Evaluation of the Potential use of Municipal Solid Waste for Recovery Options: A Case of Ma'an City, Jordan

Aiman Jaradat[*] and Omar Al-khashman

Department of Environmental Engineering, Al-Hussein Bin Talal University, Ma'an, Jordan

Abstract

Ma'an city faces serious administrative challenges in managing their municipal solid waste (MSW) due to the lack of adequate information of the composition and quantities of generated solid waste. The overall objective of this research is to gain more reliable information about quantities and composition of MSW stream in Ma'an city. In this work, field survey along with a separation study at waste generation source was conducted to quantify and determine the waste composition of Ma'an MSW stream. Main physical and chemical parameters were determined experimentally in order to assess the suitability of using the organic fraction of Ma'an MSW for recovery options. The results of this study reveal that the total waste generated daily are 72.5 tons per day with food waste compromising the largest component of Ma'an MSW stream (65%) followed by paper products (15.5 %), plastic (11 %), metals (3.4 %), glass (2.8 %), and others (2.3 %). In general, MSW in Ma'an city is characterized by high organic content compromising some 90% of the total waste stream. The estimated calorific value of collected SW (2661 Kcal/Kg) indicates that it can't be incinerated without providing additional fuel. Additionally, high moisture content (44 %) and low quantities of SW generated revealed the unsuitability of Ma'an MSW as an energy recovery option. High biodegradable organic fraction (~80 %) and good nutrient contents suggest that composting under natural conditions can be carried out efficiently if biodegradable organic waste is separated from the remaining waste stream.

1. Introduction

The generation of municipal solid wastes (MSW) has increased steadily over the past two decades as a result of rapid population growth and rise in living standards causing its management to be a serious environmental challenge confronting local authorities in many cities around the world particularly in the cities of developing countries (Seo *et al*., 2004, Zhen-Shan *et al*., 2009; Batool and Ch, 2009; Chung and Carlos Lo, 2008; Imam *et al*., 2008; Berkun *et al*., 2005; Metin *et al*., 2003). Implementing of appropriate solid waste management practices requires reliable information about the composition and quantities of solid waste generated. The lack of adequate information is posing a serious obstacle for decision makers to implement the necessary changes in solid waste management practices in any city. Ma'an city, located in the southern part of Jordan, falls into this category and faces serious administrative challenges in managing their MSW due to the lack of adequate information. Therefore, quantification and characterization of MSW is of paramount importance to help planners and decision makers in implementing a suitable system of waste management.

Several published papers have reviewed the trends of municipal solid waste management (MSWM) in different cities in Jordan. For example, Abu Qdais (2007) discussed the various practices and challenges of MSWM in three major cities in Jordan (Amman, Irbid and Zarqa). Abu hejleh *et al.* (1998) studied the feasibility of using MSW incineration plant in Jordan. Abu Qdais, M. and Abu Qdais H. (2000) studied the applicability of MSW in Jordan for energy recovery. Mrayyan and Hamdi (2006) assess the current operational and management practices of solid waste in active industrialized zone (Zarqa city) in respect to collection, storage, transport, disposal, and recycling issues. Al-Dabbas (1998) conducted an evaluation study of utilization of MSW in Amman city for energy recovery and its effect on reduction of methane emissions. Other studies have addressed the impact of Jordanian solid waste landfills on the environment to provide design and operational guidance to minimize future impacts (Chopra and Abu-El Shaar, 2001; Aljaradeen and Persson, 2010). While these studies have mainly focused on MSW practices in major cities in Jordan, local municipalities to

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[*] Corresponding author. e-mail: aimanjaradat@ahu.edu.jo.

quantify MSW in small cities like Ma'an city did little attempts to date.

This paper provides an overview of the status of MSWM in Ma'an city, analyzes the existing problems in management strategies, and provides recommendations for system improvement. The overall objective of this research is to gain more reliable information about quantities and composition of MSW stream in Ma'an city. The results obtained can be used to assist target city in implementing the main elements of integrated solid waste management (ISWM) systems which involves evaluating local needs and conditions and selecting the most appropriate waste management activities (Pichtel, 2005). This study has been carried out by means of field survey along with a separation study at waste generation source in addition to the sampling and laboratory analysis.

2. Current SWM practices in Ma'an City

Ma'an city is located in the southern part of Jordan (218 km south of the capital Amman) (Figure 1) with current population of 80,000 and an average population growth rate of 3.9% estimated for 25 years (1979-2004).

