International Journal of Renewable Energy Technology Research
Vol. 3, No. 6, June 2014, pp. 1 - 9, ISSN: 2325 - 3924 (Online)
Available online at http://ijretr.org

Research article

POTENTIAL OF MUNICIPAL SOLID WASTE, AS RENEWABLE ENERGY SOURCE - A CASE STUDY OF ARUSHA, TANZANIA.

Arthur M Omari[1*] Baraka N Kichonge[1] Geoffrey R John[2] Karoli N Njau[1] Peter L Mtui[2]

[1]School of MEWES, Nelson Mandela African Institution of Science and Technology,
P.O. Box 447, Arusha Tanzania
[2]College of Engineering and Technology, University of Dar es Salaam
P.O. Box 35131, Dar es Salaam. Tanzania
[*]E-mail of corresponding author: omaria@nm-aist.ac.tz

Abstract

This paper presents the study of municipal solid waste (MSW) as a potential source of renewable energy in Arusha city. The city of Arusha annual average MSW generated was estimated at 43,772 tonnes. Characterization revealed the main components of MSW to compose of biomass materials such as food, paper and wood waste. Based on the characteristics of the MSW, evaluation was conducted to determine energy potential that would be recovered. Results from proximate analysis of MSW samples showed average calorific value of about 12MJ/kg which indicate annual energy potential of 128.9 GWh. Results indicate there is a substantial energy potential to recover from MSW the largest share being renewable energy. The composition of waste from developing and developed countries was further compared with that of Arusha city. Results indicated that in developing countries characteristics of MSW is mainly composed of food waste as was the case of Arusha city.

Keywords: municipal solid waste, renewable energy, waste disposal, energy recovery

1. Introduction

The utilization of fossil fuels has been practice for many years as a source of energy, this utilization produce greenhouse gases such as CO_2, SO_2, NO_x and other pollutants which increase global warming and acid rain. The fossil fuel resources are depleting while the consumption is increasing. This environmental effects and fossil depletion necessitates the effort in invention of alternative source of clean and renewable energy [1].

Fossil fuel is coming from buried underground biomass deposits contains carbon which was locked for about 200 million years ago from the atmosphere. When combustion of fossil fuels occur the carbon react with oxygen to form CO_2 and releases to the atmosphere. The global concentration of CO_2 by May 2014 was 401.88 ppm. This is higher than the upper safety limit for atmospheric CO_2 which is 350 ppm [2]. The CO_2 released from combustion of fossil fuels add up to the CO_2 concentration of atmosphere. The CO_2 in the atmosphere infuse heat radiating from the surface that would leak into space and radiate it back to the surface, thus raising the global surface temperature [3, 4].

The sustainable development and economic growth poses a big challenge to environment such as greenhouse gas emissions, resource consumption and massive waste generation [5]. This economic development, enhance the growth in population, urbanization and industrialization and so increase the energy demand [6]. The prosperity and high quality of human life caused by these developments has also increase per capita solid waste and the rate of municipal solid waste generated from country to countries [7].

Satisfying energy demand through the use of renewable energy sources is the main agenda nowadays because of the fossil fuel depletion and environmental issues. Municipal solid waste is the result of human activities which if an appropriate management system isn't used it may well lead to environmental pollution and endanger mankind's health. The massive municipal solid waste generations increases can be taken as an opportunity as source of energy for power generation or industrial use. Municipal solid wastes in developing countries are composed by a big portion of biomass materials such as food, paper and wood waste. The non-recyclable combustible materials from municipal solid waste can be used for energy recovery as they can reduce the utilization of fossil fuels thus assisting in minimizing global warming [8]. The studies show that the recovering energy from municipal solid waste can be a better way of managing environment from pollution caused by municipal solid waste disposal Technologies [9]. The emission of CO_2 coming from biogenic combustion of municipal solid waste is renewable and reduce the global warming because it completes the carbon cycle as it does in biomass [10, 11].

