Municipal Solid Waste Composition Determination Supporting the Integrated Solid Waste Management in Gaza Strip

Ahmad AbdAlqader and Jehad Hamad

Abstract— **Municipal solid waste (MSW) composition studies are essential to proper management of waste for a variety of reasons including a need to estimate potential materials recovery, to identify sources of component generation, to facilitate design of processing equipment, to estimate physical, chemical, and thermal properties of the wastes, and to maintain compliance with regulations. The composition of generated waste is extremely variable as a consequence of seasonal variation, lifestyle, demographic, geographic, and local legislation impacts.**

The aim of this paper is to determine the composition of MSW in Gaza Strip. Two field studies were conducted on Gaza Strip landfills during 2010 and 2011 to find out the average composition of the MSW. The methodology and procedures for this study were derived from the Standard Test Method for Determination of the Composition of Unprocessed MSW (ASTM D 5231-92). All samples were hand sorted into 7 waste categories (paper, plastic, food waste, other organics, metals, glass, and other waste).

The composition of the entire waste stream was 52% Organics (most of them are food waste), 13% Plastics, 11% Papers, 3% Metals, 3% Glass and 18% Other Waste. Consequently, these results should be taken as a baseline for the entire area.

Index Terms—**Municipal solid waste; waste composition; landfills; gaza strip.**

I. Introduction

In many regions and countries, national and international targets have been set for MSW recycling, recovery and diversion from landfills. To develop and implement effective strategies to meet these targets requires reliable information on the composition of all parts of the MSW stream. [1]

The cornerstone of successful planning for a waste management program is the availability of reliable information about the quantity and the type of material being generated and the understanding about how much of that material can expect to prevent or capture. Waste characterization studies are also used to assist in planning, policy development, and infrastructure sizing decisions for various facets of an integrated solid waste management program. [2]-[3]

Gidarakos et al. (2005) argued that effective waste management through MSW composition studies is important for numerous reasons, including the need to estimate material recovery potential, to identify sources of component generation, to facilitate design of processing equipment, to estimate physical, chemical, and thermal properties of the waste and to maintain compliance with national law and European directives. The composition of generated waste is extremely variable as a consequence of seasonal, lifestyle, demographic, geographic, and legislation impacts. This variability makes defining and measuring the composition of waste more difficult and at the same time more essential.

The two most widely used methods for waste characterization are the materials flow method and site-specific sampling via sorting and weighing refuse by category. The materials flow method uses industry data on the production and import and export of goods to estimate waste generation. It is best applied at the national level. In addition, the materials flow approach cannot account for seasonal, geographic, and socioeconomic differences at regional or local levels. [3]

A standard method for determining waste composition by sorting method has been published by ASTM D5231-92 (2003). The ASTM method notes that: 1) the number of samples should be defined based on statistical criteria; 2) load selection for sampling should be randomized and performed over a 5–7-days period and; 3) the initial sample should weigh approximately four times the subsample that will be sorted. The method also provides an abbreviated list of waste component categories and category definition. [2]-[3]

This paper aims to determine the composition of municipal solid waste in Gaza Strip in attempt to support the integration of MSW management.

