Research article

Solid waste quantification and characterization in university of Nigeria, Nsukka campus, and recommendations for sustainable management

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A B S T R A C T

Quantification and characterization of municipal solid waste are the bases for a proper solid waste management planning but the needed collection, transportation, characterization and disposal are grossly under-investigated and scarcely implemented in Nigerian Universities. This study, therefore, quantified and characterized the waste generated in the university of Nigeria, Nsukka campus using ASTM D5231-92 method, and recommended possible integrated solid waste management strategies for a sustainable management of the waste. The average daily solid waste generation in the university was estimated to be 2,218.66kg during the 6-month study period from 24th February to 18th August in 2017/2018 academic session with organic and polythene representing the largest portion at 32.36% and 34.29%, respectively. Glass/bottle, textiles/leather, rubber, wood, e-waste, sanitary, medical, polystyrene food pack and metal wastes represented 0.97%, 2.69%, 0.28%, 0.82%, 0.98%, 2.16%, 0.16%, 1.04% and 1.67%, respectively. The campus has a per capita solid waste generation rate of about 0.06kg/day. About 96.58% of the total waste is recyclable, and has about 51.85% biomass potential. Analysis of variance showed that differently dominated areas of the campus have different quantities and compositions of wastes mainly due to significant variation of organic and polythene components across the differently dominated areas. The barriers against effective solid waste management and recommendations for integrated solid waste management strategies were made to include solid waste generation reduction, re-usage, recycling, composting, and proper training and provision of incentive and other fiscal policies.

1. Introduction

Wastes are materials or objects that are discarded or disposed-off or intended for disposal (UNEP/GRID-Arendal, 2011). Solid wastes could be garbage or discarded substances and objects gotten from industrial, commercial, mining, agricultural, general day to day activities, and a comprehensive list of such items can be found (Bamgbose et al., 2000). Most of the commonly known discarded wastes which make up the day to day items being disposed by the general public are known as municipal solid wastes (MSWs), and it includes all substances or objects thrown away as products of packaging, lawn cuttings, furniture, clothing materials, bottles/glasses, food scraps, electric appliances, newspapers, paint, and batteries, etc (Afon, 2006). The selection and proper application of suitable methods, management policies and technologies to achieve specific waste management objectives is termed as integrated solid waste management (ISWM). For this system to be successful, waste

characterization studies have to be carried out (Tchobanoglous et al., 2002). Waste characterization is very important for appropriate MSW collection, selection of transportation equipment, energy transformation and its recovery, recovery of reusable matter, as well as the proper design and implementation of optimal disposal routes and methods. The changes in the trends of MSW generation and its composition, have been as a result of the differences in the consumption behaviours of people coupled with rapid technological advances. Quantity and composition of MSW differs from one country to another country, from one region to another region, from one neighborhood to another neighborhood, even from one community to another community. The differences could either be as a result of income level, socio-economic distribution, consumption habit, or disposal habits of people (Banar and Ozkan, 2008).

Marginal attention has been paid to the composition and generation trends of wastes in Nigerian universities. Universities are expected to be the key drivers in the efforts directed towards clean and friendly