Figure 1. Location of study area.

The average family volume in Ma'an city as estimated based on 2004-population census is 6-7 persons (Department of statistics, 2004). The present level of MSWM in Ma'an city is low and disordered and lack of unified organization and management on waste collection, transportation, and sorting. Mixed collection is the only used method for waste collection in Ma'an city. No any recovery option of the waste is implemented and a large number of resources are wasted. Six types of solid wastes can be recognized in Ma'an including food, paper, plastic, metals, glass, and others (textiles, leather and rubber, and

miscellaneous) that are generated mainly from households, commercial facilities, and institutional areas. Table 1 summarizes the main waste generation sources with number of establishments.

Table 1: Main waste generation sources in Ma'an city.

Generation Source	Number of Establishments
Residential	10800
Commercial	
Super and mini markets	173
Restaurants	90
Fruit/vegetables stores	30
Meat and poultry shops	43
Institutional	
Schools	50 (8650 students)
Colleges	2 (500 students)
University	1 (8000 students)

At present, landfill is the only used mode to dispose the solid waste in Ma'an City. Waste generated from different sources are transported by trucks to the landfill site located 20 Km east of Ma'an city with an area of 50 ha. The traditional method of MSW disposal is trench method (Figure 2). Waste received to the landfill are distributed in the trenches (500 m length, 6-8 m width, and 8-10 m depth), compressed, compacted by bulldozer, and finally covered with a layer of local soil (20-25 cm) at the end of each working day.

Figure 2. Trench method of waste disposal at Ma'an Landfill site.

In general, MSW in Ma'an city are poorly managed and there are no any suggested solutions to reduce the magnitude of the problem due to the lack of adequate information about percent distribution of each waste type. Consequently, there is an urgent need to quantify and characterize the MSW in Ma'an city to improve its management strategies. In this study a field survey along with direct sampling were conducted at the waste generation sources to quantify the total waste generated and the percent distribution of each waste type.

3. Characterization of MSW in Ma'an City

Accurate information about composition and quantities of solid waste generated serves as a basic tool for any solid waste management plan. Such data is an important issue in waste management as it affects the proposed methodology of disposal and is necessary for examining recovery options. In this study, total waste generated and waste composition in Ma'an city was determined by conducting a field survey consisting of questionnaire method along with direct sampling method at the generation source during a period of 4 weeks in spring season (April, 2011). This sampling date was chosen due to the fact that the average household generation rate in Ma'an city during the spring is equivalent to the annual average generation rate as estimated by Ma'an municipality council from 1994 till 2010 based on daily records of total amount of MSW received to the landfill (Municipality of Ma'an, personal communication, 2010). Direct sampling, involving physically sampling and sorting at the source of generation, is useful on a small scale for obtaining information about MSW composition. Although MSW can be extremely heterogeneous, direct sampling is one of the most accurate characterization methods to make accurate judgments on quantity and composition of MSW (Pichtel, 2005).

This field survey study was designed and administered to collect the samples from different sources of MSW located in Ma'an city including residential, commercial, and institutional sources. A preliminary fieldwork was conducted in the early March, 2011 with a purpose of seeking the household's agreement to participate in this study and determination of public attitudes toward waste separation at home. Trained interviewers visited more than 200 individual households and obtained the necessary information from a responsible adult. Additional information such as monthly income and number of residents per household was also recorded at this stage. A hundred and thirty households out of the original list of 200 agreed to participate in the survey representing a response rate of 65%. Seventy households out of 130 who agreed to participate were chosen from different zones in Ma'an city with various income levels and family sizes and provided with questionnaires contained detailed questions about family size, educational level, and income level. This sample size (70 households out of the total 10800 households) gives 90% confidence level with confidence interval of 10 %. According to sampling theory, the sample means are normally distributed as long as the sample is large enough (n>30) (Owen and Jones, 1990). Special black plastic refuse sacks (189.3 L capacity) with labels were also provided. The householders were then asked to separate their daily waste in 6 separate bags including food waste, plastic, paper, glass, metals, and others (all materials that don't fit into previous categories such as textiles, rubber and leather, yard waste, and batteries) and to label each bag with waste type, name and location of the household. At the next day, these bags were collected by a team of city council employees using five tons tipping trucks and transferred to landfill site. At the landfill site, all bags were weighted using a scale sensitive to 5 gr and checked for waste composition by survey team. Knowing that not all paper, plastic, glass and metals are recyclable, further separation on bags containing these materials was conducted by the survey team to quantify the recyclable portion from non-recyclable portion of the waste stream. This procedure was repeated 4 times (once every week) during the period of study. So the total samples obtained from households were 280 samples (Table 2). To account for commercial sources of MSW, same procedure was repeated by distributing questionnaires and bags for waste separation among the commercial establishments as shown in Table 2. At institutional areas, information about total waste generated daily and waste composition was obtained from institutional records. However, several samples were obtained directly from waste containers at institutional areas (Table 2) for the purpose of analysis.