II. Description of the Study Area

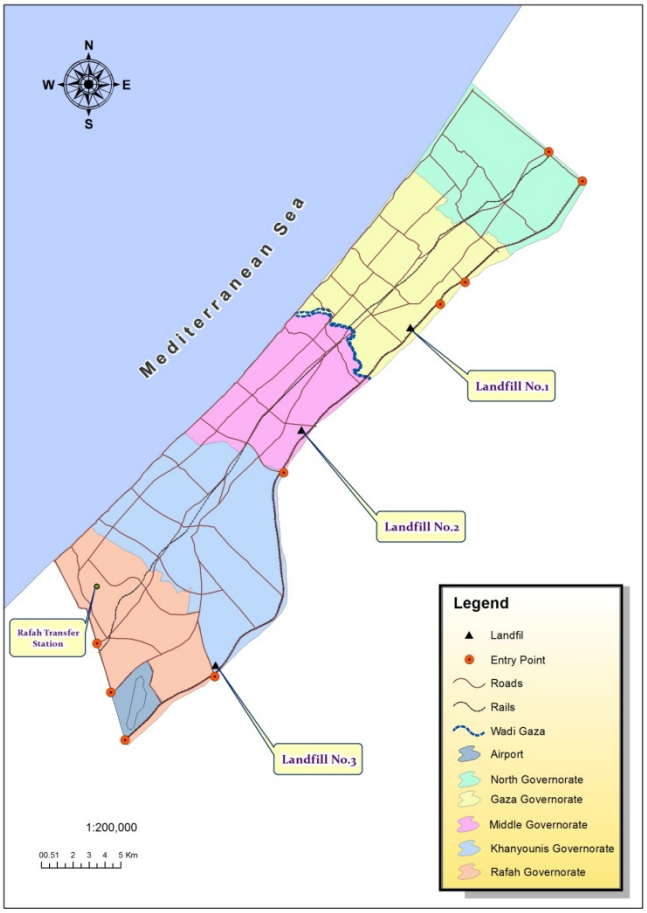
As shown in Map (1), Gaza Strip located along the coast of the eastern Mediterranean Sea stretches over a distance of approximately 45km from the city of Beit Hanoun in the north to Rafah city in the south. Its width varies between 6 and 12 km and the total area is about 365 km^2. Administratively, Gaza Strip is divided into five governorates: North, Gaza, Middle, Khan Younis and Rafah governorate in the south bordering with Egypt. Each governorate consists of municipalities that varied in number depending on the number of towns or villages and the population of each. [4]

Currently, there are three landfills in Gaza Strip; in southern part of Gaza strip, in middle area and in Gaza governorate. In Gaza Governorate, the disposal site, landfill No1. shown in Map (1), covers at least 14 hectare (1 hectare = 10000 m2) directly east of Gaza City and adjoining the Green Line with Israel. This site receives about 1000 tons per day of

Manuscript received February 3, 2012; revised March 8, 2012.

Authors are with civil engineering department, Islamic university of Gaza, P.O.Box 108 Gaza, Palestine (e-mail: aalqader@gmail.com; jhamad@iugaza.edu.ps).

wastes from both Gaza and Northern Governorates under joint agreement. [5]



Map 1: Gaza Strip Map with landfills Locations

In the Middle Governorate, the landfill No.2 shown in Map (1) is located east of Deir El Balah city and covers approximately 6 hectare and also adjacent to the Green Line with Israel. This landfill receives about 300 tons per day of wastes from both Middle Governorate and Khan Younis Governorate under Joint Service Council agreement. [5]

In Rafah Governorate a waste disposal site, landfill No.3, of approximately 2.7 hectare is located near to Sofa crossing border as shown in Map (3). This site receives 130 tons per day of waste from different communities of Rafah Governorate including different municipalities. [5]

III. Materials and Methods

Two field work were conducted in three disposal facilities where approximately all solid waste in Gaza strip reach them as shown in Map (1). The first study was conducted during the period from the end of October 2010 to the mid of November 2010 while the second study was conducted in October 2011.

For the unseen circumstance at landfill No. 3 during the sampling period, the study took place at Rafah transfer station located in the city of Rafah.

The following procedures were implemented in each facility and in both studies to ensure the same conditions in each study for comparison and analysis.

A. Pre-Sort Site Assessment

Prior to initiating the actual sorting events, it was critical to conduct site assessments at each of the solid waste facilities. The purpose of the site assessments was to promote staff support and cooperation for the sorting events and to initiate the gathering of data to develop the sampling and sorting plan for each facility.

B. Sampling and Sorting Events

Sampling was carried out at those disposal sites (landfills) according to international standard ASTM D 5231-92(2003). The determination of the mean composition of MSW was based on the collection and manual sorting of a number of samples of waste over a selected time period covering one week for each site. Therefore, sampling was carried out for a period of three weeks.

Vehicle loads of waste were designated for sampling, and a sorting sample was collected from the discharged vehicle load. The sample was sorted manually into waste components. The weight fraction of each component in the sorting sample was calculated by the weights of the components. The mean waste composition was calculated using the results of the composition of each of the sorting samples.

