Evaluation of the Potential Use of Municipal Solid Waste for Recovery Options: A Case Study of Fars Province, Iran

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ABSTRACT

A comprehensive study of municipal solid waste is essential for determining the most sustainable solid waste management strategy. The overall objective of this research is to gain reliable information about quantities and composition of household solid waste which could provide basis for implementation of a recovery, reduction and recycling waste management program. The investigation was carried out at 5 cities located at North, South, East, West and center of the Fars province in Iran, in four seasons during 2010-2011.

This study reveals that the total household solid waste generated daily are 598, 536, 594, 618, 515 gram per capita per day for 5 cities including Jahrom, Fasa, Abadeh, Kazeroun and Marvdasht respectively. The average bulk density of solid waste was found 280.67 kg m^{-3} as well. The majority of waste was putrescible (71.01 percent), suggesting a strong resource recovery potential in terms of animal feed or compost. In general, high organic content (71.01 percent) and high moisture content (70-83 percent) reveal that composting solid waste can be considered more optimal as alternative treatment such as incineration. Recyclable waste made up 15.8 percent by weight the waste composition suggesting a motivation for source separation. In addition, with regard to the noticeable fraction of putrescible which is suitable for compost, chemical analyses also carried out for determining of organic components, organic carbon, Nitrogen, C/N ratio, pH, and moisture content in order to investigate the feasibility of microorganism activity.

Keywords: Chemical analysis, Moisture content, Municipal Solid Waste, Solid waste characterization.

1. INTRODUCTION

Rapidly growing populations, rapid economic growth and rise in community living standards have accelerated the generation rate of municipal solid waste (MSW) causing its management to be major worldwide challenge. Particularly in urban cities of developing countries, MSW management (MSWM) is a highly neglected area. The awareness that improper handling of MSW leads to contamination of water, soil and atmosphere and is a major impact on public health has caused developing nations to address this issue with increasing urgency [Al-Khatib et al., 2010].

The type of decision making that leads to adequate solid waste management (SWM) requires a sound understanding of the composition and the processes that determine the generation of waste [Vega et al., 2008]. In fact, Knowledge of solid waste composition is necessary for an adequate management of urban solid waste [Dranke et al., 2007; Gomez et al., 2008; Zeng et al., 2005]. In addition, Special attention should be paid to the waste generation sources since the characteristics and composition of the waste differ according to their source [Vega et al., 2008].

The generation and composition of household waste are not homogeneous. They vary according to changes in consumer patterns and economic growth rates and depend upon standard of living, season of the year, day of the week, population habits and the geographical site of human settlement. By the same token, the generation and composition of waste have been influenced by economic recessions, the impact of legislation and the economic instruments to increase or decrease their value, e. g., reuse and recycling [Williams, 2005].

It is one of the greatest challenges that organizations face today; how to diversify the treatment options, increase the reliability of infrastructure systems, and leverage the redistribution of waste streams among incineration, composting, recycling, and other facilities to their competitive advantage region-wide [Al-Khatib et al., 2010; Sufian et al., 2007].

Different treatment technologies such as incineration, recycling and composting could be used in order to change of waste management option from landfill to more environment friendly options [Williams, 2005]. Technologically developed countries have implemented waste treatment systems of varying degrees of sophistication. However, less developed countries deposit their waste in landfills with no environmental controls or in open spaces. Landfills generate gas emissions and leaching that affect the air, soil and water. Preventing or reducing environmental emissions is a challenge for the environmental agencies of any country [Gómez et al., 2009].

In order to determine the generation and composition of MSW, different methodologies can be used for sampling. Sampling can be through door-to-door waste collection or directly from waste collection trucks [Aguilar-Virgen et al., 2010]. As to sample size, [Tchobanoglous et al., 2004] explains that 90-kilogram samples do not change significantly out of the ones taken in sampling of up to 770 kilograms obtained from the same load of waste. Other research carried out shows that samples taken for analysis can be between 90 and 180 kg [Zeng et al., 2005]. Chung and Poul reports that sample size fluctuates between 20 to 30 kg, 90 kg, 100 to 200 kg, and up to samples of around 5 to 7 tons of solid waste a week [Chung et al., 2001].

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Waste generation rates could vary depending on the season, month and day of the week [Dangi et al., 2011; Tchobanoglous et al., 2004; Worrell et al., 2011]. In addition, urban solid waste (USW) is a heterogeneous material, beside its generation rates, composition vary from place to place and from season to season [Gidarakos et al., 2006; Gomez et al., 2008; The World Resources Institute et al., 1996].