environments through the implementation of responsible waste management policies (Geng et al., 2013). Nigeria is one of the developing countries facing the serious issue of managing their increasing solid waste generation. Due to weak environmental laws, inadequate funding, uncontrolled rapid urbanization and industrialization, the main disposal route is land filling. There is not much difference from the deplorable situation in Nigeria and what is obtainable at the University of Nigeria, Nsukka (UNN) and the other Nigerian public universities and the cities of Nigeria with respect to waste management (Agunwamba, 1998). These setbacks coupled with the inadequate comprehension of the different deciding factors to the hierarchy of effective and efficient waste management impede a shift towards modern treatment of wastes on university campuses and the Nigerian cities. It becomes very important, therefore, to holistically examine the nature and composition of the MSW generated, the efficiency and effectiveness of the waste management agency and policy on campus in order to additionally create a benchmark or serve as a reference point for other Nigerian Universities to emulate. This is the first study of the quantity, trends of solid waste generation and composition in UNN. Therefore, this study provides the needed data to propose better treatment and management alternatives for the MSW in UNN. As a result, the main target of this study is to reduce the gap created by such loop hole and add to the few available published studies of Nigerian universities (Adeniran et al., 2017; Okeniyi and Anwan, 2012) for regional, and, subsequently, national coverage of Nigerian Universities. And the study addressed this target by: estimating the average daily solid waste generation in the campus; characterizing the generated waste into different categories; estimating the recyclable potential of the waste generated in the campus; estimating the biomass potential of the waste generated to ascertain the quantity of waste derivable from the generated waste; estimating the per capita waste generation and comparing it with different universities both within and outside the country; performing a statistical analysis to ascertain if different dominated areas of the university affected the trend of waste generation; finally, discussing the possible strategies for improved waste management of the solid wastes generated for a safe and healthy environment.

2. Materials and methods

2.1. The study area

The University of Nigeria is a federal university with the major campus located on a hilly savannah in the heart of Nsukka, Enugu State, Nigeria. It is about eighty kilometers north of the state capital. The climate here is tropical with much more rainfall and an average temperature of 24.9 °C. It is spread across 871 ha of land. It has an additional 209 ha of cultivable land for agricultural farming on experimental basis and 207 ha exclusively for staff housing development. According to the physical planning unit of the university, the Nsukka campus has 10 faculties, 521 senior and 63 junior staff housing units (a total of 584), 17 students' hostels (with two under reconstruction) and several administrative, academic and commercial buildings. As gathered from the Information and Communication Technology (ICT) and Personnel units of the university, it also has about 23,000 students, with about 6,000 in hostels within campus, about 6,000 members of staff for the 2017/2018 academic session and about 1,000–2,000 estimated visitors' population daily. Community services, teaching and research are the major activities in the campus and these amounted to an estimated 35,000 ± 2,000 daily populations because of numerous visitors and commercial workers. The campus comprises the Arts, Agric, Biological Sciences, Engineering, Education, Pharmaceutical Sciences, Physical Sciences, Social Sciences, Vocational Technical Education and Veterinary Medicine Faculties.

2.2. The university waste collections system

The university waste is handled by a private company, Total Facilities Ltd. The company has no recorded document regarding the quantity, rate and the trend of generation of solid waste. The solid wastes are disposed openly within the campus which is subsequently burnt very close to the university poultry farm. Waste containers are distributed at some strategic positions on campus by Total Facilities Ltd as shown in Table 1. For the ease of waste collection and transportation for disposal, the campus land area was divided into two major parts, part A and part B, by the waste management company. Part A, as shown in Table 1, is also known as the heart of the university which consists of the Vice Chancellor's administrative blocks, the university library, the senior staff quarters, the university primary school, some female hostels like Bello, Eyo-Ita Hall, Okpara and Balewa Halls, the Social Sciences faculty, the Arts faculty, the Education faculty, etc. And, as the name implies, it is assumed to be the most visited areas of the university by external bodies, as such, the wastes generated in this area are collected for disposal on daily basis. Part B, as contained in Table 1, is known as the other parts of the university. As the name implies too, it is assumed to be the less visited areas of the campus by external bodies. Therefore, the wastes generated in this area are collected for disposal on weekly basis.