Based on ASTM D5231-92, the number of sorting samples (that is, vehicle loads (n) required to achieve a desired level of measurement precision) is a function of the component(s) under consideration and the confidence level. The governing equation for n is as follows: [6]

$$n = (t^{*}s/ex)^{2} \quad (1)$$

where t* is the student t statistic corresponding to the desired level of confidence, s the estimated standard deviation, e the desired level of precision, and x is the estimated mean.

Vehicles for sampling were selected randomly during each day of the one-week sampling period at each site, as to be representative of the waste stream. According to ASTM D5231-92, for a weekly sampling period of k days, the number of vehicles sampled each day should be approximately n/k, where n is the total number of vehicle loads to be selected for the determination of waste composition. A weekly period is defined as 6 days.

Each sorting sample weighed 91–136 kg and was prepared properly (mixed, coned and quartered) from each discharged MSW vehicle load using a front-end loader with at least a 1 m^3 bucket. After sampling, hand sorting applied for the classification of MSW into seven categories. Each material category is then weighed and registered in the data sheet. The complete list of material categories and their definitions are included in the Table I.

C. Data Review and Entry

Upon completing the sampling and sorting of the materials, the data sheets were reviewed to ensure the following:

- Individual entries were legible;
- Generator area was clearly identified;
- Specific comments on unusual aspects of a sample were comprehensible; and
- A minimum of 91 kg of materials were sampled and sorted for each sample.

After that, the percentage of each category is computed by dividing the weight of it by the total weight in each sample.

An average then is calculated from all samples for each category.

TABLE I: DESCRIPTIONS OF WASTE COMPONENT CATEGORIES

Category	Description
Paper	Office paper, computer paper, magazines, glossy paper, waxed paper, newsprint and corrugated.
Plastics	All plastics.
Food waste	All food waste except bones
Other organics	Yard waste (Branches, twigs, leaves, grass, and other plant material), wood, textiles, rubber, leather, and other primarily burnable materials not included in the above component categories
Metals	Ferrous (Iron, steel, tin cans, and bi-metal cans), aluminum, and non-ferrous non-aluminum metals (copper, brass, etc.)
Glass	All glass
Other waste	Rock, sand, dirt, ceramics, plaster, and bones

IV. RESULTS

A. Number of Samples Determination

The number of samples in each site was calculated according to ASTM standards taking into consideration a 95% confidence level and assuming food waste as a govern component which mean that standard deviation (s) equals to 0.03 and estimated mean ($\bar{x}$) equals to 0.1, in addition a 10% of precision (e) is desired. Therefore 38 samples were needed to be sorted in each site so that it was taken 40 samples for classification, thus 6-7 samples were sorted each day in each site.

B. Results of Landfill No. 1(Gaza landfill)

This landfill receives daily waste of about 900-1000 ton wastes from both Gaza Governorate and Northern Governorate. [7] Since there are about 852,000 inhabitants in the both governorates [8], the per capita production of waste almost equal to 1.2 kg/capita/day.

In the both field studies, forty samples were collected and analyzed in this site during six days from vehicles coming from various locations covering all areas disposing in this landfill. All of samples were sorted in the same site day by day.

The waste composition for the waste stream entering this landfill is shown in Table II. The percentage composition of waste combined from all locations was 47% organic, 15% plastic, 11% paper (most of them are corrugated), 4% metal, 3% glass and 19% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

TABLE II: COMPOSITION OF MSW IN LANDFILL NO.1 (WEIGHT BASIS)

Component	Weight % (2010)	Weight % (2011)	Average %
Organics	44.9	50	47
Plastic	12.2	18.3	15
Paper	14.8	7.7	11
Metals	5.1	2.5	4
Glass	4.6	1.9	3
Other Wastes	18.4	19.6	19
Total	100	100	100

Furthermore, it is found that most of samples were taken from Gaza governorate (about 85%) inasmuch as it has larger area and more population than north governorate and this is similar actually to the percentage of vehicles entering the landfill from this governorate. In spite of that the samples were covered all areas disposing in Gaza landfill.