In this study, a one-week door-to-door sampling of waste in five cities for four seasons during the time period 2010–2011 was carried out. The primary goal was to come up at a representative and statistically sound estimate of waste composition for Fars province of Iran and prescribing suitable recovery options. The aforesaid five cities were Abadeh, Jahrom, Kazeroun, Fasa, and Marvdasht (Table 1 and **Error! Reference source not found.**).

For the purpose of this study, a survey was conducted by the Department of Civil and Environmental Engineering of Shiraz University as part of the Urban and Rural Integrated Solid Waste Management Plan of Fars Province [Shiraz University, 2010-2011]. The planned output of the study was the identifying composition, physical and chemical characterization and seasonal variations of waste. For this aim, solid waste was collected directly from the origin; the households.

This is a well-established method of solid waste characterization [Tchobanoglous et al., 2002].

Table 1 Study areas and population (Population Association of Iran 2010)

Name of city	Jahrom	Fasa	Kazeroun	Abadeh	Marvdasht
Population	119048	110820	134949	83196	134835

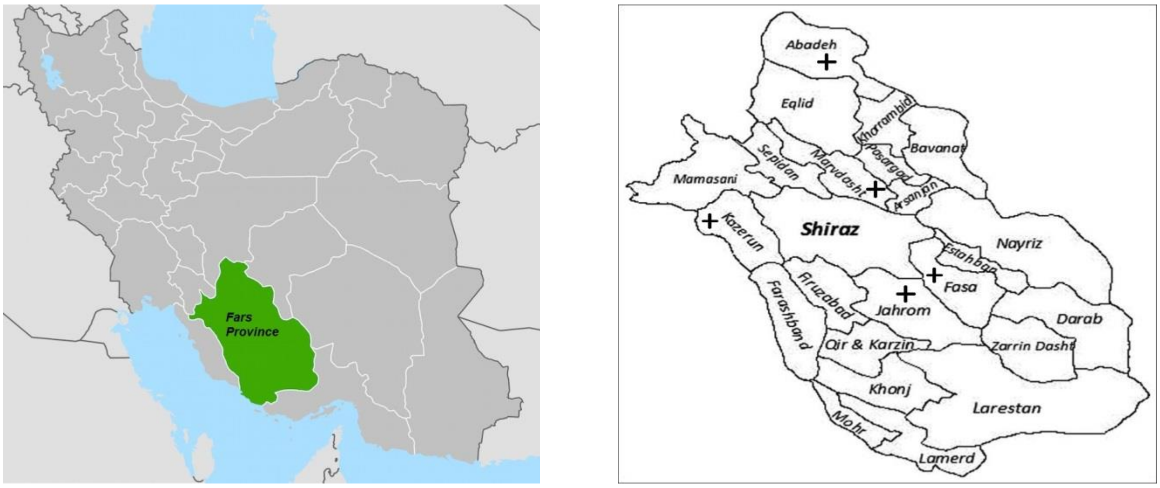

Figure 1 Study area (sampling sites are marked)

2. MATERIAL AND METHODS

2.1. Sampling Methodology

During a one week period of collecting samples door-to-door from various districts in five cities of Fars province, two tons of solid waste was collected for physical analysis. In addition, a 20 kg sample of putrescible fraction of the solid waste was extracted for chemical analysis. The sampling was carried out in four phases corresponding to mid-seasons, beginning in March 2010 and ending in February 2011. The study was conducted through a field survey along with a separation study at the waste generation source and laboratory experiments. All analyses followed ASTM and US EPA guidelines. In summary, the project consisted of inviting households to participate and providing them with basic instructions, collecting the waste during a one week sampling period, transportation, and finally sorting, classification and quantification of the waste.

2.2. MSW Composition Analysis

Those participating in the project received instructions on different phases of integrated solid waste management, recognizing the type of matters, segregation and weighting, determination of per capita waste generation and completion of a questionnaire.

In this study, weight- and volume- analysis which is one of the prevalent methods in estimation of quantity and composition of solid waste was used [Tchobanoglous et al., 2004]. The mean composition of MSW was determined after collecting and sorting the waste over a specific time period, covering one week in the middle of each season. Accordingly, the waste was categorized into 14 main groups, as shown in Table 2, and packed into high-density polyethylene containers. Next, they were weighted for analysis. The weight fraction of each component of the sorted sample was calculated by the weights of the components. Weight percentage of each waste component was also determined.