2.3. Sampling procedure

The ASTM D5231-92 method (Standard Test Method) was used to carry out the sampling. The exact number of sorting samples required was a function of the solid waste components to be sorted. The standard recommends that each unprocessed solid waste samples for sorting weighs 200–300 lb (91–136 kg) but as a result of sorting at the dump sites before collection for disposal as applied in this study, the average sample size was between 30-130kg. A calculational method as contained in the standard was used to calculate the precise number of samples. Using the equation by ASTM D5231-92, the number of samples to be sorted, n required to give a high level of measurement precision is given as

$$n = \left(\frac{TS}{EX}\right)^2 \tag{1}$$

where T is the student's t-test corresponding to the desired confidence level, S is estimated standard deviation, E is the desired precision level, and X is the estimated mean. The number of samples to be collected was statistically determined in two phases. In the first phase, using the student T value of 1.645 at 90% confidence level, E of 10%, S value at 0.03 and X at 0.10 as corresponding to n = ∞ in the manual (using organic/food waste as the governing waste composition from the ASTM D5231-92 manual), then the n value of 24 was gotten. In the second phase, with other parameters being constant, the student T value corresponding to n = 24 at 90% confidence level is 1.714 which gave a new n = 26. Since 26 is within 10 % of 24, a total of 26 samples were sorted from each of the two parts of the university, whether Part A or Part B. The waste container average sample size is between 30-130kg. Manual sorting was employed to get the values of each component and the average weights summed to give the total quantity of solid waste at each dumpster. Afterwards, the weights of the individual components were added to give the quantity of waste at a particular dumpster/collection site. Samples were collected at least once weekly for 6 months (from 24th February to 18th August, 2018) taking note of the seasonal variations and holidays.

2.4. Waste quantification and characterization

This study employed quantification at the point of waste collection because there are no well-structured collection/disposal mechanisms and records in UNN at present. Investigations/sorting were carried out at least once in a week throughout the study at the respective locations. The weight of each sorted composition was measured with a weighing balance and recorded. At the end of every sorting, the individual weights were summed together to give the average daily total weight of MSW at that location. For the cases where the waste at a location stayed more than a day before sorting and quantification, the measured weight was

Table 1. The two major parts of the campus land area.

The Heart of the University (PART A)		Other Parts of the University (PART B)	
Location	No of Containers	Location	No of Containers
Bello/Eyo-Ita Hall	4	Access ICT/Mechanical/Civil Lab.	4
Okpara/Balewa Hall/St. Peters Chaplaincy	6	Electrical Engineering Department	3
Social Sciences Faculty	3	Faculty of Engineering Building	4
Diamond Bank	2	Back of Abuja Building	4
Vice Chancellor's Lodge	2	Engineering Faculty Mechanic Workshop	4
Institute of Education	3	Pharmacy/Agric. Faculty Lecture Halls	4
University Primary School	3	Faculty of Agric./Agric. Extension	4
Arts Faculty/Works Department	3	Awolowo/Ajanwachukwu Hall	4
General Studies Building	2	Vertinary Teaching Hospital/Agric Economics	4
University Store	2	Merry Sclessor Hall	4
HPE Department/Jimbazz Building	3	Old Student Union Building	6
Chitis/Physics/Astronomy Building	4	Back of Presidential Hall	4
Microbiology/Biological Science Building	4	Isa Kaita Hall/fidelity/UBA banks	5
First Bank/CEC Building	4	Akintola/Akpabio Hall	6
		VTE/ESA Building	2
		Odili PG Hall	4
		Alvan-Ikoku/Eni-Njoku Halls	4
		Nkwuruma Hall	4
		CEC/FAC. of Arts Lecture Hall/Senior Staff Club	2
		Biological Sciences Lecture Theatre	3

divided by the number of days it stayed before sorting in that particular week. The percentage composition of each of the components was then calculated.

Differentiating the solid wastes among recyclable and non-recyclable categories was done after obtaining the weight percentage of each individual component. The recyclability potential of each solid component was determined by categorizing them as follows; (1) for wastes that there exists a market for the recycling like metals, polythene bags, paper and plastic, (2) for recyclable wastes that there does not exist a market like e-waste, glass, leather, organic waste and textile and (3) for non-recyclable wastes like sanitary waste and inert materials.