The main objective of this paper is to study the potential of municipal solid waste as source of renewable energy. The analysis of generation capacity and composition of Municipal solid waste will be main focus to establish the amount of energy that can be recovered from Municipal solid waste.

2. Method of waste disposal for energy recovery.

The energy from waste can be directly derived. Waste can be converted into biogas, syngas or heat. The technological methods in converting energy from waste can be physical, thermal or biological. These technologies are easily outlined in Figure 1

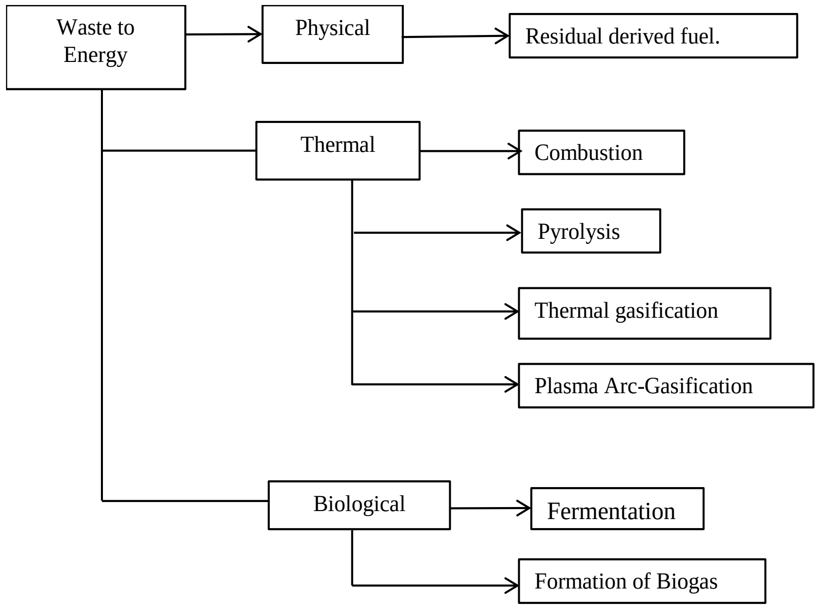

Figure 1: Technology tree, methods of waste disposal for energy recovery

2.1 The physical process

The physical process of waste is when waste processed mechanically to produce more suitable forms for use as fuel. Examples are pellets, wood briquettes and wood chips.

2.2 The thermal methods

The thermal method of waste treatment is by using heat of combustion to treat waste in the following processes:

2.2.1 Direct combustion Incineration or mass burn.

The heat from the combustion can be used to change water into steam and utilize the steam to run steam turbine for power generation.

2.2.2 Pyrolysis

Pyrolysis used to break down the material in the absence of oxygen to produce combustible gases, liquid and solid residues. The products from pyrolysis are such as methane, hydrocarbons, hydrogen and carbon monoxide.

2.2.3 Gasification and plasma arc gasification

Gasification takes place in the limited amount of oxygen. Plasma arc gasification is the using a plasma arc torch to produce high temperature arc that breaks down waste and forming syngas and slag. The gas produced can be used to heat up boiler for heat generation or they can be used in combustion through internal combustion engines [12, 13]

2.3 Biological method.

Biological method is the technology of using microbes to produce fuel from waste.

2.3.1 The biogas

This is the process of using anaerobic digestion to produce gas. The waste is placed in the air tight digester container. The biogas can then either be burned directly in boilers or used as natural gas [11].

2.3.2 Fermentation

By using yeast the biomass fraction of municipal solid waste can be fermented to generate ethanol which can be used to run internal combustion engines [14].

3. Material and methods

3.1 Materials:

The municipal solid wastes from Arusha city were used as raw materials .The equipment and tools used are according to regulated standards.

