On Suitable Solid Waste Characterization Method for Nigerian University Campuses

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Abstract
Characterization of waste is the first step in planning any sustainable waste management policy that will stand the test of time. Many published works gotten from various publication domains such as Science Direct, Engineering village, Springer books, etc. were reviewed to understand different approaches by different authors on the different solid waste characterization methods. The different waste characterization methods have been reviewed in this paper. The methods include two major categories viz; materials flow approach and site-specific/output approach. The materials flow approach utilizes the production data and product weight to estimate the waste quantity and composition on a national basis. The site-specific/output approach involves the sampling, sorting, and measurement of the respective components of a local waste stream. The site-specific approach is further divided into direct sampling at the source and vehicle load sampling of solid wastes. Based on some socio-economic and environmental factors like weak environmental laws, indiscriminate waste disposal, inadequate facilities, poor maintenance, poor environmental campaigns, and lack of well-structured waste collection pattern peculiar to Nigerian universities, direct Sampling or characterization at Source promises to be a suitable method for stratifying municipal solid wastes in the country's Campuses.

Keywords: Municipal Solid Waste, Characterization Methods, Sorting Methods, Direct Sampling, Stratified Sampling

1. Introduction
Objects or materials, in any form, which are no longer needed or used by the organism or system that has been utilizing or producing it are termed wastes (Ugwu et al., 2020). Wastes also are materials that are intended to be disposed of or already discarded or required to be disposed of by the provisions of national laws stipulated by the producers (Ugwu et al., 2020). Waste can be classified on the basis of origin, form and property. Based on origin, hospitals produce clinical wastes. Households generate domestic refuse whereas agricultural waste originate from animal farms and farmlands. There are other types of wastes from industries and construction sites, as well as nuclear wastes from petrochemical establishments. Solid, liquid or gaseous wastes make up the three major waste forms. Based on its property, waste can be inert, toxic, combustible, biodegradable or carcinogenic (Kemp, 1998). Solid wastes therefore, are wastes that are no longer wanted or discarded or disposed-off materials including agricultural, commercial, institutional, industrial or household wastes found in garbage dumps. Most of these discarded wastes/materials are from municipal sources like polythene packaging bags, used papers from academic and administrative activities, water/beverage bottles and cans, boxes, woods, food and its leftovers, grass from lawn cuttings, clothing/textiles, broken furniture, electronic appliances, newspapers, automobile tires, batteries, etc. are called municipal solid wastes (MSW) (EPA, 2015).

Amounts and composition of MSW changes due to the variations in consumption behaviours and income level of the generators and generally, the rapid technological advancement. Consequently, quantities and compositions of MSW differ from one place to another and even within the same location. The first step in every efficient MSW management program requires a proper knowledge of the constituent elements hence, characterizing the solid wastes to be disposed of. For a successful implementation of any intended sustainable waste management policy or strategy, ranging from the selection of optimal collection and transportation pattern to proper disposal stage or treatment stage or recovery of some potential energy or recyclable components, proper waste characterization studies is very essential. The aim of this review is to evaluate and compare the different waste characterization methodologies among different countries, cities, institutions and communities with a view to providing better characterization approach for Nigerian universities.

1.1 Solid Waste Characterization

Characterization is the sorting of the overall waste at a particular point into different categories/components which are measured individually and added together to give the total quantity (Ugwu et al., 2020). Characterization can be through visualization or through hand sorting but the latter gives a more accurate result. Waste characterization also means finding out the actual components of the different/individual components such as paper, glass/bottles, food waste, textiles/clothing materials, polythene bags, e-waste, rubber, wood, sanitary, medical etc. discarded in a waste stream. The evaluation of the composition of solid wastes can be difficult because of their heterogeneous nature which makes strict statistical procedures difficult to execute properly. Consequently, field procedures, based on direct observation and random sampling technique is employed in evaluating the composition. Waste composition results provide reliable details on municipal solid waste (MSW) generation trend and the specific weights of individual waste components. It also provides the actual information required for proper decision-making and further improving the management strategies of the wastes. There exists other factors that contribute to every successful waste management system but for their proper comprehension, there should be a qualitative researche approach (Taboada-González et al., 2011).