2.5. Statistical analysis

The hypotheses to be tested are:

H_0: Location does not affect quantity and composition of MSW on campus,
H_1: Location does affect quantity and composition of MSW on campus.

The hypotheses are to be tested using one-way analysis of variance (ANOVA) in SPSS 22 to ascertain whether the differently dominated areas/locations had influence on the trend in MSW generation in UNN. This is judged by testing if there are differences between their mean values at 95% confidence interval for which the threshold probability for significance is $p \leq 0.05$. Also, it is intended to use Post Hoc tests to determine if the mean difference between individual solid waste components is statistically significant.

3. Results and discussion

3.1. 1Waste generation rate

University of Nigeria, Nsukka generated a daily average of 2,218.66 kg by weight of solid waste daily during the 6-months study period in 2017/18 academic session. Waste generation in UNN showed variation by months, seasons and different locations (whether academic/administrative, staff residential, commercial or hostel areas). The summary of monthly daily average is contained in Table 2. Solid Waste generation was highest during academic periods (April to June and September to January/February) and lowest during breaks and vacation periods though, the generation is spiked by the presence of sandwich/part-time students between August and September within the vacation period. A total of 2,604.77kg/day was generated during full academic periods (April to June), 2,332.16 kg/day during examination period (July), and the lowest (1770.70 kg/day) during Easter break, even though some first and second year students were still writing their examinations during the break time. Based on differently dominated areas, academic/administrative, staff residential, commercial and hostel areas generated 763.29kg, 494.49kg, 566.03kg and 879.94kg respectively. Consequently, the quantity of waste generation was more influenced by the quantity of waste collected in the academic/administrative and hostel dominated areas. But when the collection sites were considered exclusively for where they are positioned, the values for staff residential and commercial areas were affected greatly at 261.76kg and 313.68kg respectively. This is because some collection centers are mutually used for more than one or two dominated areas. Generally, during the break times, especially during Easter periods, at the end of the year during Christmas break, and during holidays, the number of students as well as the activities performed on campus is reduced drastically. However, significant numbers of students are present at the campus and the activities become steady for the rest of the year. The university has neither solid waste prevention, reduction, recovery, recycling nor composting measures nor even proper disposal mechanisms. Rather, the university

Table 2. Monthly Summary of Waste Generation at different dumpsters in the University (in kg/day).

Month	Average Daily Generation (kg/day)
February	2,301.01
March	2,111.60
April	1,760.41
May	2,450.45
June	2,636.33
July	2,331.97
August	1,939.20
Total Average	2,218.70

has just been collecting the solid wastes from their sources and transporting them to a specific location behind the university poultry farm and burnt in open air.

In comparison with other Nigerian universities, UNN generates per capita waste at a low rate of approximately 0.06kg/day which is same generation rate reported in (Okeniyi and Anwan, 2012) for Covenant University while the university of Lagos, Akoka campus, generates per capita waste at a much higher rate of 0.34 kg/day (Adeniran et al., 2017). When compared to other universities beyond Nigeria like Bahir Dar Institute of Technology and University of Tabriz which respectively generate 0.17 kg/day (Tadele et al., 2015) and 0.13kg/day (Sepideh et al., 2012), it can still be seen that per capita waste generation rate of UNN alongside Covenant University is relatively low. The differences could either be as a result of income level, socio-economic distribution, consumption habit, or disposal habits of people (Banar and Ozkan, 2008).

3.2. Waste characterization

Figure 1 provides the percentage of waste composition by weight of the MSW generated in the university of Nigeria, Nsukka. Organic waste forms the biggest component of the MSW generated in the campus which is about 34.29%. This is closely followed by polythene at 32.36%, with paper and plastics at 14.05% and 8.53%, respectively. Generally, glass/bottle is 0.97%, textiles/leather is 2.69%, rubber is 0.28%, wood is 0.82%, E-waste is 0.98%, sanitary is 2.16%, medical is 0.16%, polystyrene food pack is 1.04% and metal waste is at 1.67%. Figure 2 shows the waste composition for the differently dominated areas on the studied campus.

