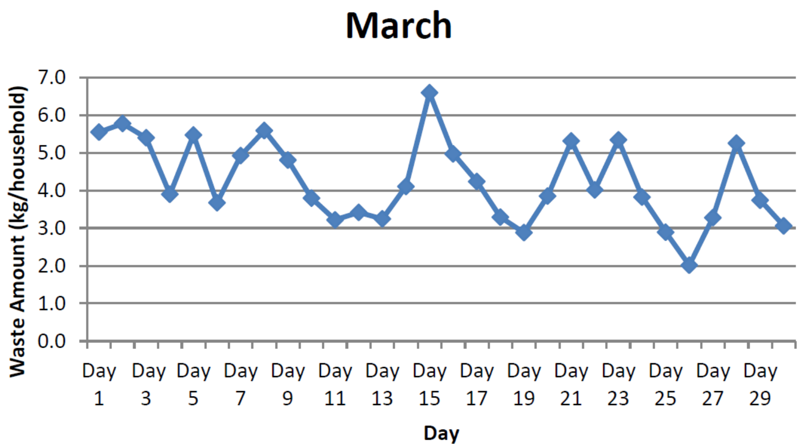

Figure 26: Household Waste Generated in March 2015

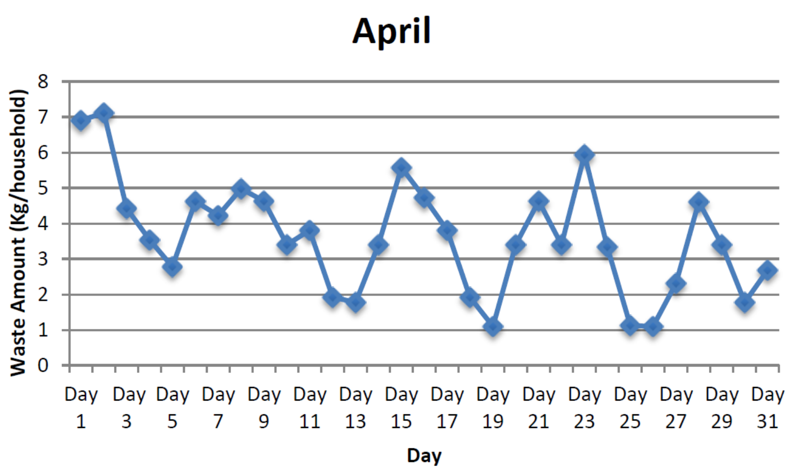

Figure 27: Household Waste Generated in April 2015

The primary data was used as a guideline in order to calculate the total amount of waste generated in Qatar per year. The total waste generated per house was divided by the number of residences. Then the average amount per capita per day was calculated and multiplied by the population of Doha. The value was found to be 1.135 kg/capita/day.

As mentioned in chapter 3, the secondary data represents data collected from stakeholders other than data collected by the survey. As reported by these stakeholders, the quantity of DSW in Qatar is 1.6-1.8 kg/capita/day. Consequently, the quantity of household waste (1.135 kg/capita/day) lies within that range.

To estimate the quantity of household waste generated by the population of Qatar, the quantity of waste per household (1.135 kg/capita/day) is multiplied by the number of population (2,545,603). The quantity is found to be 2,889,259.405 kg/day.

The ministry of Development Planning and Statistics shared the total amount of waste generated in Qatar for the years 2008-2013. As shown in the figure (25), there is a tendency for the generation of waste to increase gradually over the years.

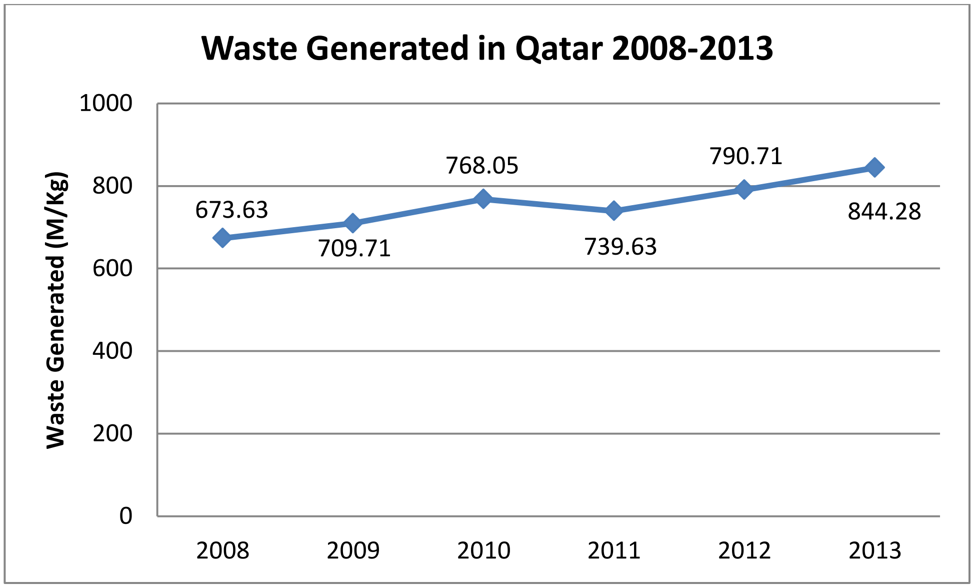

Figure 28: Waste Generated in Qatar 2008-2013

4.2 Waste Characterization

The survey also helped in understanding the types of waste generated. The following figure shows the percentages of different categories of waste. As shown, organic waste/food waste has the highest percentage with 60.98%, plastics come second place with 8.85%, followed by clean paper and glass and ceramic scrap with 8.46% and 6.10%, respectively.