1.2 Solid Waste Characterization Methods

Reliable patterns of waste quantification, generation and composition data are useful in developing waste management policies. The quality of any waste composition information can be affected by the method used and its application during the sampling process. According to a report by EPA (2017), there are two main methods employed in estimating the physical features of a solid waste stream at any level viz; materials flow approach and site-specific approach. Materials flow approach estimates the waste quantity and composition on a nationwide basis, which implies that it is more applicable to very large studies and large geographical areas such as the entire country instead of small-scale studies (Hoang, 2017). It utilizes the production data like the materials weight in the process of estimating the trend. This approach is preferable while analysing a waste stream on a larger scale. However, one of the problems associated with the approach is that product residues accompanying other items are usually left in containers and can be missed-out during counting. Some of these product residues include remnants of food wastes in containers, left-over detergent in bottles, dried paint in buckets, pesticide left in a can, etc. (EPA, 2015). The site-specific approach involves the sampling, sorting, and measurement of the individual waste components in a waste stream. It provides both waste composition and generation information prior to the actual disposal exercise. This approach is more reliable in sampling and quantifying a local waste stream, because it incorporates variations due to climatic, seasonal, population density, regional differences, demographic and income status, etc. Furthermore, some waste components like food wastes, lawn cuttings are best estimated through direct sampling and weighing (EPA, 2017). Direct sampling at the source of generation and Vehicle load characterization are the two major sampling methods employed under this approach (Hoang, 2017).

Direct sampling at the source as the name implies involves the characterization of solid wastes directly at the generation points such as households, commercial areas, farms, shops, classrooms, etc. (Curi, 1997). This method provides the composition information in tandem with the related generator information. For instance, it provides the opportunity for the collection of the geographical information and personal data such as the demographic details, socio-economic status (single or multifamily incomes), educational level, etc., from the participating households. It also allows for the comparison of the waste characteristics from different locations, socio-economic status, consumption behaviours, etc. Furthermore, this approach has the unique tendency of reducing the risks and difficulties in sorting some highly degradable waste categories like food and vegetables, which contaminates other waste so easily. This can also lead to emission of poisonous gases into the atmosphere. Moreover, it makes stratified

sampling (division of the study location into non-overlapping sub-locations) for uniform coverage of the entire study area. A disadvantage of this approach is that whenever any error is introduced during the characterization or sampling exercise with a limited number of samples and the result is magnified to represent a larger population or a whole national estimate for a larger period, it will be misleading. In addition, if this extensive sampling approach is to be employed for making the national estimates, which so far has not been practical, it will be highly expensive. Vehicle load sampling involves the characterization of solid wastes received at treatment facilities like incinerators, disposal sites like landfill, transfer stations, etc. This approach minimizes the amount of resources like time, energy and cost expended during waste characterization and sampling processes hence, it is as cost effective as it is very simple. The technique allows for better estimation of large quantity wastes, or even oversize materials like mattresses (CCME, 1999). According to Hoang (2017), vehicle load sampling approach comes with a number of drawbacks, which include lack of information about the waste sources; inaccuracies, errors or variations of the study results due to water loss and cross-contamination between different waste components. Change in the individual waste weight, fraction and characteristics due to the mechanical stress and blending during compaction mechanism of the compactor vehicle are part of the inherent inconveniences. Notwithstanding these observed disadvantages of this characterization methodology, the composition and generation data is still significant.

The major difference between the two methods is that sorting at the source method provide the waste composition details and accurate location details, while the vehicle sampling/characterization method provides the general data associated to waste composition without accurate information about the geographical attributes, location details or generation source types. Visual characterization of samples involves the observation and sorting of the wastes into different categories by mere sighting. Visual sorting is most appropriate for waste categories that are bulky or contain large quantities or heavy items like concrete or demolition materials. It can also be used to sort materials that are too small like ash or materials that are harmful to the health like chemicals. Furthermore, this approach is also important in sorting materials that are of one type. One advantage of this approach is that it saves the individuals from harmful materials and poisonous emissions.