3.2.1. Organic waste

Solid Wastes from the lawn cuttings, the cleaning of green areas and fallen leaves from trees which are generally known as garden wastes, constitute 78% of the total organic waste while food waste constitutes the rest 22%. This is a complete opposite of what is obtained in some studies carried out in other universities. For instance, according to Adeniran et al. (2017), University of Lagos, Akoka campus, had more of food wastes at 66.67% than other organic wastes. This is as a result of the presence or rather the steady visitation of farmers to the dumpsters as the

food wastes serve as feed to animals. Sometimes, the university cleaners sort the more useful wastes at the point of generation. It could also be as a result of UNN having more green areas and trees to be trimmed possibly due to larger landmass or higher horticultural culture. As seen from Table 3, organic/food waste generation rate was discovered to be largest (48%) at the staff residence dominated areas due to more intense cooking culture of staff families in the university quarters. The male hostel dominated areas have very high figure as well due to the cafeterias directly located behind the hostels, and the lowest (13.49%) is generated in the academic/administrative areas. Organic waste has the potential to release greenhouse gas into the atmosphere and attract vectors to households, pose many environmental and health hazards, if not properly disposed-off or harnessed to generate power for the university, feed for animals or compost for farming.

3.2.2. Polythene bags

Polythene bags are majorly low density bags used to package sachet water and other like items. These low density bags accounted for 32.36% out of the entire wastes generated in UNN. This is also the largest recyclable category of MSW generated in the UNN campus. Commercial and academic areas generated the largest percentage of polythene bags at 37.23% and 37.22% respectively, as seen in Table 3, due to lack of pipe borne water at these places. Polythene bags are low (28.01%) at hostels due to the availability of pipe borne water. Greater parts of the polythene bags are always contaminated with organic wastes partly because the bags are used to dispose other wastes making the sorting exercise a bit difficult because additional cleaning process was required especially during the rainy season if they were to be sent out for reuse or recycling.

3.2.3. Plastics

Plastics are polyethylene terephthalate (PET) bottles which represented relatively high percentage in the MSW stream. They are mostly used for packing water, liquors and soft drinks. It is also high density plastics mainly generated from broken and damaged household materials such as plastic chairs buckets, plates and other cooking utensils. University of Nigeria, Nsukka generated 8.53% plastics of the total waste stream. It has a reasonable similarity with the MSW stream reported in some studies carried out in other universities elsewhere, for instance, University of Lagos, Akoka campus generated 9% plastics as waste
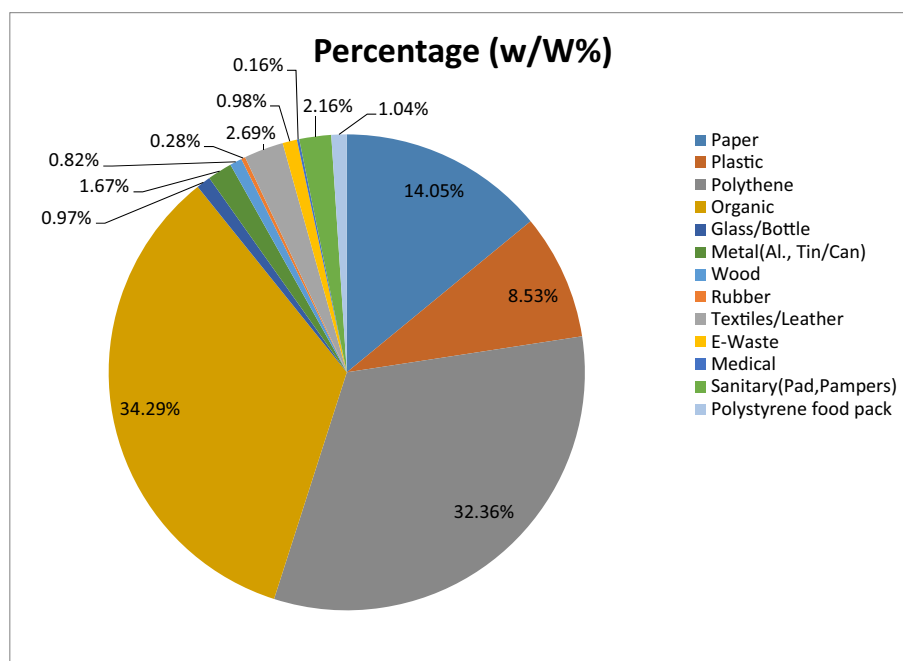