Table 2. Solid waste sampling sources and sampling frequency.

Generation Source	Number of Establishments	Number of Sampling Sources	Sampling Frequency	Total Number of Samples per Source
Residential	10800	70	4	280
Commercial				
Super and mini markets	173	10	4	40
Restaurants	90	10	4	40
Fruit/ vegetables stores	30	5	4	20
Meat and poultry shops	43	5	4	20
Institutional				
schools	50 (8650 students)	5	4	20
colleges	1 (500 students)	1	4	4
University	1 (8000 students)	1	4	4
Total				428

The daily average generation rate in each household with per capita generation was evaluated. The total amount of MSW generated from residential areas was estimated by knowing total population. Similarly, the daily average waste generation rate in each commercial establishment was evaluated first and then the total amount of MSW generated was estimated by knowing the total number of commercial establishments. In institutional areas, the total amount of MSW generated was known previously from the institutional records and then the daily average waste generation per student (for educational institutions) was evaluated.

To assess the suitability of using the organic fraction of MSW in Ma'an city for energy recovery, three samples (1 Kg each) of the combustible organic fraction (food, paper, and plastic) were selected randomly for each waste type from different bags representing different generation sources and analyzed for the main physical characteristics including moisture content, volatile solid content, and ash residue. These tests represent the proximate analysis, which is usually used as an indicator for capability of MSW as a fuel (Singer, 1981). Moisture and ash content

represent the noncombustible component of the MSW. Both are undesirable in MSW as they add weight to the fuel without adding to the heating value. The volatile matter and the fixed carbon content are the preferred indicators of the combustion capability of MSW. Similarly, to assess the suitability of using the biodegradable organic fraction (food and paper) for biological conversion, three samples (1 Kg each) of biodegradable organic materials were taken after mixing the food and paper wastes from different sources together to account for weight percentage of each waste type. These samples were analyzed for pH, moisture content, carbon, and main nutrient contents (N, P, and K). Carbon and Nutrient levels in addition to pH and moisture content are considered as principal factors regulating the speed and degree of biological conversion (Pichtel, 2005). This procedure was repeated 4 times during the period of study, thus 12 samples were analyzed for each parameter. For physical analysis, the moisture tests were performed first by oven drying at 105°C for one day until a constant weight was achieved (Moldes *et al.*, 2007). The samples were then grounded and milled in a blender and a 10 mesh Willey Mill. Approximately 200 mg of dried sample was weighed using small aluminum pans which were then placed into a muffle furnace at 550°c for 20 minutes. The samples were then removed and weighed and the volatile solids contents were reported as a percentage loss from the dried samples. Ash residue is the amount remained in muffle furnace after burning at 550°C (Alamgir and Ahsan, 2007). Moisture and ash residue together represent the non-combustible fraction of the organic waste. Calorific values of major components of the organic fraction of MSW (food, plastic, and paper) were also evaluated based on physical composition using the model developed by Khan and Abu Ghrarah (1991) and proximate analysis using Bento's Model (Abu Qdais, M. and Abu Qdais H., 2000) which includes assessment of the levels of combustible and non-combustible. The pH was measured by preparing a mixture of MSW and deionized water (waste:water = 1:1). After approximately 5 hours, the measurements were taken with pH meter. For nutrient contents, the organic materials were first dried at normal temperature and then grinded into powder form. Wet oxidation Kjheldhal method was used for determination of carbon and nitrogen (Alam *et al.*, 1991). Potassium and phosphorous were determined by flame photometry (BWB, 2011) and spectrophotometry (Pierzynski, 2000) methods, respectively.

4. Results and Discussion

4.1. Waste quantity and generation rate

The 70 households surveyed in this study were 4-7 family members representing (61.54%) followed by 1-3 members having (20 %) and 8-10 members having the lowest percentage (18.46%). The average family size was 6.3 persons which agreed well with that estimated by department of statistics (6-7 persons) (2010) suggesting that the surveyed samples were representative concerning number of persons per household.