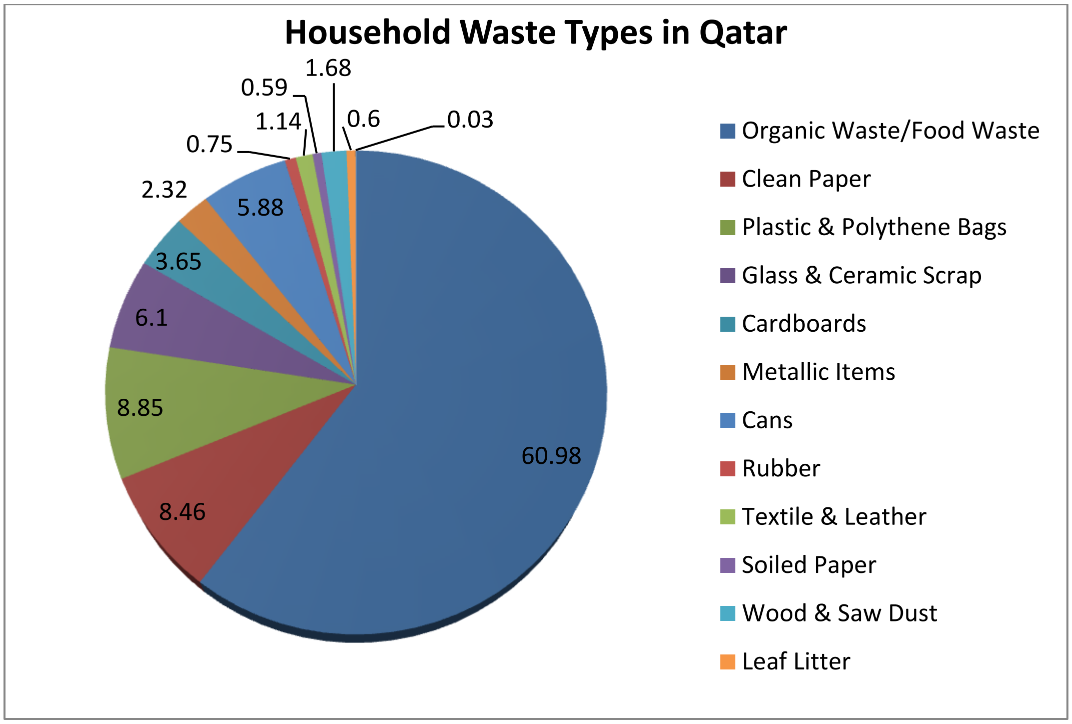

Figure 29: Household Waste Types in Qatar

In order to ensure that the correct sample size was used in this project, the following formula was used:

$$ss = \frac{z^2 \times p \times (1-p)}{c^2}$$

Where

z= confidence level = 90% (which corresponds to 1.645)

p= response distribution = 50%

c= confidence interval= 9%

Therefore, after solving the equation

$$ss = \frac{1.645^2 \times 0.5 \times (1 - 0.5)}{0.09^2} = 83.52$$

Since the sample size was found to be 83.52, and the confidence interval or percentage of error is 9%, then the sample size used for this project is valid.

The following table shows the sample that was chosen for this study in different municipalities in Qatar.

Table 2: Sample of the Study (Number of Houses Surveyed Per Municipality)

Municipality	**Area (Km^2)**	**No. of Houses Surveyed**
Al-Shammal	902	5
Al- Khour	1,551	5
Umm Salal	310	7
Al- Daayen	236	7
Doha	234	34
Al-Wakra	2,520	7
Al-Rayyan	5,818	19

4.3 Analysis of Current DSWM System

As mentioned earlier, a previous study conducted in spring 2015 covered the analysis of the current system. The analysis was conducted with two different impedances, once with 5 km impedance, and the other with 10 km impedance.

Obviously, the 10 km impedance covers more population as the distance between the demand points and WTS is higher.

Based on the data from the previous study, it was suggested that for the current system, it is more efficient to cover more population with 10 km impedance cutoff, than using 5 km impedance.

4.4 Analysis of Proposed DSWM System

Since the objective of this project is proposing sustainable solutions, it should be taken into consideration that in sustainable cities, visual waste and waste accumulation are not acceptable. Therefore, the first model used was Minimize Facilities. This model will define the number of WTSs needed for the State of Qatar.

After using ArcGIS by following the steps mentioned in chapter 3, the results of this model showed that the minimum number of facilities required to cover the demand was 7 waste transfer stations.

The second model; Maximize Coverage, was run taking into consideration the initial result. The type of all stations was left as “Candidate”, however, the current stations were chosen as “Required”.

This problem type was solved three times, in order to find the feasible solution. The first iteration ran with 7 WTSs. The results of this iteration are shown in table (4).

Table 3: Maximize Coverage Results with 7 WTSs

Facility	Type	Coverage
Dukhan	Required	3121
Mesaieed	Chosen	7598
Doha South	Required	8
Mesamier	Required	29130
Onaiza	Chosen	27277
Nuaija	Chosen	11109
Doha West	Required	17073
Total		95316
Demand Coverage	0.859245	86%

Considering that the minimum number of WTS was found to be 7, the second iteration was run to resolve any concerns about having more or less stations. The idea was to ensure that there is either a slight to no difference in the percentage of coverage between having 6, 7, or 8 waste transfer stations. Keeping in mind that there are already four WTSs, the cost of constructing 3 more is high, and the percentage coverage is approximately similar to constructing only 2.

Thus, the second iteration had 6 facilities to choose. The results are in table (5).

Table 4: Maximize Coverage Results with 6 WTSs

Facility	Type	Coverage
Dukhan	Required	3830
Mesaieed	Chosen	7598
Doha South	Required	8
Mesamier	Required	31512
Onaiza	Chosen	27277
Doha West	Required	22105
Total		92330
Demand Coverage	0.832327	83%

Comparing the first two iterations, we can find that the coverage of 7 WTSs is higher by 3%.

In the third iteration, 8 stations were considered. The following are the results in table (6).

Table 5: Maximize Coverage Results with 8 WTSs

Facility	Type	Coverage
Dukhan	Required	138
Al-Shahaniya	Chosen	2364
Mesaieed	Chosen	7598
Doha South	Required	8
Mesamier	Required	31248
Onaiza	Chosen	27277
Nuaija	Chosen	8351
Doha West	Required	19403
Total		96387
Demand Coverage	0.868899	87%

The difference between the coverages of 7 and 8 stations is only 1%.

As a result, it can be concluded that 7 waste transfer stations in Qatar is the optimal. For the coming years, if the number of populations keeps increasing, and so does waste generation and accumulation, then, there might be a need to construct more waste transfer stations.

Figure (27) shows the selected WTSs in red starred boxes, candidates in grey boxes, and population in brown circles.