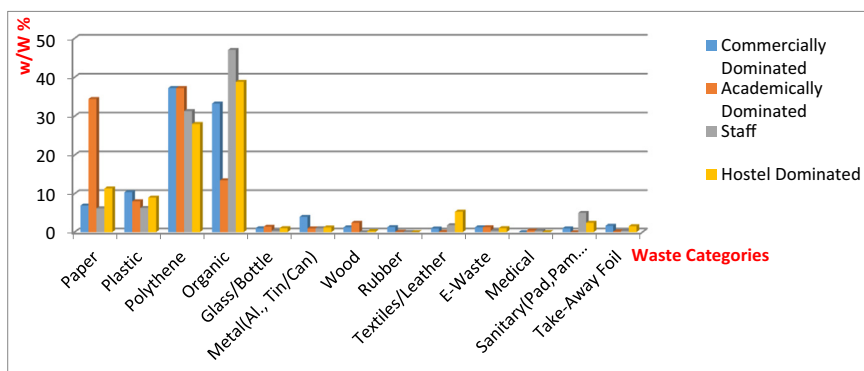**Figure 1.** Summary of percentage waste composition (w/W%).

Figure 2. Comparison of differently dominated areas (w/W %).

Table 3. Percentage Comparison of Different Dominated Areas (in w/W).

DifferentAreas				
WasteCategories	CommerciallyDominated	Academically Dominated	Staff Residence Dominated	Student Hostel Dominated
Paper	6.91	34.43	6.17	11.36
Plastic	10.37	8.04	6.27	8.99
Polythene	37.23	37.22	31.31	28.01
Organic	33.24	13.49	48.01	38.36
Glass/Bottle	1.02	1.41	0.36	1.04
Metal (Al., Tin/Can)	3.97	0.99	1.01	1.19
Wood	1.21	2.44	0	0.23
Rubber	1.27	0.09	0.02	0.01
Textiles/Leather	0.94	0.09	1.78	5.31
E-Waste	1.23	1.24	0.38	1.03
Medical	0	0.42	0.35	0.02
Sanitary (Pad,Pampers)	0.98	0	5.01	2.42
Take-Away Foil	1.63	0.14	0.33	1.86
Total	100	100	100	100

(Adeniran et al., 2017) while the University of Baja generated 8% (Smyth et al., 2010). Plastics contribute relatively great volume to the total waste stream irrespective of its light weight. It is highest in commercially areas at 10.37% and lowest in staff residential areas at 6.27%.

3.2.4. Papers

Paper is a waste category that is very dominant in all MSW stream especially in universities from the administrative and academic buildings. This particular r the report from the analysis of university waste by Smyth et al. (2010) who discovered large proportion of paper waste in the universities of the British Columbia located in Vancour at 32% and that of the Northern British Columbia in Canada at 29.1% respectively. The paper wastes collected represented 14.05% of the total waste generated in UNN which is in contrast to paper waste dominance in some Universities especially in developed countries. The study by Adeniran et al. in the Akoka campus of the University of Lagos also registered a comparable low paper waste percentage at 15%, indicating a Nigerian universities' peculiarity. This comparable lowness could be due to the amount of paper waste sold directly to the informal recyclers by some cleaners and administrative staff. Due to the contamination after mixing with some organic waste, paper wastes found in the waste containers are usually not fit for sale to recyclers. Newspaper and cardboard papers are not major parts of the paper wastes generated on Nsukka campus.