3.2 Methods:

The methods of waste flow analysis and waste composition analysis will be done by using standard operating procedure

3.2.1 Analysis of waste flow of Arusha

The quantity of waste generated monthly at Arusha was recorded daily by the office of City Health officer. The recorded data were analysed for studying purpose. The data for consecutive 3 years were collected and analysed.

3.2.2 Waste composition analysis of Arusha

The case study was done by sorting waste as they received from waste collecting centres of Kaloleni, Sakina and Central market within the Arusha city. The waste were then sorted to categories and weighted. The work continued for five consecutive days. The percentage composition of the complete waste data for the whole period was calculated. The result was taken as the sample for Arusha city.

3.2.3 Waste composition from various countries worldwide

The waste compositions from various countries were recorded randomly grouped in 3 categories. The lower income countries, middle and higher income countries. The results were tabulated in table 1

3.2.4 Proximate and ultimate analysis of Arusha waste.

The laboratory analyses for proximate and ultimate values of Arusha waste were taken from the work done and published earlier by Omari et al., [15].

3.2.5 The energy content analysis

The energy contents analysis of the waste was studied using bomb calorimetry type wagtech Gallen kamp Auto bomb. The bomb fired and after the temperature stabilization, the difference were noted and recorded. The calorific value of the municipal solid waste was calculated according to ASTM D240 standard method [16].

4. Results and Discussions:

4.1 Waste flow analysis.

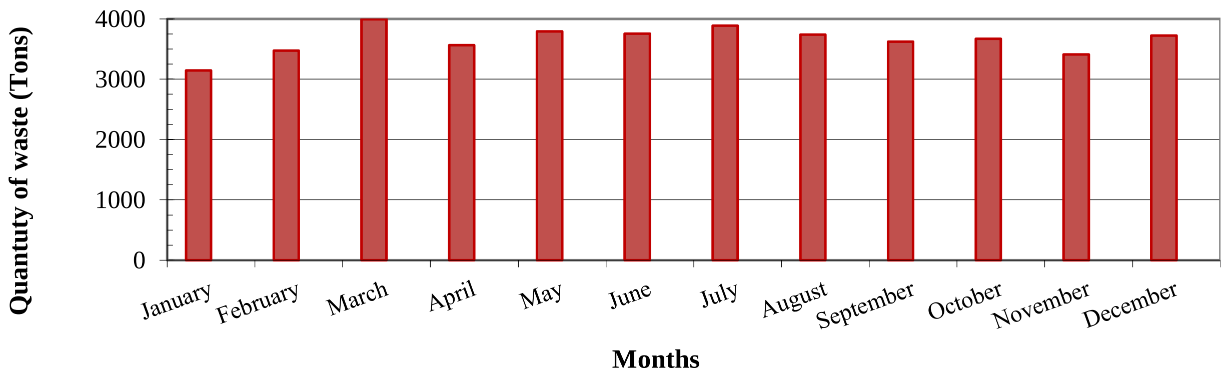

Figure 2: Waste generated and collected per month.

Figure 2 and Figure 3 show the average summary of the total waste generated within Arusha city for consecutive 3 years between 2010 and 2012. These wastes are estimated to be about 20% of the total waste generated in Arusha. The big portions of waste are generated in March and July. This may be caused by year seasons. March is in a rainy seasons while July is the harvesting time. The value seems to be constant, this may be caused by the capacity of city trucks which can handle and dispose waste to Murriet dumpsite at an average mass of about 100 and 120 tons daily.