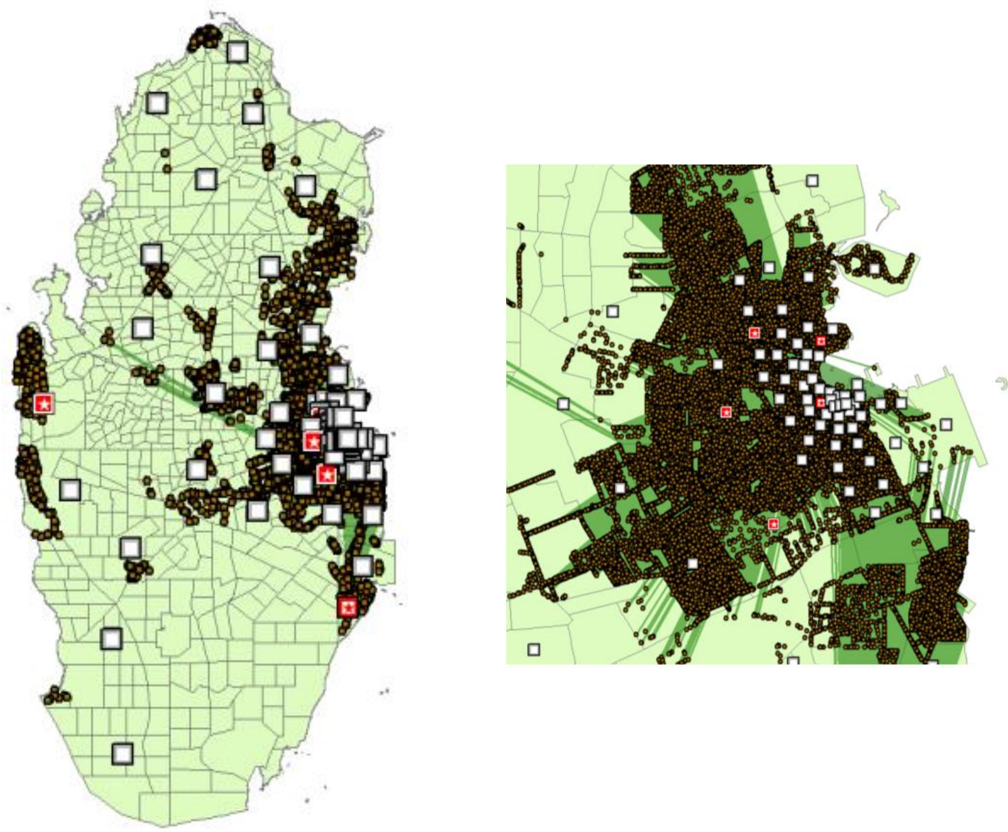

Figure 30: Selected WTSs by Maximize Coverage Model

To analyze the results of maximize coverage model, Service Analysis was used in ArcGIS. This function will analyze the numbers and percentages of population and districts covered. Figurer (28) shows the coverage of each station represented by the grey polygons.

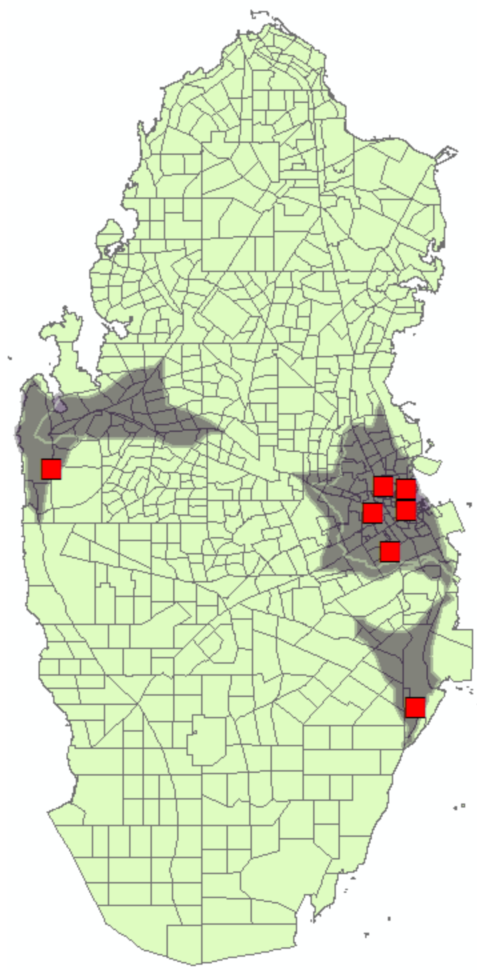

Figure 31: Qatar Map with Service Analysis Function

Keeping in mind that the number of population is 2,545,603, and there are 755 districts, the statistics of this model showed the following percentages as shown in table (7):

Table 6: Percentage of Coverage (Population, Districts)

Population Covered	% Coverage	Population not Covered	% Non-Coverage	Total Districts Covered	Total Districts Not Covered	% District Coverage
1,396,856	54.87%	1,148,747	45.13%	203	552	26.89%

The last analysis conducted was OD Cost Matrix. Here, the function refers to the relative cost of moving between houses and waste transfer stations. It is a relative cost because it depends on geographical information from ArcGIS and does not factor into account other issues like fuel and usage costs of waste transfer vehicles.

As shown in figure (29), the solver will find the least relative cost path between origins (houses) and each of the seven waste transfer stations.

Name	OriginID	DestinationRank	Total_Length
Location 1 - Onaiza	2	1	2799.171462
Location 1 - Doha West WTS	2	2	10913.440949
Location 1 - Mesamier WTS	2	3	12326.316436
Location 1 - Nuaija	2	4	21077.382508
Location 1 - Mesaieed	2	5	23839.897361
Location 1 - Doha South WTS	2	6	61201.028327
Location 1 - Dukhan WTS	2	7	86385.183337
Location 2 - Onaiza	3	1	2255.091202
Location 2 - Doha West WTS	3	2	14340.432249
Location 2 - Mesamier WTS	3	3	15817.829817
Location 2 - Nuaija	3	4	24486.721978
Location 2 - Mesaieed	3	5	26874.989793
Location 2 - Doha South WTS	3	6	63848.307047
Location 2 - Dukhan WTS	3	7	89032.462058
Location 3 - Onaiza	4	1	2873.851663
Location 3 - Doha West WTS	4	2	13689.8638
[illegible]	[illegible]	[illegible]	[illegible]

Figure 32: OD Cost Matrix Attributes

Figure (30) shows the frequency distribution of this matrix. The minimum relative cost is 0. This means that there are some households that are very close to WTSs, so their relative cost is almost negligible.