Table 2 Waste constituents for solid waste characterization

Number	Waste fractions	Waste components
1	putrescible	Food, animal excrements, wood, garden and yard trimmings
2	paper	Office paper, newspapers and magazines, wrapping paper,
3	Cardboard	Corrugated cardboard, boxboard, egg containers
4	textile	
5	metal	Aluminum cans, ferrous and non-ferrous material
6	plastic	Film PE, small plastic, polyethylene(PE) bag, food containers, PET, HDPE, PVC, LDPE, PP, PS and etc.
7	glass	Containers of solid food and or liquids and other glassed-in container
8	Yard waste	Wood, branches and leaves
9	batteries	AA or AAA batteries
10	Feminine pads	
11	Special wastes	Other than feminine pads and batteries
12	fertilizer	
13	Dirt and construction debris	
14	Others or miscellaneous	

2.3. Chemical Analysis

An integrated solid waste management system normally requires many management options. They may include source reduction, curbside recycling, material recovery, Waste-to-Energy (WTE), landfilling, and composting. If organic materials make up the bulk of the local municipal solid waste stream, composting facilities would be favored. However, high fractions of plastics and paper in the waste stream could indicate that choosing the incineration option may be bolstered by mildly high heating values [Chang et al., 2008]. Other variables such as moisture affect the energy content and determined the suitability of waste for composting [Durán-Moreno et al., 2013]. Accordingly, considering the high fraction of moisture content in the analyzed solid waste which is due to the high percentage of putrescent, chemical analysis was also conducted. This provided a means to determine the compostability of the waste.

Composting can help to address solid waste problems and provides a sustainable way to enhance soil fertility. It can be defined as the controlled aerobic conservation of mixed organic materials into a form that is suitable for addition to soil [Hubbe et al., 2010]. Since composting is a biological process of decomposing organic materials, it requires special conditions, particularly of temperature, moisture, aeration, pH, particle size and C/N ratio, related to optimum biological activity in the various stages of the process [Rini et al., 2013; Sharma et al., 1997; Tchobanoglous et al., 2004].

In this study, Chemical analysis were also carried out in order to investigate the suitability of waste (composting mix) for composting regarding to biological activity requirement. The laboratory analysis consisted measurements of moisture content percentage, content percentage in carbon (C), nitrogen (N), C/N ratio and pH.

The sample used in the experiments was 20 kg of putrescible waste (comprised of food waste, yard waste, and leaves) extracted from the household solid waste. Water-proof sealed bags were used for temporary storage and transportation of the sample to the laboratory. The time interval from collection to analysis was less than four hours. Size reduction of the material was performed using knives and scissors in order to prevent alteration of the moisture content. After 24 hours drying of the solid waste sample in an oven at 105 ˚C, moisture content could be determined.

3. RESULTS

3.1. Waste Quantity

The estimated values of MSW as household production in the area under study are reported in Table 3.

Table 3 Solid waste generation

City	Per capita waste generation (gram per capita per day)	MSW production (ton per day)	MSW production (ton per year)
Abadeh	594	49.42	18037.72
Jahrom	598	71.19	25984.61
Fasa	536	59.4	21680.82
Kazeroun	618	83.4	30440.45
Marvdasht	515	69.44	25345.61
Average	572	66.57	24297.84

3.2. MSW Composition

Waste composition analysis results of the solid waste samples collected from various districts of five cities in Fars province during the time period of 2010–2011 are given in Table 4. The three main categories of waste, namely, putrescent, paper, and plastic in all the five cities is of note here.

Table 4 Waste composition analysis (mean values)

No.	Solid Waste Composition		Abadeh	Jahrom	Fasa	Kazeroun	Marvdasht	Mean
1	Putrescible		70.57	71.60	71.72	70.59	70.87	71.07
2	Paper		2.12	1.70	1.28	1.78	2.23	1.82
3	Cardboard		3.29	3.62	2.72	3.83	3.91	3.47
4	Textile		1.53	1.60	1.97	1.89	2.32	1.86
5	Metal	Cans and aluminum containers	0.10	0.21	0.13	0.12	0.16	0.15
		Ferrous and non-ferrous materials	1.00	0.96	0.56	0.74	0.82	0.81
		Total	1.09	1.17	0.69	0.87	0.97	0.96
6	Plastic	Pet bottle	0.56	0.74	0.53	0.67	0.63	0.63
		Colored and transparent bottle	0.13	0.09	0.11	0.06	0.14	0.11
		Nylon	4.44	3.91	4.43	3.51	4.94	4.25
		Disposable dish	0.57	0.94	0.77	0.61	0.87	0.75
		Other kind of plastic	1.88	2.00	2.71	2.23	2.49	2.26