1.3 Socio-Economic and Environmental Factors Affecting Waste Management in Nigeria

Several factors, both socio-economic and environmental, affect the generation, quantification, characterization and general solid waste management in Nigeria. Such factors include lack of continuity of government policies, weak environmental laws, poor environmental campaigns and sensitizations, inadequate and poorly maintained facilities, poor funding and insufficient budget allocations by Nigeria government, high population growth, disposal habits of the people and rapid urbanization and industrialization.

2. Materials and Methods

Waste management is a subject that has drawn a lot of attention from all parts of the World. There can be no effective waste management without first characterizing the waste stream to ascertain the physical components, generation rate and total waste generation. There are many waste characterization approaches employed by different studies. As a result, many research works were reviewed to understand different approaches by different authors. These published works were gotten from various publication domains such as Science Direct, Engineering village, Springer books, etc.

2.1 Review of Related Literature

Due to lack of an accepted international standard for characterization of solid waste, there exists a number of sampling and characterization methods (Dahlen & Lagerkvist, 2007), prompting a review of different approaches used in different studies with the interest of recommending a better approach for Nigerian cities and universities based on the social, economic and environmental factors peculiar to Nigeria. Staff, students and scholars of universities and research organizations have carried out a good number of studies on this subject. Table 1 thematically describe methods employed in some studies on waste composition analysis.

Table 1. Thematic Categorization of Waste Characterization Methods

Method description	**Characterization Method**	**Number of components characterized**	**Study Area**	**Author(s)**
Characterization carried out by hand picking waste samples into their individual fractions on a plain table made of mild steel	Vehicle load sampling method based on ASTM D5231 standard	19 waste components	Ilorin, Capital of Kwara State, Nigeria	Ibikunle et al., 2020
Characterized the household solid waste into respective waste fractions by hand sorting	Direct characterization method	5 main categories	Rishikesh, Uttarakhand	Rawat and Deverey, 2018
Characterized the waste samples into individual waste components by hand sorting	Vehicle load sampling, ASTM D5231 and Resource Conservation Reservation Authority, RCRA draft	12 major categories	University of Lagos, Akoka campus	Adeniran et al., 2017
Stratified sampling: Uses economic status and Geographical Information Systems (GIS). Also use information from census data.	Direct characterization method based on the recommendations of the SWA-Tool standards	20 waste categories	Tandil (Argentina)	Villalba et al., 2020
Quantified and characterized the MSW into individual components by hand sorting	Direct characterization method based on the recommendation of the ASTM D5231 standard	13 waste components	University of Nigeria, Nsukka	Ugwu et al., 2020
Stratification according to major cities- high, medium and low class areas; characterization by hand sorting at the households selected.	Direct characterization method based on the guideline by Nordtest method for sampling waste from household	9 waste categories	The 10 regions of Ghana	Mesiah et al., 2015s
Characterized by physical components by hand sorting	A combination of direct and vehicle loading approaches	8 major components	North central part of Nigeria	Oumarou, 2012
Characterization by stratifying the study area into three major income groups. It adopted hand sorting approach.	Direct characterization method (On-site waste separation and measurements)	10 waste components	Karu Nasarawa State, Nigeria	Anyanwu and Adefila, 20
Characterisation based on the recommendations of Bernache-Perez by hand sorting	Direct characterization (source generator-based study) method	8 waste materials	Covenant university, Ota campus, Nigeria	Okeniyi and Anwan, 2012
Characterization by sorting the individual components of the MSW at the dumpsite.	Direct characterization (Site-specific study Methodology)	12 waste categories	Thika Municipality of Kiambu County, Kenya	Mugo et al., 2015

Characterization of the physical composition involved on-site observations and hand sorting.	Direct characterization (on-site observations and hand sorting)	19 Physical Components	Ota, Ogun State, Nigeria	Olukanni and Mnenga, 2015