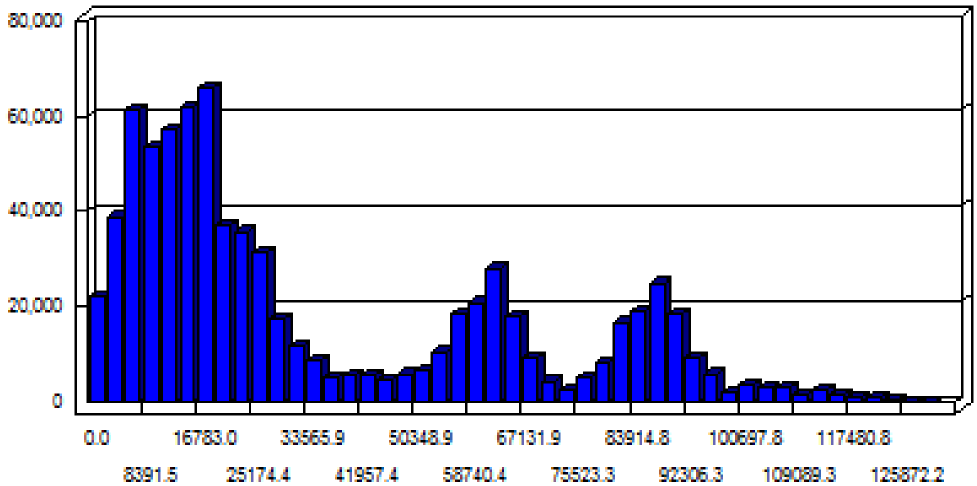

Figure 33: Frequency Distribution of OD Cost Matrix

Figure (31) shows the distribution of OD Matrix lines on the map of Qatar. Lines are represented in pink.

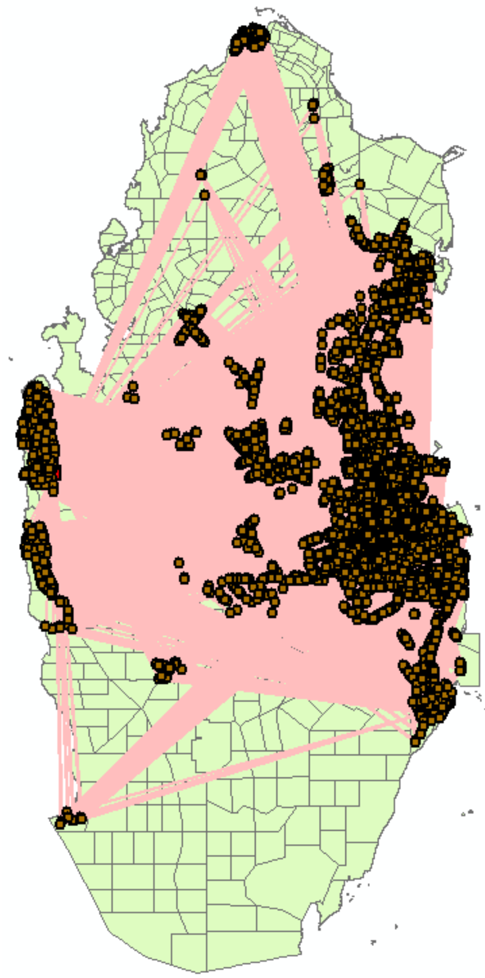

Figure 34: Qatar Map with OD Cost Matrix

In order to achieve the objective related to sustainability of domestic solid waste management, as discussed earlier, one of the methods to ensure the sustainability of the system is recycling. Needless to say, there isn’t strong recycling infrastructure in Qatar, and waste accumulation is expected to increase by 2022, as there will be many events held in Qatar from now till the World Cup 2022. Therefore, the project also proposes the location of new recycling plants in Qatar. Since the country needs to construct many recycling plants for different types of materials, the best location for these plants is industrial areas. Qatar has four industrial areas located in Dukhan petroleum city, Ras Laffan industrial city, Mesaieed industrial city, and Doha industrial city.

For solving this problem, the characterization of waste explained earlier will be used as a guideline. However, some types of waste were combined as one as they represent the same material and can be recycled in the same plant. For example, clean paper and cardboards, and metallic items and cans. For soiled paper, it will not be combined with other types of paper waste, as soiled means that the paper is already recycled, and it will be difficult to separate its fibers in the process.

Since DSWMC has a recycling plant that already recycles food to produce compost by 34%, the analysis here will focus on locating plants for plastics, paper, and metals. The percentages of each of these types are shown in table (8).

Table 7: Percentage of Recyclable Materials in Qatar

Type	**Percentage**
Paper	12.11%
Plastic	8.85%
Metal	8.20%
Residue	71.28%

To solve this problem, it was first assumed that three recycling plants are needed for the three types of waste, i.e. one for plastics, another for paper, and the third for metals.

After that, ArcGIS was used for this problem type. The model used was Maximize Coverage. Since the area of each of the four industrial areas is large, in ArcGIS, many candidates were located to almost cover all of the areas. The impedance cutoff was chosen to be 84 km. This impedance represents the distance between Doha and the furthest industrial area away from the capital. This industrial area is in Dukhan located on the west coast. The distances of the other industrial areas are: 80 km north of Doha, 40 km south of Doha, and 20 km in Doha, for Ras Laffan, Mesaieed, and Doha, respectively.

The following figure shows the candidates recycling plants as squares. As shown, the plants were located to cover each industrial area. However, areas close to households were discarded, in order to avoid any negative impacts. ArcGIS also avoided automatically any areas that will be difficult to reach, for reasons of road infrastructure.