3.3. Recyclable potential of the solid waste generated in UNN

A reasonable proportion of the MSW generated in UNN campus is recyclable or is potentially recyclable as seen in Figure 3. It shows that

96.58% of the waste streams are potentially recyclable. This is justified by the rating in Subsection 2.4 as regards the recyclability of the wastes generated from each dominated area. The dominated areas had great waste recyclability potential. The academic/administrative areas had 95.81%, staff residential areas had 94.24%, commercial areas had 95.31% and hostel areas had 96.31%. The UNN campus has a lower non-recyclable potential at 3.42% when matched with some reported university studies by Chee and Sumiani (2014), Adeniran et al. (2017), Armijo de Vega et al. (2008) and Smyth et al. (2010) at 8, 25, 34 and 28.2% respectively as contained in Table 4. At present, UNN is not able to recycle, reuse or recover energy from any of its waste categories.

3.4. Biomass potential of the solid waste on campus

Biomass is an energy source which is renewable and it has a limitless supply. The waste generated from UNN has very high biomass content (51.85%). The thermal treatment of MSW generates about 500–600 KWh
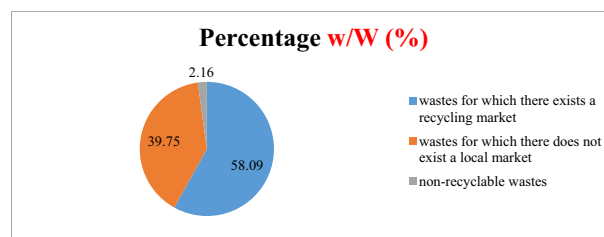

Figure 3. Recyclable potential rating (%).

per ton of electricity (2000lbs or 2204.6lbs) (Kamel et al., 2009). Consequently, the campus is capable of producing at least 1.1MWh of electricity from its 2.22 or 2.45 tons of waste daily which is about one third of the 3MWh of electricity consumption in UNN daily. When this quantity of electricity is properly harnessed and transmitted into usage in the campus, much cost will be saved from the cost of grid electricity. As the waste decays, methane gas is produced. For safer environments, new regulations have to be enacted so that landfills should be harnessed to collect methane gas. This methane gas is odorless and colorless making it difficult to detect hence, very harmful to living things. The gas has the capacity to cause explosions if it gets ignited when it seeps into homes. Landfills can be harnessed to collect the deadly gas, purify it, and it becomes fit to be used as fuel. Methane can also be produced from agricultural and human wastes through anaerobic composting in digesters. Waste can be fermented in biogas digesters to produce a methane-rich gas. The gas can be harnessed to produce a reasonable amount of energy for electricity, cooking, lighting and a host of other energy consuming needs. Municipal solid waste has the potential to become a valid resource and fuel for the urban sustainable energy mix of tomorrow Nigerian universities.

3.5. Statistical analysis

An analysis of variance (ANOVA) on the collected waste stream was carried out using SPSS 22 to see whether the differently dominated areas/locations had influence on the trend of MSW generation in UNN and to see if there are differences between their mean values. The analysis of variance in Table 5 shows the significant level of <0.0001 which is less than the threshold value of 0.05, showing that the null hypothesis, H_0 can be rejected in the favour of the H_1. In conclusion, the differently dominated areas do affect the quantity/composition of waste on campus thus confirming the differences of waste generation rates and compositions in Subsections 3.1 and 3.2. Using post hoc testing, plastic has a mean difference of 2.66038kg between the academic/administrative and commercial areas (relatively a small value), with the significance level of 0.708 which indicates that the H_0 cannot be ignored for the comparison of plastic in the two differently dominated areas because there is no statistical significant difference between them. Also, the null hypothesis for paper between staff residential area and commercial area cannot be rejected because it has a mean difference of 8.6000 kg and a significance level of 0.441, hence, there is no statistical significant difference between them. However, the null hypothesis is rejected for both plastic and paper between other locations that were not specifically mentioned in this section, for instance, the null hypothesis can be rejected for paper between academic/administrative area and commercial area or between staff residential area and academic/administrative area. Also, the null hypothesis for both organic and polythene can be rejected between all locations at all times because a very wide mean difference existed between all groups for the both. These results prove that organic and polythene components are mainly behind the differences of quantity and composition across differently dominated areas.