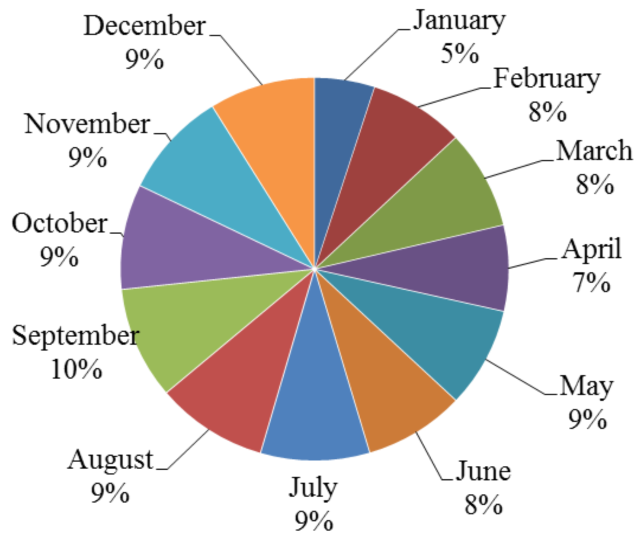

Figure 3: Arusha waste generation, monthly fraction contribution for one the year

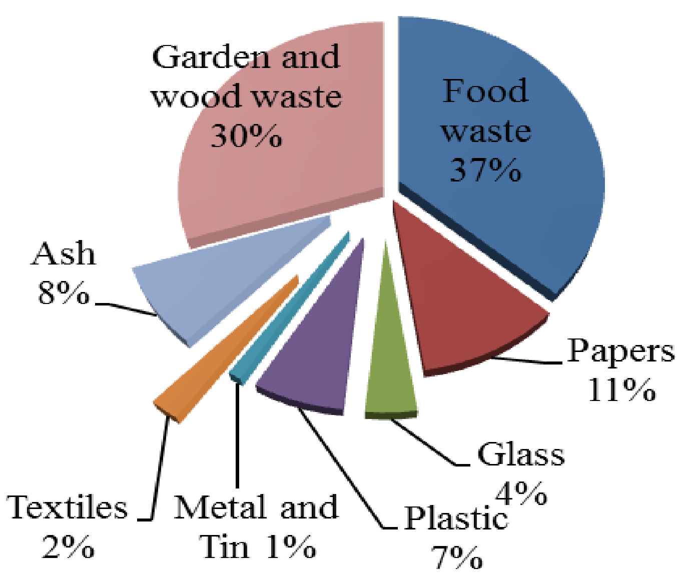

Figure 4: Waste composition of Arusha, Tanzania

Figure 4 shows the municipal solid waste composition of Arusha city. The ratio of the composition is taken based on the mass of the waste. The composition of garden and wood waste is 30%, food waste 37%, Papers 11%, plastic 7%, glass 4%, metal and tin 1%, textiles 2% and ash 8%. The composition for combustible waste totalize to 87% while non-combustible waste composition is 13%. The combustible waste fraction has 89.7% biodegradable and 10.3% non-biodegradable waste. This implies that the waste of Arusha can be recovering its energy by either thermo or non-thermo degradation technology. The recover technology which recovers materials and energy from waste, the energy would otherwise be dispose-off to the dumpsite. By recovering of these waste, the released of greenhouse gases to the atmosphere will be minimized.

4.2 Waste composition

Table 1: Waste composition in various countries:

	Country	**Composition**							**Source**
		Combustible waste				**Non-combustible waste**			
		Food waste	**Papers**	**Plastics**	**Textiles**	**Glass**	**Debris and construction**	**Metal/ tin**	
Middle income countries	India	42	30	10.4	7	5	1.5	4.1	[17]
	Nepal	60	7.5	12	12	1.3	6.7	0.5	[18]
	Thailand	42.7	12.1	10.9	7.3	6.6	6.9	3.5	[19]
	Gaza strip	54	10	12	0	3	18	3	[20]
	Malaysia	61.5	16.5	15.3	1.9	1.2	0.4	0.3	[21]
	Bangladesh	68.3	10.7	4.3	2.2	0.7	-	2	[22]
	Indonesia	70.2	10.9	8.7	6.2	1.7	-	1.8	[23]
	S. Korea	32.8	23.8	0	40.6	2.8	-	0	[23]
	Philippines	49	19	17	9	-	-	6	[23]
	Poland	35	18	11	20	12	-	4	[23]
	China	67.3	8.8	13.5	4.5	5.2	-	0.7	[23]
	Average	**53**	**15.2**	**10.5**	**10.1**	**4.0**	**6.7**	**2.4**	
High income countries	Turkey	43	7.8	14.2	23	6.2	0	5.8	[24]
	Japan	34	33	13	12	5	0	3	[24]
	USA	13.9	28.5	12.4	8.4	4.6	19.8	9	[5]
	UK	17.3	21.4	8.8	3.3	9	26.6	4	[5]
	Greece	42	21	11	17	5.4	0	3.6	[5]
	Germany	21	31	10	17	16	0	5	[5]
	Denmark	39	23	7	21	6	0	4	[5]
	Russia	34.9	15	11.3	4.8	13.7	15.1	4.7	[3]
	France	24	26	13	19	14	0	4	[5]
	Average	**29.9**	**23**	**11.2**	**13.9**	**8.9**	**6.8**	**4.8**	

Low income countries	Tanzania	37	11	7	2	4	8	1	-
	Kenya	52	17.3	11.8	5.1	6.7	2.4	2.8	[25]
	Uganda	37.8	6.7	7.8	1.3	0.7	33.6	0.8	[4, 25]
	Algeria	62	9	12	0	1	0	2	[1]
	Nigeria	47	6	10	7	7	18	5	[26]
	Ghana	73	6.6	3.3	2.2	1.5	11.2	2.1	[27]
	Average	**51.5**	**9.4**	**8.7**	**2.9**	**3.5**	**17.2**	**2.3**	

Table 1 shows the comparison of waste generated from other countries with Arusha municipal solid waste. The waste compositions are categorized to low income countries, middle income countries and higher income countries. The results showed that there is a slightly difference between Tanzania and other countries. From middle and lower income countries much waste was dominated by food waste with higher portion from Indonesia followed by Bangladesh, China and Algeria. South Korea followed by Poland, Thailand and Indonesia have a big portion in textile wastes while plastic waste is dominated by Malaysia followed by China and Thailand. In comparisons with high income countries, such as United States of America, Japan and United Kingdom, paper is dominating the waste composition followed by food waste, textiles and plastics. In low income countries the waste from Nigeria, Kenya, Algeria and Ghana contains more food waste than others while wood and yard waste has higher portions in Tanzania and Uganda. Glass wastes have a big portion in Kenya and Nigeria wastes. Comparing the waste composition by average of each group we found that food waste is generated more in middle income countries followed by low income; textile waste is very little in low income countries while glass waste and papers are much higher in higher income countries. Yard and wood waste are more in higher and lower income countries. In general combustible waste has an average of 89% at middle income countries, 78% in higher income countries and 73% in lower income countries. Despite of the average waste for energy recovery from lower income countries to be lower than higher and middle income countries, the percentage of waste available for energy recovery is more than higher and middle income countries, this is caused by poor recycling technology.

4.3 Proximate and ultimate analysis of Arusha waste

Table 2: Proximate, ultimate analysis and HHV of Arusha municipal solid waste

Proximate analysis					
Location	**Moisture of received MSW (wt. %)**	**Volatile (wt.%) dry basis**	**Ash (wt. %) dry basis**	**Fixed carbon (wt. %) dry basis**	**HHV (MJ/kg)**
Kaloleni	59.67	74.43	8.16	17.41	11.90
Sakina	63.99	84.00	10.00	6.00	11.37
Central market	55.70	78.30	13.48	8.22	12.76
Average value	**59.8**	**78.9**	**10.5**	**10.5**	**12**