C. Results of Landfill No.2 (Middle area landfill)

This landfill receives wastes from both Middle Governorate and Khan Younis Governorate under Joint Service Council (JSC) agreement. In addition it is recorded that about 350 tons reached the landfill every day [9] and the population in both governorates are 530,000 [8] which means that the per capita production is 0.66 kg/capita/day, this value may return in one hand to the wrong practice of some municipalities which prefer to use illegal dumpsite than send the waste to the landfill, thus they don't pay fees for using the landfill. On the other hand many of the areas using the landfill are rural which known of low waste production especially in the east of Khan Yuonis governorate.

Forty samples were collected and analyzed at this site during six days from vehicles coming from various locations covering all areas disposing in this landfill. All of samples were sorted in the same site on daily basis.

The waste composition for the waste stream entering this landfill is shown in Table III. The percentage composition of waste combined from all locations was 54% organic, 12% plastic, 11% paper (most of them are corrugated), 3% metals, 3% glass and 18% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

TABLE III: COMPOSITION OF MSW IN MIDDLE LANDFILL (WEIGHT BASIS)

Component	Weight % (2010)	Weight % (2011)	Average %
Organics	50.4	57.7	54
Plastic	11.1	13	12
Paper	13.1	8	11
Metals	3.2	2.2	3
Glass	3.1	2	3
Other Wastes	19.1	17.1	18
Total	100	100	100

D. Results of Landfill No.3 (Rafah landfill)

Rafah waste disposal site is located near to Sofa crossing border, where the security situation is very dangerous. Therefore the survey was conducted in Rafah transfer station located within the city area in the west of Rafah which received solid waste from Rafah municipality only and other municipalities use the landfill directly. Actually, to get over this problem some vehicles from municipalities using the landfill were requested to the transfer station and they were unloaded in it so that some samples were taken from them.

Based on Rafah municipality records about 120 ton of solid waste are produced daily in Rafah governorate [10] which has 193,000 inhabitants live in it [8]. In other words the residents in Rafah governorate produce 0.62 kg/capita/day of solid waste. Fundamentally this low value may resulted from the wrong practice of some municipalities which prefer to use illegal dumpsite than sending the waste to the landfill, thus they don't pay fees for using landfill. Also

some areas using this landfill are rural which known of low waste production especially in the east of Rafah governorate; in addition some recyclable materials are extracted and converted to small scale recycling facilities.

Forty samples were collected and sorted during six working days from vehicles coming from various locations covering all areas disposing in Rafah landfill.

The waste composition for the waste stream entering Rafah landfill is shown in Table IV. The percentage composition of waste combined from all locations within Rafah governorate was 56% organics, 11% papers (most of them are corrugated), 11% plastics, 3% metal, 2% glass and 18% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

TABLE IV: COMPOSITION OF MSW IN RAFAH TRANSFER STATION (WEIGHT BASIS)

Component	Weight % (2010)	Weight % (2011)	Average %
Organics	49.2	62	56
Plastic	12.3	10.5	11
Paper	14.7	6.3	11
Metals	3	2.5	3
Glass	2.5	1.9	2
Other Wastes	18.3	16.8	18
Total	100	100	100

E. Overall Solid Waste Compositions in Gaza Strip

A year later (2011) the study has been repeated. Three-weeks of field sorting events were conducted at three participating facilities. A total of 240 samples were collected and sorted in this analysis. Knowing that the average weight of each sample was more than 100 kg then the total weight of samples was about 24,000 Kg.

Statistically, the results can be considered representative because the participating facilities manage approximately 100% of the Gaza strip waste. In addition, the samples were well distributed between the residential areas.

Depicted in Table V and Fig.1 are the results by each facility and weighted average of MSW composition in Gaza Strip.

It can be inferred also that Rafah governorate as well as Gaza and northen governorates have the same paper and plastic percentages. Additionally, there is a similar food waste percentage in Gaza, Deir El-Balah, and Khan Younis governorates.