		Total	7.57	7.68	8.54	7.08	9.07	7.99
7	Glass	Food and drinking glassed-in containers	1.65	1.00	0.69	1.16	1.56	1.21
		Other kind of glass	0.31	0.37	0.21	0.52	0.33	0.35
		Total	1.95	1.37	0.89	1.67	1.89	1.56
8	Wood, branches and leaves		2.14	3.03	5.62	1.41	1.53	2.75
9	Batteries		0.02	0.02	0.01	0.02	0.02	0.02
10	Feminine pads		0.93	0.57	0.82	0.74	0.87	0.79
11	Special solid wastes		0.51	0.39	0.65	0.56	0.70	0.56
12	Fertilizer		0.00	0.48	0.00	0.06	0.11	0.13
13	Dirt and construction debris		3.70	1.90	1.56	2.10	0.61	1.97
14	Miscellaneous		4.56	4.86	3.53	7.39	4.89	5.05
Total			100.00	100.00	100.00	100.00	100.00	100.00

Waste component values for Fars province obtained by averaging the components of the wastes in each season for 5-cities are also illustrated in Figure 2. It is evident from the data that 71.01 percent of the waste is putrescible matter alone, followed by plastic waste at 7.99 percent, and paper at 5.29 percent. As was pointed out earlier, these three categories account for a considerable 85 percent of the total household produced solid waste. In this regard, recycling is highly advised for this area.

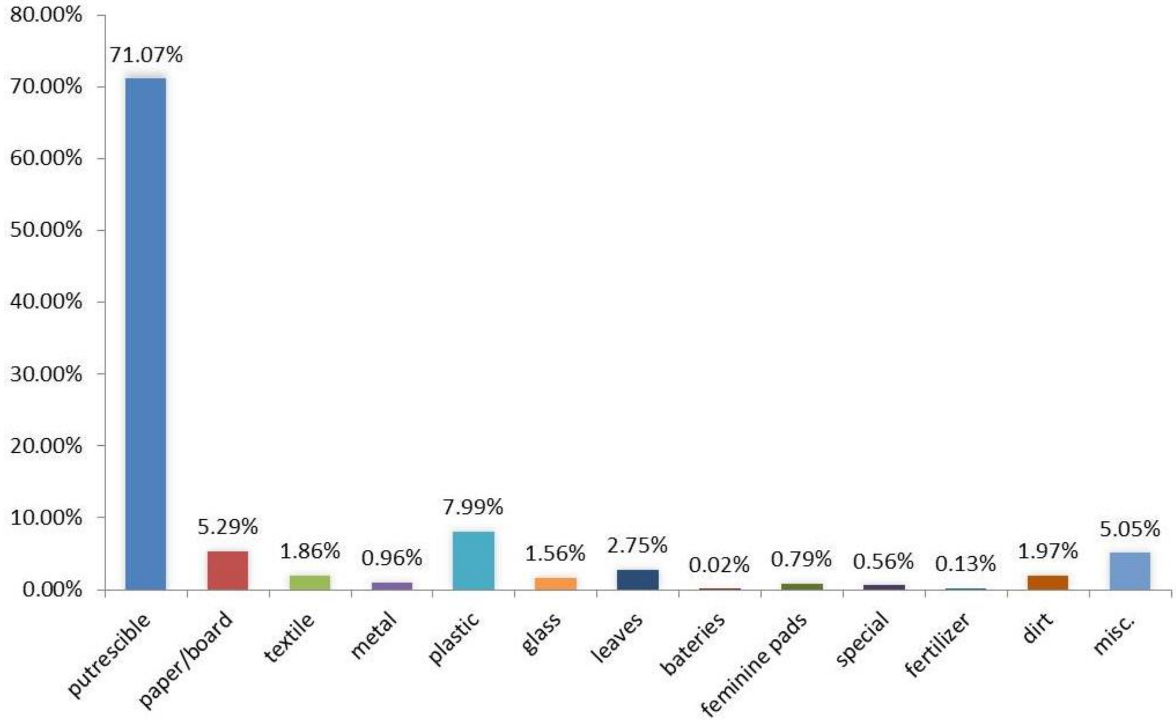

Figure 2 Average composition of MSW

The low percentage of metal components is also of note here. Ferrous material, aluminum, and other metals comprise only 0.96 percent of the total composition. This is while the total portion of combustible material content such as paper, nylon, plastic, etc. is 21 percent for the studied area.