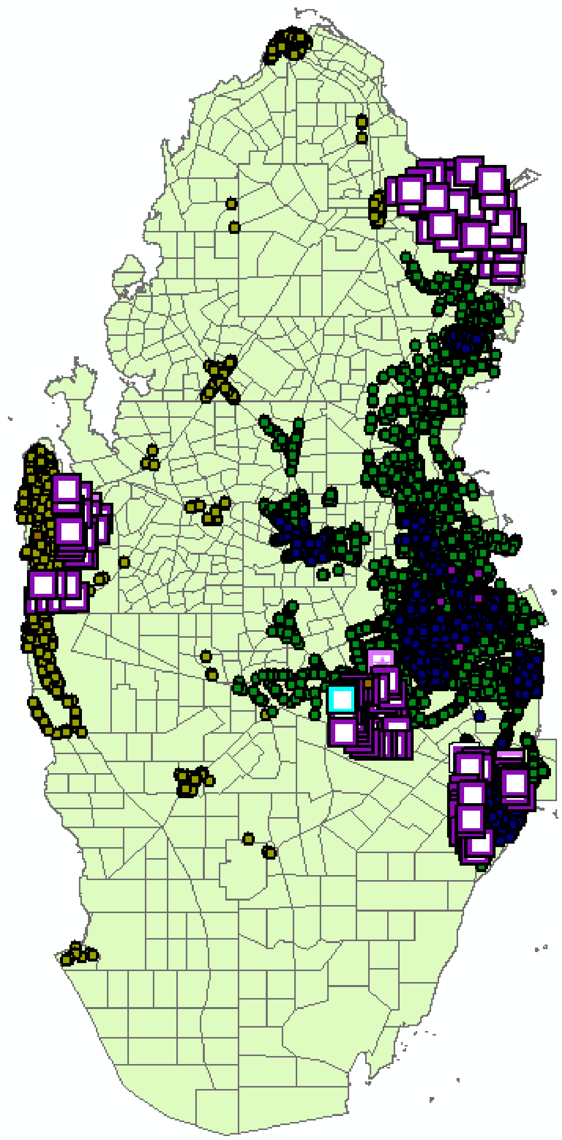

Figure 35: Qatar Map with Proposed Recycling Plants

After solving the model, three recycling plants were chosen; Dukhan, Doha, and Mesaieed. These plants will recycle plastics, paper, and metals, respectively. Figure (33) shows the solution after removing all the other recycling plants candidates. The chosen plants are represented by purple starred squares, and the blue square represents DSWMC. Lines show the distribution of service between recycling plants to WTSs.

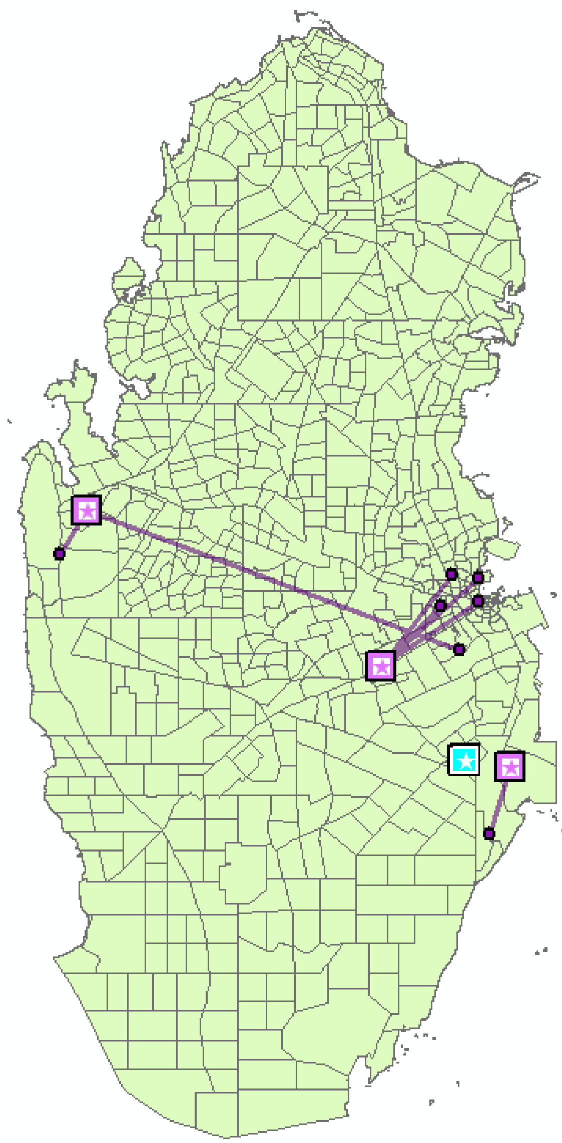

Figure 36: Qatar Map with Chosen Recycling Plants

Recycling was first started in 1826, when Matthias Koops produced white paper from waste paper. However, its impacts were only investigated late 1970s (Nazhad, 2005; Nazhad and Paszner, 1994). Recycling issues have arisen due to the fact that there are negative impacts to dumping waste in landfills. In general, recycling helps in:

1- Reductions in energy consumption, GHG emissions, noise, odours and visual disturbance
2- Reduction in solid waste as there will be less materials in landfills or incinerators. This will help in reducing air and water pollutions, as well as GHG emissions.
3- Less use of energy, water, and chemicals for making through the recycling process, this will lower air and water pollutants.
4- Increases employment opportunities and contribute to community prosperity

The US Environmental Protection Agency (EPA), published few facts and figures about recycling papers, plastics, and metals.

- Recycling one ton of papers will help to:
    - power one home with enough energy for six months
    - save 7,000 gallons of water
    - save 2.5 cubic meters of landfill
- Recycling plastics:
    - recycling one ton will save 3.8 barrels of crude oil that is used manufacturing virgin plastics
    - recycling one pound of PET, the common plastic used in water bottles, will save units of 12,000 units of energy

    - recycling plastics of each family can reduce carbon dioxide emissions by 154 kg annually
- Recycling Metal:
    - reduces GHG emissions between 300 – 500 tons
    - uses less energy than deriving it from raw materials; 95% and 60% less energy is used for recycling aluminum and steel, respectively
    - recycling one soda can will power 60 watt light bulb for four hours

5. Chapter 5 – Conclusion

The main objective of the project was to study the current domestic solid waste management system in Qatar, locate new waste transfer stations, and propose sustainable solutions for this system. A typical sustainable solution discussed in this project is the issue of recycling household waste material. ArcGIS was used as a tool modeling and simulating feasible locations and location-allocations of household waste to waste transfer stations and waste from transfer stations to recycling plants.

To this end, it was found that Qatar needs seven waste transfer stations, and three recycling plants for plastic, paper and metals. The plants are located in Dukhan industrial area, Doha industrial area, and Mesaieed. In addition, the Domestic Solid Waste Management Center located in Mesaieed will continue to recycle the remaining residue of household waste, which will mainly consist of organic waste. Major findings of this project are summarized in the following subsection.