TABLE V: COMPOSITION OF MSW IN GAZA STRIP (WEIGHT BASIS)

Component	Weight % (2010)	Weight % (2011)	Average %
Organics	47.4	56.6	52
Plastic	12.1	14	13
Paper	14.5	7.3	11
Metals	3.8	2.4	3
Glass	4.6	2	3
Other Wastes	17.6	17.7	18
Total	100	100	100

Obviously, there is a significance difference in Plastics percentages between Gaza landfill from one side and both of Deir El-Balah landfill and Rafah transfer station from the other side. This percentage in Gaza landfill be justified by the ample existence of Plastics importers and Plastics factories in Gaza governorate.

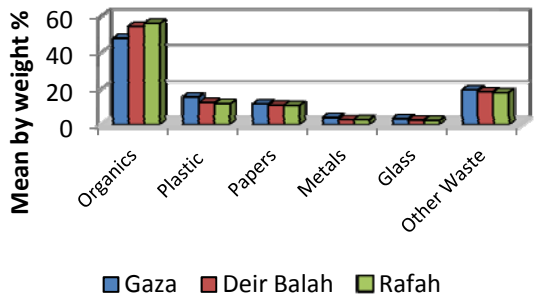


Fig. 1. Aggregate composition by major material category in each facility

In Gaza strip as shown in Fig. 2, Organic wastes constitute the largest component in the waste stream by weight. These organic wastes comprise nearly half of the weight of waste which half of them are food waste and the rest are other organics.

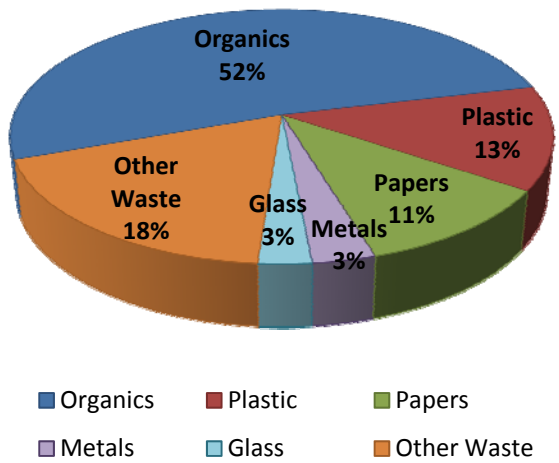


Fig. 2. MSW Composition in Gaza Strip

This is followed by plastics which generally comprise nearly 13% of waste composition which most of it is cardboard. The category "plastic" included all grades of plastic bags, bottles, packaging, all-weather sheeting, and all grades of hard and soft plastics from toys, appliances, and many other sources. Papers, being the third in components order, make up 11% of the waste stream which most of it is cardboard. Paper and Plastic have a significant percentages and this is somewhat surprising. Subsequent to plastic, metals and glass represent about 6% (3% metals and 3% glass) of waste stream. And finally, the other waste materials comprise 18% of waste composition which most of them are sand and fine materials.

F. Comparison with Other Regional Studies

In developing countries the organic fraction is high and may reach up to 60%. Solid waste characterization and quantification is very helpful and economically feasible, since the method of handling, storage and processing of solid wastes at the source plays an important role in public health,

aesthetics and the efficiency of the municipal solid waste system. [11]

Table VI shows the results of composition studies conducted in various districts within the West Bank/Palestine as well as the most recent published study in Israel.

TABLE VI: COMPOSITION OF MSW IN GAZA STRIP (WEIGHT BASIS) [12] –[15]

Study Reference	Study Region	Components %					
		Organics	Plastics	Papers	Metals	Glass	Others
Our Study (2010-2011)	Gaza Strip	53	13	11	3	3	18
Alkhatee, 2009	Ramallah and Jericho	41	25	16	3	3	12
AbuZahr, 2006	Nablus	63	8	10	3	3	13
Al Khatib et al, 2010	Nablus	65	8	9	3	3	12
Israeli MoE, 2007	Israel	40	13	25	3	3	16

V. CONCLUSION

The two years of field sampling and analysis of municipal solid waste in Gaza strip reveal the composition of solid waste in this part of the world. The results show that there have been a significant percentage of recyclable materials. The study reveals some differences with other studies in West Bank and Israel. Overall the study indicated that the average composition of municipal solid waste in west bank, Israel and Gaza Strip ranging between 42 to 60 % organics, plastics between 13 to 25 % and paper is about 11 to 25%. It is also clear that about 12 to 18% of waste classified as others mainly sand.