Ultimate analysis							
Location	**C (wt. %)**	**H (wt. %)**	**O (wt. %.)**	**N (wt. %)**	**S (wt. %)**	**Cl (wt. %)**	**P (wt. %)**
Kaloleni	55.57	5.34	34.88	2.09	0.31	0.04	0.10
Sakina	55.70	5.29	34.27	2.13	0.22	0.07	0.13
Central Market	53.20	5.24	34.71	2.86	0.37	0.04	0.11
Average value	**54.8**	**5.29**	**34.6**	**2.36**	**0.3**	**0.05**	**0.1**

Source: [15]

4.4 Calorific value and energy recovery from municipal solid waste

The value of energy released as shown in table 2 shows that the value obtained is about 12MJ/Kg. The energy value was obtained using the bomb calorimeter this is the energy containing in municipal solid waste in dry basis. In this case the energy of 1kg municipal solid waste is equivalent to energy of 1.60 kg of net municipal solid waste. This is because 60% of moisture is taken out during bomb calorimetry. The moisture of 0.60 kg requires 1.411MJ/kg to dry municipal solid waste. This energy ultimately should be obtained from 12MJ/kg. The balance of 10.6 MJ/kg is the energy that one would recover per kg of dry municipal solid waste from the municipal solid waste energy conversion. For the case studied, the total waste generated is about 43772 tons of waste per year. This is equivalent to energy equivalent to 128.9 GWh.

5. Conclusion and recommendations

This paper presents a report on waste quantity and quality for energy recovery.

- Precise measurement of waste generation, its composition characteristics and availability is important in waste management plans. This study covers only Arusha city. The more research should be covered to the whole of Tanzania.
- The energy contents in the municipal solid waste is about 30% of the energy contain in coal and about 67% of energy contains in pure biomass. Utilization of waste from energy can be useful in energy recovery and to the environment.
- The waste generated and its composition analysis can help in decision making on which method of energy recovery can be utilized. For waste with a big portion of organic waste the composting or incineration can be utilized while the presence of large recyclable waste pinpoint the possibility of material recovery from municipal solid waste. For the waste with a big fraction of construction waste there is a possibility of utilizing waste material in road construction works.
- For every kg of dry municipal solid waste thermal energy recovery of 10.6 MJ/kg is expected to realize.

6. Acknowledgements

The authors wish to thank the Nelson Mandela African Institute of science and Technology, Arusha City Council and Commission for Science and Technology, Tanzania. Their generous support allows this research work to be conducted.

7. References

[1] B. T. Eddine and M. M. Salah, "Solid waste as renewable source of energy: current and future possibility in Algeria," *International Journal of Energy and Environmental Engineering,* vol. 3 (2012) pp. 1-12.

[2] M. McGee (2014). What the world need to watch. http://www.co$_2$now.org/. Accessed on 16th June, 2014.

[3] M. Rodionov and T. Nakata, "Design of an optimal waste utilization system: a case study in St. Petersburg, Russia," *Sustainability,* vol. 3 (2011) pp. 1486-1509.

[4] M. E. Kaseva and S. E. Mbuligwe, "Appraisal of solid waste collection following private sector involvement in Dar es Salaam city, Tanzania," *Habitat International,* vol. 29 (2005) pp. 353-366.

[5] E. Gentil, J. Clavreul, and T. H. Christensen, "Global warming factor of municipal solid waste management in Europe," *Waste Management & Research,* vol. 27 (2009) pp. 850-860.

[6] S. Mohapatra, "Technological Options for Treatment of Municipal Solid Waste of Delhi," *International Journal of Renewable Energy Research (IJRER),* vol. 3 (2013) pp. 682-687.

[7] N. Guermoud, F. Ouadjnia, F. Abdelmalek, F. Taleb, and A. addou, "Municipal solid waste in Mostaganem city (Western Algeria)," *Waste Management,* vol. 29 (2009) pp. 896-902.

[8] C. Ryu, "Potential of Municipal Solid Waste for Renewable Energy Production and Reduction of Greenhouse gas emissions in South Korea," *Air and Waste Management Association*, vol. 60 (2010) pp. 176-183.