Bulk density is the quantity often used in designing management strategies such as transportation. It is a function of the physical composition, moisture content, and degree of compaction. In order to determine the bulk density of non-compacted waste, a wooden container with volume $V_1 = 0.1\ m^3$ and weight W_1 was used. The container was filled with household waste, dropped three times from a height of 10 cm to make extra room, and filled again until no more waste could be added [Environmental Protection Agency, 1996]. In case there was not enough waste to fill the container, the volume was measured as V_2. No extra pressure was exerted on the content so that the bulk density would be unaltered. Finally the mass of the full container was measured as W_2, and the bulk density (kg m^{-3}) was calculated as equation (1):

$$Bulk\ density\ (kg\ m^{-3}) = (W_2 - W_1)/V_1 \quad (1)$$

As is reported in Table 5, the values of bulk density of the waste show a narrow spread of 270–285, with an average of 280.67 kg m^{-3} for the area under study. Waste with high moisture content, such as food leftovers is the main factor that influences the bulk density. Finally, we mention that the average value obtained here is in agreement with the national average reported by Diaz and Golueke [Diaz et al., 1985].

Bulk density is important for the selection of waste collection equipment. For example, compactor trucks are most effective if the waste has a low bulk density [Coad, 2011].

Table 5 Bulk density of MSW of 5-cities

Study Area	Abadeh	Jahrom	Fasa	Kazeroun	Marvdasht	Average
Specific gravity (kg m^{-3})	285	285.7	284	273	275.67	280.67

3.3. Chemical Analysis

Considering the significance of the amount of putrescent in household solid waste and the feasibility of composting process, chemical analyses were conducted. The results for the five cities in each season of the study period are reported in Table 6 in conjunction with the standard values [Zucconi et al., April 1986].

The chemical composition of the bulk material affects some parameters, especially the C/N ratio. Very high C/N ratios delay the microbial metabolism, whereas low values cause the loss of nitrogen through ammonia volatilization [Sharma et al., 1997]. It has been recommended that compost mixtures should be prepared so that the initial C/N values are between about 25:1 and 40:1 [Dickson et al., 1991] or even high as 50:1 [Tchobanoglous et al., 2004]. The residual carbon to nitrogen ratios of 20.55, 23.05, 20.30, 22.08, and 20.55 for Abadeh, Fasa, Jahrom, Kazeroun, and Marvdasht respectively are nearly consistent with the standard value.

To obtain a high quality compost, the C/N ratio of the waste can be adjusted to an optimum level by adding cow manure, poultry manure, garden waste etc. [Jilani, 2007] as well as Wood elements (such as sawdust) can be added to the waste because the wood has high C/N ratio, which is 200-400 [Tchobanoglous et al., 2004].

Another parameter of significant importance is the percentage of water content in the feed material. It is to be noted that the higher water content may cause problems for the complete oxygenation of the material, whereas the lower values, on the other hand, may interrupt the process prematurely [Sharma et al., 1997]. To calculate moisture contents, equation (2) with pre- and post-drying sample weights as inputs was used. The results for the samples from the five cities are shown in Table 6.

$$M = \frac{(W - d)}{W} \times 100 \quad (2)$$

Where *W*: initial weight of sample, (kg); *d*: weight after being dried under 105^0C, (kg); *M*: moisture content.

The moisture level in a compost mixture should be optimized in order to achieve the best results [Hubbe et al., 2010]. Dickson et al. and Dougherty [Dickson et al., 1991; Dougherty, 1998] recommended a moisture content in the range 40 percent to 60 percent, whereas Tchobanoglous et al. recommend 50 to 60 percent moisture [Tchobanoglous et al., 2004]. Hwang et al. recommended that the moisture content should be kept 46 percent for the composting of kitchen garbage [Hubbe et al., 2010; Tay et al., 2002]. The high levels of MSW mean moisture content of 69.25, 72.25, 79.75, 72.25, and 74.5 for Abadeh, Fasa, Jahrom, Kazeroun, and Marvdasht respectively, must be reduced through aeration during the composting process.