As there are no previous studies in the last decade about municipal solid waste composition in the Gaza Strip, these results should be taken as a baseline for the entire area.

REFERENCES

[1] S. J. Burnleya, J. C. Ellis, R. Flowerdew, A. J. Poll, and H. Prosser, "Assessing the Composition of Municipal Solid Waste in Wales," *Resources, Conservation and Recycling* vol. 49, no. 3, pp. 264-283, 2007.

[2] E. Gidarakos, G. Havas, and P. Ntzamilis, "Municipal Solid Waste Composition Determination Supporting The Integrated Solid Waste Management System in The Island of Crete," *Waste Management* vol. 26, no. 6, pp. 1-12, 2005.

[3] B. F. Staley and M.A. Barlaz, "Composition of Municipal Solid Waste in the United States and Implications for Carbon Sequestration and Methane Yield," *Journal of Environmental Engineering*, vol. 135, no. 10, pp. 901-909, 2009.

[4] A. Khalaf, "Assessment of Rainwater Losses due to Urban Expansion of Gaza Strip," MSc thesis in Water Resources Management, Islamic University of Gaza, Palestine, 2005.

[5] A. Nassar and A. Jaber, "Assessment of Solid Waste Dumpsites in Gaza Strip," A report published by Environmental Quality Authority (EQA), 76 p, 2007.

[6] ASTM D 5231 – 92 (Reapproved 2003), Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste. ASTM International, 6 p, 2003.

[7] Gaza Municipality GM, unpublished report about solid waste management. Palestine, 2010.

[8] Ministry of Planning MoP, Sectoral Planning in Gaza Strip. Ministry of Planning, 100 p, 2010.

[9] Solid Waste Management Council – Middle Area SWMC, unpublished report about the yearly status of solid waste management in Middle and Khanyounis governorates, Palestine, 2010.

[10] R. Municipality, unpublished report about solid waste management in Rafah, Palestine, 2010.

[11] M. R. A. Moghadam, N. Mokhtarani, B. Mokhtarani, "Municipal Solid Waste Management in Rasht City, Iran," *Waste Management* vol. 29, no. 1, pp. 485-489, 2009.

[12] A. Al-Khateeb, "Municipal Solid Waste Management in Jericho and Ramallah Cities in the West Bank, Palestine," M.Sc Thesis. Birzeit University, Palestine. 2009.

[13] A. F. Abu Zahra, "Evaluation of Solid Waste Management Practices in Nablus District,". M.Sc Thesis. An-Najah University, Palestine. 2006.

[14] I. A. Al-Khatib, M. Monou, A. F. Abu Zahra, H. Q. Shaheen, D. Kassinos, "Solid Waste Characterization, Quantification and Management Practices in Developing Countries. A Case Study: Nablus District – Palestine," *Journal of Environmental Management* vol. 91, pp. 1131-1138, 2010.

[15] *Ministry of Environmental Protection*, Planning For Integrated Solid Waste Management in Israel, Israel Environment Bulletin 32, 14-19, 2007.

Jehad T. Hamad has a Ph.D. in the field of Geotechnical/Geoenvironmental Engineering - Louisiana State University - December 1990. He worked at Southern Illinois University and Bir-ziet University. Currently, He is a member of the Civil Engineering department at the Islamic University-Faculty of Engineering.

He worked as a consultant engineer in a number of private and public engineering firms in USA and Gaza Strip in the field of Geotechnical /Geoenvironment Engineering.

Dr Hamad has published many papers in field of analysis and design of landfills, improvement of soils and the impact on environment.

Ahmed F. Abdalqader has MSc. in the field of Civil Engineering/Infrastructure – June 201. He worked as a teaching assistant in the Civil Engineering department at Islamic University of Gaza.

Currently, he works as a head of infrastructure department in the Ministry of Planning since 2008. Mr. Abdalqader is one of the Engineers association members.