The average generation rates for different families are shown in Figure 3. Based on the obtained results, the

overall weighted average generation rate for Ma'an City is 0.78 kg per capita day^{-1} which is lower than that recorded for Jordan (0.94 Kg/capita day^{-1}) (Chopra, 2001; Daradki, 2008; METAP, 2008) which is attributed to the fact that the income level in Ma'an city is slightly less than that in other Jordanian cities. Table 3 summarizes the weighted average generation rates and total wastes generated from all sources. The residential sources were found to be the primary generators compromising 86.2 % of the total waste generated followed by commercial 7.4 % and institutional 6.4 %. This amount of the total waste (72.500 tons/day) is slightly higher than that estimated as total waste received daily by trucks to the landfill site (65.0 tons/day). This difference in total wastes estimated from the generation sources and the amount received to the landfill site is mainly attributed to main two factors including, the role of scavengers who collect the recyclable items from solid waste containers and the fact that not all wastes are collected in containers (some people used to burn their wastes due to the lack of containers near to their households or due to the long distance to a container).
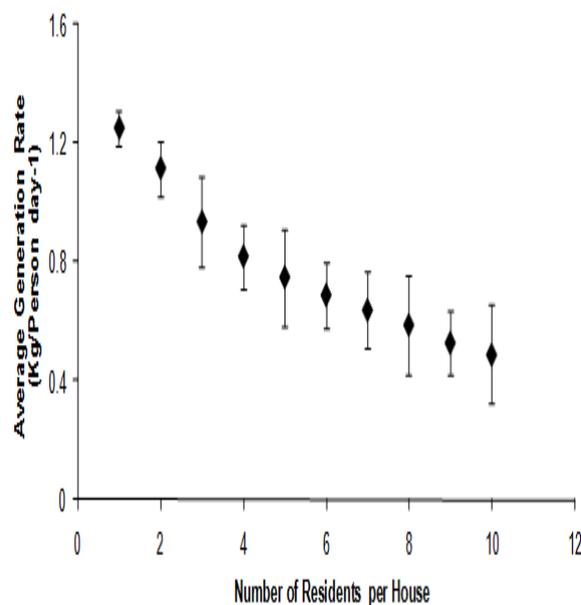

Figure 3. Average generation rate for different families (Kg/person^{-1}day^{-1}).

Results of physical composition and typical percentage distribution of MSW in Ma'an city obtained by separation study are shown in Table 4. Food waste include uneaten food, meat, cooked food, and food preparation wastes from residences, commercial establishments (restaurants, shops), and institutional sources such as school cafeterias, comprise the largest component of Ma'an MSW stream (65%). This result is expected and agreed well with those obtained for other Jordanian cities (Mrayyan and Hamdi, 2006) where the food was found to be the major component of the solid waste stream generated. Paper and paper products comprise the second largest component of Ma'an MSW stream (15.5%). The products that comprise paper and paperboard wastes are newspapers, magazines, office papers, tissue paper and towels, paper plates and cups, corrugated boxes, milk cartons, and egg dishes. Plastic products comprise 11.0 % of the total MSW

in Ma'an city. Plastic products were found in durable goods (appliances, furniture, carpets), nondurable goods (plastic plates and cups, trash bags, disposable diapers), and plastic containers and packaging (soft drink bottles, bags, sacks, wraps). By resin, the plastic products are consisting mainly of polystyrene (plastic food items), high-density polyethylene (trash bags, milk and water bottles), and polyethylene terephthalate (PET) (soft drink bottles). Metals comprising 3.4 % of the total MSW consists mainly of aluminum (beverage containers, food cans, foil), ferrous metals (iron and steel found in appliances, furniture, and containers and packaging materials), and non-ferrous metals (copper, zinc, and lead found in durable products such as appliances and consumer electronics).

Table 3. The weighted average generation rate and total wastes generated from all sources.