5.1 Summary of Major Findings

- The current waste management system in Qatar is not sufficient since the waste transfer system started operations in 2011 and it was not updated to account rapid changes in infrastructure, rapid growth and changes in population in Qatar since 2011. The major issue in this case is related to waste accumulation in the landfills.

- Domestic waste quantities in Qatar increase year after year due to the increase in population. As per the data collected from households, the generation of waste in Qatar is 1.135 kg/capita/day. Total quantity of household waste generated per day was found to be 2,889,259.405 kg/day. Also, waste was categorized to different types: organic waste/food waste, clean paper, plastic and polythene bags, glass and ceramic scrap, cardboards, metallic items, cans, rubber, textile and leather, soiled paper, wood and saw dust, and leaf litter. Organic waste had the highest percentage of generation.
- Currently, there are only four waste transfer stations to serve all households in Qatar. A previous showed that the service of the four transfer stations is very low. To cope with the rapid development that the country is going through, it was found in this project that three more waste transfer stations are required in order to improve the service level of the transfer stations. This will ensure that more houses are served and covered thus reducing the consequences of waste generation and waste accumulation.
- This project has proposed a sustainable solution in the form of recycling household waste. It was found that Qatar needs three dedicated recycling plants (for paper, plastic and metals) in order to deal with the issues of waste generation and waste accumulation in a sustainable manner.

Based on the major findings of this project, the contributions of this project are discussed in the next section.

5.2 Contribution of the Study

- In Qatar very little work on household waste management is available on the public literature. In a previous study it was found that the minimize impedance model was effective in optimizing the location of the waste transfer stations. In the same study, the required number of WTSs was found to be 6, and the percentage of households and districts coverage were 56.37% and 16.03%, respectively. However, this project has showed that a total of 7 WTSs are needed to cover as much demand as possible. Also, 54.87% of households were covered, and 26.89% of districts were covered. It is notable that the coverage of districts has increased; however, household coverage is lower. This lower percentage could be due to the fact that the population has increased by 10% between March 2015 and end of February 2016. In addition, a lot of residential areas have been located (demolitions) and new residential areas have been created.
- In the public literature, no studies have been made to determine the optimal number and location of recycling plants in Qatar. This study has filled this gap by showing that three recycling plants are needed in Qatar for papers, plastics and metals. This result is a significant contribution to sustainable waste management practices in Qatar.

5.3 Recommendations

For this proposal to be effective, there are some changes that need to be made in Qatar.

1- Government legislations are required to ensure that all companies have initiatives to use the 6Rs
2- Develop standards for recycling materials to encourage local companies to use recycled materials and hence promote sound economic models for business ventures into waste recycling
3- Awareness campaigns to the public about the negative effects of waste accumulation, and positive outcomes of recycling and waste separation at the source
4- Develop a marketing strategy to increase the awareness of recycling at the generation source
5- Promote the benefits of using and following 6Rs
6- Promote recycling and waste separation to various education levels and encourage students and teachers to recycle at schools, and educate their families to do so as well at home
7- Plan to have a campaign for recycling water bottles
8- Government should have policies for food-related companies in order to participate in food recycling courses
9- Learn the experiences of different countries in promoting recycling to the public and try to apply the same in Qatar, whenever applicable

10- Share successful experiences from inside and outside the country with the public for encouragement

5.4 Future Work

1- The results in this study were obtained using the maximize coverage model in ArcGIS. Future studies could focus on other ArcGIS models.

2- ArcGIS software was used as a tool for analysis and simulation. Future studies could use heuristics, metaheuristics or mathematical modelling to optimize the location and allocation of waste transfer stations and recycling plants

References

Akbari, V., Rajabi, M. A., Chavoshi, S. H., & Shams, R. (2008). Landfill site selection by combining GIS and fuzzy multi criteria decision analysis, case study: Bandar Abbas, Iran. *World Applied Sciences Journal*, *3*(1), 39-47.

Akinci, G., Guven, E. D., & Gok, G. (2012). Evaluation of waste management options and resource conservation potentials according to the waste characteristics and household income: A case study in Aegean Region, Turkey. *Resources, Conservation and Recycling*, *58*, 114-124.

Alhumoud, J. M. (2005). Municipal solid waste recycling in the Gulf Co-operation Council states. *Resources, Conservation and Recycling*, *45*(2), 142-158.

Al-Khatib, I. A., Monou, M., Zahra, A. S. F. A., Shaheen, H. Q., & Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district–Palestine. *Journal of Environmental Management*, *91*(5), 1131-1138.

Annepu, R. K. (2012). Sustainable solid waste management in India. *Columbia University, New York*.

Biazaran, M. & SeyediNezhad, B. (2009). Center Problem. In: R. Z. Farahani & M. Hekmatfar, eds. Facility Location: concepts, Models, Algorithms ad Case Studies. Berlin Heidelberg: Springer, pp. 193-216.

Bilitewski, B. (2008). Pay-as-you-throw–A tool for urban waste management. *Waste management*, *28*(12), 2759.

Bonomo, L., & Higginson, A. E. (Eds.). (1988). *International overview on solid waste management: a report from the International Solid Wastes and Public Cleansing Association (ISWA)*. Academic Pr.

Bortoleto, A. P., Kurisu, K. H., & Hanaki, K. (2012). Model development for household waste prevention behaviour. Waste Management, 32(12), 2195-2207.

Bsaisu, A.,Ghadban, N., & Nasr, S. (2015). An Initiative for Integrated Domestic Solid Waste Management in Qatar. (senior project, Qatar University)

Canterbury, J. L. (1994). Pay-as-you-throw: Lessons learned about unit pricing of municipal solid waste. United States Environmental Protection Agency.

Chang, N. B., Parvathinathan, G., & Breeden, J. B. (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of environmental management, 87(1), 139-153.

Chandrappa, R., & Brown, J. (2012). *Solid waste management: principles and practice*. Springer Science & Business Media.

Chatzouridis, C., & Komilis, D. (2012). A methodology to optimally site and design municipal solid waste transfer stations using binary programming. *Resources, Conservation and Recycling*, *60*, 89-98.

Chung, S. S., & Lo, C. W. (2008). Local waste management constraints and waste administrators in China. *Waste Management*, *28*(2), 272-281.

Church, R. L. & Revelle, C. S. (1974). The maximal covering location problem. Regional Science Association, Volume 32, pp. 101-118.

Clarke, S. F., & Almannai, S. (2014). Sustainable Waste Management in Qatar. *Sustainable Development: An Appraisal from the Gulf Region*, *19*, 367.