[9] N. Yang, H. Zhang, M. Chen, L.-M. Shao, and P.-J. He, "Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery," *Waste Management*, (2012)

[10] H. Cheng and Y. Hu, "Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China," *Bioresource Technology*, vol. 101 (2010) pp. 3816-3824.

[11] M. Sharholy, K. Ahmad, G. Mahmood, and R. Trivedi, "Municipal solid waste management in Indian cities–A review," *Waste management*, vol. 28 (2008) pp. 459-467.

[12] Q. Zhang, L. Dor, D. Fenigshtein, W. Yang, and W. Blasiak, "Gasification of municipal solid waste in the Plasma Gasification Melting process," *Applied Energy*, vol. 90 (2012) pp. 106-112.

[13] A. Klein, "Gasification: an alternative process for energy recovery and disposal of municipal solid wastes," Columbia University, 2002.

[14] E. Viitez, J. Mosquera, and S. Ghosh, "Kinetics of accelerated solid-state fermentation of organic-rich municipal solid waste," *Water science and Technology*, vol. 41 (2000) pp. 231-238.

[15] A. Omari, M. Said, K. Njau, G. John, and P. Mtui, "Energy recovery routes from Municipal Solid Waste, A case study of Arusha-Tanzania.," *Journal of Energy Technology and Policy*, vol. 4 (2014) pp. 1-7.

[16] ASTM_International, "ASTM D240, Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter," ed, 2012.

[17] S. Pattnaik and M. V. Reddy, "Assessment of municipal solid waste management in Puducherry (Pondicherry), India," *Resources, Conservation and Recycling*, vol. 54 (2010) pp. 512-520.

[18] M. B. Dangi, C. R. Pretz, M. A. Urynowicz, K. G. Gerow, and J. Reddy, "Municipal solid waste generation in Kathmandu, Nepal," *Journal of environmental management*, vol. 92 (2011) pp. 240-249.

[19] S. Udomsri, M. P. Petrov, A. R. Martin, and T. H. Fransson, "Clean energy conversion from municipal solid waste and climate change mitigation in Thailand: Waste management and thermodynamic evaluation," *Energy for Sustainable Development*, vol. 15 12// (2011) pp. 355-364.

[20] A. AbdAlqader and J. Hamad, "Municipal solid waste composition determination supporting the integrated solid waste management in Gaza strip," *Int. J. Environ. Sci. Dev*, vol. 3 (2012) pp. 172-177.

[21] M. O. Saeed, M. N. Hassan, and M. A. Mujeebu, "Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpur, Malaysia," *Waste Management*, vol. 29 (2009) pp. 2209-2213.

[22] M. Alamgir and A. Ahsan, "Characterization of MSW and nutrient contents of organic component in Bangladesh," *EJEAFChe*, vol. 6 (2007) pp. 1945-1956.

[23] A. Idris, B. Inanc, and M. N. Hassan, "Overview of waste disposal and landfills/dumps in Asian countries," *Journal of material cycles and waste management*, vol. 6 (2004) pp. 104-110.

[24] C. Liamsanguan and S. H. Gheewala, "The holistic impact of integrated solid waste management on greenhouse gas emissions in Phuket," *Journal of Cleaner Production*, vol. 16 (2008) pp. 1865-1871.

[25] R. K. Henry, Z. Yongsheng, and D. Jun, "Municipal solid waste management challenges in developing countries – Kenyan case study," *Waste Management*, vol. 26 (2006) pp. 92-100.

[26] T. Ogwueleka, "Municipal solid waste characteristics and management in Nigeria," *Iranian Journal of Environmental Health Science & Engineering*, vol. 6 (2009) pp. 173-180.

[27] K. O. Boadi and M. Kuitunen, "Environmental and health impacts of household solid waste handling and disposal practices in third world cities: the case of the Accra Metropolitan Area, Ghana," *Journal of environmental health*, vol. 68 (2005) pp. 32-36.