Waste Source	Total Number	Generation Rate	Unit	Total Waste (Kg/day)	Waste %
Residential	80,000	0.78 ± 0.035	Kg/ pers.day^{-1}	62400	86.2.
Commercial Supermarkets	173	9.59 ± 0.13	Kg/ market.day^{-1}	1659.368	
Restaurants	90	32.7 ± 1.2	Kg/ rest.day^{-1}	2944.04	
Fruit/ veget. store	30	13.38 ± 0.64	Kg/ store.day^{-1}	401.46	
Meat/ poultry shops	43	6.84 ± 0.87	Kg/ shop.day^{-1}	294.404	
Sub Total				5353	7.4
Institutional					
Schools	8650	0.22 ± 0.01	Kg/ student.day^{-1}	1908.64	
Colleges	500	0.38 ± 0.04	Kg/ student.day^{-1}	190.864	
University	7500	0.337 ± 0.012	Kg/s student.day^{-1}	2528.948	
Sub Total				4628.452	6.4
TOTAL				72381.45	100

Table 4: Percent distribution of physical components of Ma'an MSW from different sources.

% By Weight							
	Food	**Plastic**	**Paper**	**Metals**	**Glass**	**Others**	**Total %**
Residential	58.32	8.7	12.9	2	1.94	2.14	86.00
Commercial	4.65	1.05	1.15	0.3	0.20	0.05	7.4
Institutional	1.95	1.27	1.52	1.1	0.65	0.11	6.6
Total %	64.92	11.02	15.57	3.4	2.79	2.3	100

Glass products comprise 2.8 % of the total MSW and occurred primarily in the form of containers as soft drink bottles, bottles and jars of food, and other consumer products. Textile (occurred in discarded clothing) and rubber and leather products (occurred in automobile and truck tires, clothing and footwear) were found in Ma'an MSW stream in small amount (<1.5 %). Yard waste includes grass clippings, leaves, and tree trimmings from residential, institutional, and commercial sources were present in small fraction (<1%). Some hazardous materials were also recognized in MSW stream of Ma'an city such as paint strippers, batteries, electric lighting, and paint residues.

Table 2 shows that about 33 % of total waste generated have a potential for recycling and consisting of paper products (14.6 %), plastic (11.8 %), metals (3.6 %), and glass (2.8 %). Knowing that not whole portion of paper, glass, and plastic are applicable for recycling; a separation study conducted to separate all materials into recyclable and non-recyclable portion showed the following trends: (1) the majority of paper products are recyclable (78%) and consist of newspaper, magazines, office paper, paper plates and cups, and cardboard. The non-recyclable portion (22%) consist of napkins and paper towels, paper plates, cigarette packages and paper contaminated with food residual such as pizza boxes (2) The majority of plastics (>70%) are recyclable and consists of most commonly recycled plastics including polyethylene terephthalate (PET) and High Density Polyethylene (HDPE) while the non-recyclable (30 %) contain mainly acrylic, some types of kid toys and nylon (plastic bags). (3) The majority of metals (>80%) are recyclable and consist of steel (or "tin") from domestic wastes, instant food Aluminum (Al) containers , Iron and steel containers for oil olive and dates, household stainless steel knifes. The other remaining portion (<20%) consists of metals products represented by corroded metal scrap that are not accessible for recycling. (4) The recyclable portion of glass waste is 80% of total glass waste and consists of all glass food containers, beverage containers (food glass jars), soft drink bottles and juice containers while the other non-recyclable portion (20%) consists of light pulps, window glass and pans. In general the overall portion of recyclable products (paper, plastic, metals, and glass) is about 25% of the total MSW mixture. This suggest that applying recycling program in Ma'an city will reduce cost, minimize waste volume by 25% , and decrease pressure and prolong the lifetime of the landfill.

In general, MSW in Ma'an city is characterized by a high organic content with combustible matter consisting of food, paper, and plastic comprising some 90% of the total waste suggesting that both decomposable and combustible matter is very high. However, to assess the suitability of using the organic fraction of the MSW in Ma'an city for both energy recovery and biological conversion processes, several samples of the organic fraction were collected and analyzed. The results are discussed below