Dangi, M. B., Urynowicz, M. A., & Belbase, S. (2013). Characterization, generation, and management of household solid waste in Tulsipur, Nepal. *Habitat International*, *40*, 65-72.

Daskalopoulos, E., Badr, O., & Probert, S. D. (1998). Municipal solid waste: a prediction methodology for the generation rate and composition in the European Union countries and the United States of America. *Resources, Conservation and Recycling*, *24*(2), 155-166.

de Oliveira Simonetto, E., & Borenstein, D. (2007). A decision support system for the operational planning of solid waste collection. Waste Management, 27(10), 1286-1297.

Diaz, L., Savage, G., & Eggerth, L. (2005). Solid Waste Management (Vol 1).

Directive, H. A. T. (1975). Council directive 75/442/EEC of 15 July 1975 on waste. Official Journal L, 194(25/07), 0039-0041.

Enas Fares. (2014). An Innovative Approach for Modeling Multi-Facility Location Allocations in Emergency Medical Service Systems. (Thesis, Qatar University)

Eiselt, H. & Sandblom, C. (2010). Location Models. In: Operations Research: A Model-Based Approach. Berlin: Springer , pp. 217-256. Retrieved 14 March 2015.

Eisted, R., & Christensen, T. H. (2011). Characterization of household waste in Greenland. Waste management, *31*(7), 1461-1466.

Emberton, J. R., & Parker, A. (1987). The problems associated with building on landfill sites. *Waste Management & Research*, *5*(1), 473-482.

European Environment Agency (2013). Managing Municipal Solid Waste-A Review of Achievements in 32 European Countries.

Fakayode, S. O. (2005). Impact assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan, Nigeria. African Journal of Environmental Assessment and Management, 10, 1-13.

Fallah, H., NaimiSadigh, A. & Aslanzad, M. (2009). Covering Problem. In: R. Z.

Farahani & M. Hekmatfar, eds. Facility Location: Concepts, Models, Algorithms and Case Studies. Berlin Heidelberg: Springer, pp. 145-176.

Farahani, R. Z. et al. (2012). Covering problems in facility location: A review. Computers & Industrial Engineering, Volume 62, pp. 368-407

Folz, D. H., & Giles, J. N. (2002). Municipal Experience with" Pay-as-You-Throw" Policies: Findings from a National Survey. *State & Local Government Review*, 105-115.

Fotheringham, A., Densham, P. J., & Curtis, A. (1995). The Zone Definition Problem in Location-Allocation Modeling. Geographical Analysis, 27(1), 60-77.

Ghobadi, M. H., Babazadeh, R., & Bagheri, V. (2013). Siting MSW landfills by combining AHP with GIS in hamedan province, western iran. Environmental Earth Sciences, 70(4), 1823-1840.

Hazra, T., & Goel, S. (2009). Solid waste management in Kolkata, India: Practices and challenges. *Waste management*, *29*(1), 470-478.

Henry, R., Yongsheng, Z., & Jun, D. (2006). Municipal solid waste management challenges in developing countries–Kenyan case study. *Waste management*, *26*(1), 92-100.

ISWA. (2012). International Solid Waste Association Report 2012.

Jamshidi, M. (2009). Median Location Problems. In: H. Fallah, A. NaimiSadigh & M. Aslanzad, eds. Facility Location: Concepts, Models, Algorithms and Case Studies. Berlin Heidelberg: Springer, p. 177_191.

Jia, H. (2006). Models and solutions approaches for facility location of medical supplies for large-scale emergencies, Ph. D, USA: University of Southern California.

Joos, W., Carabias, V., Winistoerfer, H., & Stuecheli, A. (1999). Social aspects of public waste management in Switzerland. Waste Management, 19(6), 417-425.

Jowett, B. (1925). The dialogues of Plato.

Kara, C., & Doratli, N. (2012). Application of GIS/AHP in siting sanitary landfill: A case study in northern cyprus. Waste Management and Research, 30(9), 966-980.

Khatib, I. A. (2011). Municipal solid waste management in developing countries:

Future challenges and possible opportunities. INTECH Open Access Publisher.

Kingdom, U. (2002). Department for Environment, Food & Rural Affairs. Annual Report and Accounts 2013-2014. https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs/about/statistics

Kontogianni, S., Karkanias, C., Malamakis, A., Feleki, E., Somakos, L., Aravossis, K., & Moussiopoulos, N. (2014). Pay-as-you-throw; modern pilot application in Greece. In Fifth International Symposium on Energy from Biomass and Waste, CISA Publisher, San Servolo, Venice.

Kontos, T., Komilis, D., & Halvadakis, C. P. (2005). Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste management, 25(8), 818-832.

Luppi, B., Parisi, F., & Rajagopalan, S. (2012). The rise and fall of the polluter-pays principle in developing countries. International Review of Law and Economics, 32(1), 135-144.

Magrinho, A., Didelet, F., & Semiao, V. (2006). Municipal solid waste disposal in Portugal. Waste Management, 26(12), 1477-1489.

McDougall, F., White, P., Franke, M., & Hindle, P. (2001). Integrated solid waste management: a life cycle inventory. 2nd ed. Blackwell Science; 2001, ISBN 0-632-05889-7.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., & Yi, L. (2009). Municipal solid waste management in Pudong New Area, China. Waste management, 29(3), 1227-1233.

Ministry of Development Planning and Statistics. Qatar National Development Strategy. [cited 2016 March 31st]; Available from: http://www.gsdp.gov.qa/portal/page/portal/gsdp_en/nds.

Moghadam, M. A., Mokhtarani, N., & Mokhtarani, B. (2009). Municipal solid waste management in Rasht City, Iran. Waste Management, 29(1), 485-489.

MoEF, G. (1998). The Gazette of India: Extraordinary. Notification on the Bio-medical Waste (Management and Handling) Rules,[Part II–Sec. 39 (ii)].

Mondelli, G., Giacheti, H. L., Boscov, M. E. G., Elis, V. R., & Hamada, J. (2007). Geoenvironmental site investigation using different techniques in a municipal solid waste disposal site in Brazil. Environmental Geology, 52(5), 871-887.

Montiel, I., Husted, B. W., & Christmann, P. (2012). Using private management standard certification to reduce information asymmetries in corrupt environments. Strategic Management Journal, 33(9), 1103-1113.