Table 1. Thematic Categorization of Waste Characterization Methods Continues

Method description	**Characterization Method**	**Number of components characterized**	**Study Area**	**Author (s)**
Characterization of unprocessed MSW fractions: by the ASTM 5231-92 Standard Test Method	Direct characterization (at the intermediate collection centre)	23 material categories	University of Malaya	Chee & Sumiani, 2014
Characterization due to Bernache-Perez (2001) and Oyelola, & Babatunde (2008): involving Manual sorting.	Direct characterization method (before being transported to landfills)	8 waste categories	Covenant University, Ota	Okeniyi et al., 2012
Sampling average composition of MSW.	Vehicle load characterization method	7 waste categories	Gaza Strip	AbdAlqader and Hamad, 2012
Characterization of waste samples from point of generation.	Direct characterization method (visualization and hand sorting)	8 categories	Bahir Dar Institute of Technology, Ethiopia	Tadele et al., 2016
Stratification according to major cities-The first waste trucks from the residential routes for every socioeconomic status were selected for quartering each day.	Vehicle load characterization method as stipulated in the Mexican Standard NMX-AA-0151985	8 major categories and 5 minor categories	Ensenada, Mexico	Aguilar-Virgen et al., 2010
Characterization based on seasonal variations. Wastes were collected from different locations to represent the diverse socio-cultural settings and different income levels.	Vehicle load characterization method	17 waste components	Kartal district of the province of Istanbul, Turkey	Ozcan et al., 2016

2.2 Discussion

Out of the 17 reviewed articles, 6 were studies done in universities, the rest were done in communities and cities. Interestingly, the 6 studies in universities employed the direct sampling/characterization at the source, except the study at university of Lagos. Among other reasons behind their choice for this approach, is to make sure that there is uniform coverage of different areas of the university. Most of the studies also applied stratified sampling by dividing the study area into non-overlapping sub-areas with similar characteristics. The stratification approach helps to see the influence of the different sub-areas on the general waste generation trend and the correlations among subareas. The on-site source sampling approach made it possible for some of the wastes to be characterized along socio-economic status. These studies might have also employ this approach probably because most universities in the country do not have a regular pattern of waste collection. Therefore, to avoid introduction of error in waste characterization, they employ sorting at source. For the study at the University of Lagos, it employed vehicle load sampling/characterization method because the university has a well-structured pattern of waste collection. For instance, the University landmass is divided into four zones, for ease of waste collection. It also employed the services of two different waste managers to this effect (Adeniran et al, 2017). With this well-structured waste collection pattern, all the advantages derived from direct source approach are addressed. Despite the higher cost associated with this approach, it has some outstanding advantages over other approaches. Some of the obvious merits include but not limited to provision of the composition as well as the generator information. The geographical information and personal data such as the demographic details, socio-economic status, and educational level are

typical examples of such data. It also allows stratified sampling for uniform coverage of the entire study area as well as reduces the risks and difficulties in sorting some highly degradable waste categories like food and vegetables, which decreases the amount of emission of poisonous gases into the atmosphere. Furthermore, the supposed higher cost incurred during characterization/sampling process cannot be compared to the long-time benefits derivable from a proper and reliable data characteristic of the approach. In sum, for a non-misleading data/information for an effective and sustainable solid waste management, direct sampling/characterization approach gives a more holistic and reliable information.

3. Conclusion

The different methods of municipal solid waste sampling and characterization were reviewed in this work to recommend an optimal method for waste characterization in Nigerian universities considering the socio-economic and environmental factors peculiar to Nigeria as a state. Due to weak environmental laws that leads indiscriminate waste disposal, inadequate facilities and poor maintenance, poor environmental campaigns, lack of well-structured waste collection pattern, etc., the most appropriate waste characterization method for Nigerian universities is direct method. It reduces the risks and difficulties in sorting some highly degradable waste categories like food and vegetables by providing different waste bags/containers for such wastes. However, it consumes more time, energy and fund. On the other hand, vehicle load sampling/characterization method can be very effectively applied in the university system if there exists a well-structured waste collection system. If collection trucks are made available to major subareas such as academic, residential, administrative, commercial areas, etc. on daily basis, it is more resource conservative. Though this method encourages poor waste disposal habit because most people find it difficult to drop their wastes at waste collection stations for waste trucks. Thereby leading to incomplete collection of wastes for disposal/sampling/characterization. Based on these socio-economic and environmental factors peculiar to Nigerian universities, the proposed optimum method for sampling/characterizing MSW is Direct Sampling/Characterization at Source.

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Bibliographies

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