4.2. Physical and Chemical Characteristics of MSW in Ma'an City

Twelve samples of the combustible organic components (food, plastic, and paper) were collected and analyzed for physical characteristics. The results obtained

are summarized in Table 5. The average value of moisture content was found to be high (44.4 %). High moisture content of solid waste has negative and undesirable effect on applicability of MSW for energy recovery as it adds weight to the fuel without adding to the heating value (Pichtel, 2005). The combustible fraction of the whole organic portion of MSW was estimated to be 46.15%. The calorific values estimated based on physical composition (Khan Model) and proximate analysis (Bento's Model) were found to be 2532 Kcal /Kg and 1825 Kcal/Kg, respectively. The results of calorific values obtained using Khan and Abu Ghrarah Model (2661 Kcal/Kg) agreed well with the measured values obtained by others for identical solid waste in Jordan (2747 Kcal/Kg) (Abu Qdais, M., and Abu Qdais, H., 2000). In their work, a good correlation was found between the experimentally measured calorific values with those predicted using Khan and Abu Ghrarah Model and weak correlation with those predicted by Bento's Model. However, the calorific value of collected SW (2661 Kcal/Kg) indicates that it can't be incinerated without providing additional fuel. Also, high moisture content and low quantities of SW generated revealed the unsuitability of Ma'an MSW as energy recovery option.

Table 5. Physical properties of Ma'an MSW.

Waste Type	Sample weight (Kg)	Num. of Samples	pH	Moisture Content(% FM)	Volatile Matter (% DM)	Ash Residue (% DM)	Combustible (% FM)	Non-combu-stible (% FM)
Food	65	8		70.25	86.25	13.75	25.7	74.3
Plastic	11	8		2.57	79.75	20.25	77.7	22.3
Paper	15	8		7.55	82.5	17.5	76.3	23.7
Total	91	24	7.5	44.4			46.15	53.85

Chemical characteristics of the biodegradable fraction of MSW samples are summarized in Table 6. The C/N ratio ranged from 22.38 to 26.46 with an average value of 24.32. The concentration of phosphorous and potassium were ranged from 0.28 to 0.36 % and 0.63 to 0.69 % with an average values of 0.322 and 0.658 respectively. Moisture content of the biodegradable portion of the organic fraction (food and paper) excluding plastic was found to be 52 %. Given that the biodegradable portion of the MSW stream in Ma'an city is ~80 %, with high moisture content and C/N ratio, composting under natural conditions can be carried out efficiently if food and paper waste are separated from the remaining waste stream. This will significantly reduce the amount of SW to be disposed in the landfill by >75%. Although other biological treatment processes like anaerobic processes for methane generation and biogas generation can also be considered for treatment, these processes are successful only on a large scale where good quality equipment and adequate technical and management skills are available (Tumpa and Sudha, 2009). This is not a case in our studied area where total wastes generated are only 72 tons per day. At small or medium scale treatment plants, biogas generation suffers

from problems like fluctuations in the quality and quantity of gas (Tumpa and Sudha, 2009).

Table 6. pH, moisture and main nutrient contents of MSW in Ma'an city

	pH	M%	C/N	N_{total} (%DM)	P (% DM)	K (% DM)
Biodegradable Organic Waste	7.6	52	24.32± 0.66	1.88± 0.017	0.322± 0.03	0.658± 0.02

Segregation of materials that are applicable for recovery options from mixed waste is difficult and expensive process. Therefore, the residents should be sensitized towards the importance of segregation of wastes at source. Result of this survey study has shown that 66% are aware of the separate collection and recovery program especially if properly managed by a municipality council.

5. Conclusions

Field survey along with a separation study at waste generation source were conducted to quantify and determine the waste composition and to evaluate the applicability of Ma'an MSW for recovery options. MSW in Ma'an city is mainly organic compromising some 90 % of the total waste stream (72 tons/day). The estimated calorific value of collected SW was estimated to be 2661 Kcal/Kg. High moisture content and low quantities of SW generated revealed the unsuitability of Ma'an MSW as an energy recovery option. High biodegradable organic fraction (~80 %) and good nutrient contents suggest the applicability of MSW stream for implementing composting operations. Since Ma'an area is located within an arid region with low annual precipitation and it is soil type is sandy with poor quality, applying compost as soil amendment will be valuable as it will improve the soil fertility by supplying main nutrients such as N, P, K, as well as increase water holding capacity due to its high organic matter content. Additional analysis to measure more parameters such as fusion point of ash, sulfur, halogens, H, O, and trace metals would be required to gain a more complete picture about the chemical composition of MSW in Ma'an city.

Further separation of recyclable fraction of plastic, metals, and glass products would be helpful and can reduce the total waste disposed by additional 21%. Thus if composting and recycling were applied, more than 95% of the total waste stream can be used as a source materials leaving only a small portion (5%) to be disposed at the landfill. This will decrease the cost and environmental footprints dramatically.

Result of this survey study has shown that 66 % are aware of the separate collection and recovery program especially if properly managed by a municipality council

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