Morrissey, A., & Browne, J. (2004). Waste management models and their application to sustainable waste management. Waste management, 24(3), 297-308.

Mrayyan, B., & Hamdi, M. R. (2006). Management approaches to integrated solid waste in industrialized zones in Jordan: A case of Zarqa City. Waste Management, 26(2), 195-205.

National Academy of Sciences, 1969. Eutrophication: Causes, Consequences, Correctives. Symp.Proc, Washington, D.C., NAS, 661 p.

Neal, H., & Schubel, J. (1987). Solid waste management and the environment: The mounting garbage and trash crisis. Prentice-Hall.

Nilsson-Djerf, J. (2000). Social factors in sustainable waste management. Warmer Bulletin, (73), 18-20.

Nissim, I., Shohat, T., & Inbar, Y. (2005). From dumping to sanitary landfills–solid waste management in Israel. Waste management, 25(3), 323-327.

Ojeda-Benitez, S., de Vega, C., & Ramí, M. (2003). Characterization and quantification of household solid wastes in a Mexican city. Resources, Conservation and Recycling, 39(3), 211-222.

Ouda, O., Cekirge, H., & Raza, S. (2013). An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia. Energy Conversion and Management, 75, 402-406.

Petts, J. (2000). Municipal waste management: inequities and the role of deliberation. Risk analysis, 20(6), 821-832.

Pichtel, J. (2005). Waste management practices: municipal, hazardous, and industrial. CRC Press.

Pokhrel, D., & Viraraghavan, T. (2005). Municipal solid waste management in Nepal: practices and challenges. Waste Management, 25(5), 555-562.

Reddy, P. (2011). Municipal solid waste management: processing-energy recovery-global examples. CRC Press.

Republic of Singapore. (1968). The Environmental Public Health Act 1968 (Act 32 of 1968). Pp. 315.

Rossel, S., & Jorge, M. (1999). Cuban strategy for management and control of waste. Recovery, recycling, re-integration, 287-290.

Schübeler, P., Christen, J., & Wehrle, K. (1996). Conceptual framework for municipal solid waste management in low-income countries (Vol. 9). SKAT (Swiss Center for Development Cooperation).

Şener, Ş., Şener, E., Nas, B., & Karagüzel, R. (2010). Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Management, 30(11), 2037-2046.

Skumatz, L., & Freeman, D. (2006). Pay-as-you throw (PAYT) in the US: 2006 Update and analyses. Final Report. EPA Office of Solid Waste, Skumatz Economic Research Associates. 31p, 20.

Sun, Y. (2010). Municipal solid waste characterization study for Indiana (Doctoral dissertation, PURDUE UNIVERSITY).

Tadesse, T., Ruijs, A., & Hagos, F. (2008). Household waste disposal in Mekelle city, Northern Ethiopia. Waste Management, 28(10), 2003-2012.

Taha, R., Al-Rawas, A., Al-Jabri, K., Al-Harthy, A., Hassan, H., & Al-Oraimi, S. (2004). An overview of waste materials recycling in the Sultanate of Oman. Resources, conservation and recycling, 41(4), 293-306.

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). Integrated solid waste management: engineering principles and management issues. McGraw-Hill, Inc..

The dialogues of Plato. Vol. 4. Scribner, Armstrong, 1874.

Thomas, B., & McDougall, F. (2005). International expert group on life cycle assessment for integrated waste management. Journal of Cleaner Production, 13(3), 321-326.

Tınmaz, E., & Demir, I. (2006). Research on solid waste management system: to improve existing situation in Corlu Town of Turkey. Waste management, 26(3), 307-314.

Toregas, C., Swain, R., ReVelle, C. & Bergman, L. (1971). The location of emergency services facilities. Operation Research, Volume 19, pp. 1363-1373.

Troschinetz, A., & Mihelcic, J. (2009). Sustainable recycling of municipal solid waste in developing countries. Waste management, 29(2), 915-923.

US EBA (2002). Solid Waste Management: A Local Challenge with Global Impacts.

US EBA (2007). Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006.

US EPA (2008). Municipal Solid Waste Generation, Recycling and Disposal in the United States, Facts and Figures for 2007, EPA-530-R-08-0 1 0

US EPA (2009). Waste guidelines: Waste definitions (Report No. EPA 842/09). Retrieved from http://www.epa.sa.gov.au/xstd_files/Waste/Guideline/guide_waste_definitions.pdf

US EPA. (2013). Municipal solid waste in the United States: 2011 facts and figures. Washington US EPA. 160pp

Van Houtven, G. L., & Morris, G. E. (1999). Household behavior under alternative pay-as-you-throw systems for solid waste disposal. Land Economics, 515-537.

Van Ewijk, S., & Stegemann, J. (2014). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. Journal of Cleaner Production.

Vatalis, K., & Manoliadis, O. (2002). A two-level multicriteria DSS for landfill site selection using GIS: case study in western Macedonia, Greece. Journal of Geographic Information and Decision Analysis, 6(1), 49-56.

Vesilind, P., Worrell, W., & Reinhart, D. (2002). Solid waste engineering. Brooks/Cole Publishing Company, pp 1-3.

Victor, D., & Agamuthu, P. (2013). Strategic environmental assessment policy integration model for solid waste management in Malaysia. Environmental Science & Policy, 33, 233-245.

Wang, G., Qin, L., Li, G., & Chen, L. (2009). Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. Journal of environmental management, 90(8), 2414-2421.

World Bank (2012). What a waste: a global review of solid waste management.

World Commission on Environment and Development (WCED). (1987). Our common future: report of the World Commission on Environment and Development.

Worrell, W., & Vesilind, P. (2002). Solid waste engineering. Cengage Learning, 2011, (Vol 2), pp 1-3.

Zamorano, M., Molero, E., Hurtado, Á., Grindlay, A., & Ramos, A. (2008). Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology. Journal of Hazardous Materials, 160(2), 473-481.

Zhu, D., Asnani, P., & Zurbrugg, C. (2008). Improving municipal solid waste management in India: A sourcebook for policymakers and practitioners. World Bank Publications.

Zurbrügg, C., Gfrerer, M., Ashadi, H., Brenner, W., & Küper, D. (2012). Determinants of sustainability in solid waste management–The Gianyar Waste Recovery Project in Indonesia. *Waste management*, *32*(11), 2126-2133.