PH is one of the critical parameters in composting process, the ideal range of which for microorganism activity is 5.5-7 [Committee CS-037 et al., 2003]. A pH level of compostable solid waste that falls outside this range, implies too acidic or too basic material. The required additives that bring this pH back to the normal levels incur extra costs. The results of the chemical analyses however, indicate a standard pH range of 5.5–7 for the area under study.

Table 6 Chemical analyses of solid waste

Name of City	MSW Components	Spring	Summer	Autumn	Winter	Mean	Standard Values*
Abadeh	Organic Content	84	86.87	76.47	77.23	81.14	>20
	C	46.7	48.26	42.48	42.9	45.09	30-40
	N	2.83	2.61	1.806	1.81	2.26	>0.6
	C/N	16.5	18.49	23.52	23.7	20.55	25-50:1
	pH	4	6.4	8.57	5.54	6.13	5.50-8
	Moisture	76	77	55	69	69.25	<50
Fasa	Organic Content	88.17	86.57	89.34	70.99	83.77	>20
	C	48.98	48.09	49.63	39.44	46.54	30-40
	N	2.32	2.86	2.18	1.25	2.15	>0.6
	C/N	21.11	16.81	22.72	31.55	23.05	25-50:1
	pH	6.1	6.54	6.22	5.58	6.11	5.50-8
	Moisture	67	88	71	75	75.25	<50
Jahrom	Organic Content	83.04	87.86	91.42	74.24	84.14	>20
	C	46.13	48.81	50.78	41.2	46.73	30-40
	N	2.3	2.82	2.65	1.49	2.315	>0.6
	C/N	20.056	17.31	16.19	27.65	20.302	25-50:1
	pH	5.6	4.12	6.03	5.47	5.305	5.50-8
	Moisture	81	80	78	80	79.75	<50
Kazeroun	Organic Content	70.68	82.97	88.88	87.46	82.5	>20
	C	39.27	46.09	49.38	48.59	45.83	30-40
	N	2.2	2.16	1.96	2.04	2.09	>0.6
	C/N	17.85	21.34	25.29	23.82	22.08	25-50:1
	pH	5.2	6.48	5.76	5.38	5.71	5.50-8
	Moisture	69	71	77	72	72.25	<50
Marvdasht	Organic Content	84	86.87	76.47	77.23	81.14	>20
	C	46.7	48.26	42.48	42.9	45.09	30-40
	N	2.83	2.61	1.806	1.81	2.26	>0.6
	C/N	16.5	18.49	23.52	23.7	20.55	25-50:1
	pH	4	6.4	8.57	5.54	6.13	5.50-8
	Moisture	76	77	55	69	69.25	<50

* *Dickson, Richard, and Kozlowski (1991)*

4. CONCLUSION

Determination of waste characterization is crucial for structuring and executing waste management programs. The aim of this study within this context was to conduct characterization of waste collected in 5 cities of Fars Province, Iran. The results of this study reveal that the total waste generated daily are 598, 536, 594, 618, 515 gr per capita per day for Jahrom, Fasa, Abadeh, Kazeroun and marvdasht respectively. The average bulk density of solid waste was found 280.67 kg m^{-3}.

As a result, the analysis of solid waste composition indicates that 71.01 percent of the solid waste is made up of putrescible materials mainly due to the use of unprocessed food in the daily diet of inhabitants. This indicates that composting/biodegradation can be used for the disposal of this fraction and the product can be sold as fertilizer. High amount of easily recyclables such as paper/board, glass, metal composed of 15.8 percent within the total waste emphasize the implementation of waste management policies such as individual collection of recyclables.

Moisture content of household solid waste was calculated as 70-80 percent in this study. This value is a little bit high with regard to the literature. However, the reported organic matter proportion solid waste composition had suggested an increase in the moisture content as well.

In this study, since putrescent constitutes remarkable fraction of total household solid waste and composting is a biological process of decomposing organic materials, it requires special conditions, particularly of temperature, moisture, aeration, pH, particle size and C/N ratio. The results of chemical analyses reveal that average C/N ratio of the solid waste was almost close to the standard and pH values also ranged between 5.5 and 7, which satisfies optimum values for composting. Mean relative humidity was high and may be reduced by aeration during the process of composting. In order to avoid any eventual slowing of the microbial degradation during the process of composting, it is necessary to mill the organic components to have a more homogeneous mater.

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