4. Recommendations for improved MSW management

The characterization of MSW is the basis for every sustainable Solid Waste Management (SWM) planning. Based on a clear knowledge of the percentage composition of the individual MSW, a plan for strategies to prevent, reduce, separate, collect and recycle becomes more effective.

The solid waste generated in UNN presented a very high recovery/recyclable potential as illustrated in Figure 3. Proper and effective waste management will lead to raw materials conservation, high electricity generation and a remarkable reduction in green-house gas emission reduction. Despite the existence of collection sites and transportation systems, though these collection sites and transportation system need to be more effective, it will still cost UNN great investments to develop treatment and recycling plants. The Reduce, Reuse and Recycle approach should be the first steps to consider before other alternative means of solid waste management for the exercise to be holistic and effective. Every university waste management policy for effective Zero Waste Principle must focus on preventing some waste categories like provision of pipe borne water will prevent polythene waste considerably; reducing waste from source through well planned reduce, reuse of resources; recycling of some wastes like transforming the broken plastics for use in Lion Table Water and then recovery of energy thereby making disposal the last option because waste is a valuable resource that if harnessed properly has the potential to reduce pollution on the environment, create employment and wealth for the university and its surroundings.

4.1. Organic wastes

It has been reported by Diaz et al. (1993) that organic wastes form the greatest category of waste in every MSW stream, consequently, take the largest disposal cost or have the capacity to emit the highest green-house gases. Due to the ineffective management of most Nigerian dumpsites and landfills, uncontrolled biological digestion reaction occurs and this poses alarming threats to the immediate environment through the release of landfill gases. A landfill gas is made of 45–60% CH_4, 40–55% CO_2 and trace components which gives rise to GHGs (Ezudu et al., 2019). Organic waste finds application in compost production for soil enrichment and energy generation. As reported by Sepideh et al. (2012), many institutions/universities in the United States like the Allegheny College (Meadville, PA), the Appalachian State University (Boone, NC) and the Guilford College (Greensboro, NC), use organic waste for compost formation. Some universities also utilize their organic wastes from gardens to form compost for the sole of reforestation and preservation of green areas on campuses.

The case study university has the organic waste potential (760.78kg daily) to fit adequately into the agricultural practices as proposed by the federal government. Proper education of the commercial operators especially at the cafeteria centers with high food wastes will cultivate the habit of food waste separation at the sources. Staff residential apartments and student hostels also have high food waste generation rate (at 232.46kg and 341.83kg respectively) and could be targeted for separation at the sources. The compost could be a valuable asset for the university farms, and other surrounding farms. The university waste stream has high biomass content (at 1,150.37kg) and could be considered as feedstock for biogas generation which is a good source for renewable energy for in-campus consumption. Wetland wastewater system can be constructed for anaerobic digestion of organic waste for higher methane gas production, and simultaneously double as secondary wastewater treatment. According to EPA (2008), the anaerobic digestion of organic waste has the capacity to produce almost three times methane gas production than the municipal wastewater. Furthermore, about 100–105 tons of organic waste has the potential to generate electricity for about 1000 homes on daily basis (EPA, 2008). Cost saving which is achieved from the replacement of soil conditioner by compost is an additional

Table 4. Comparison of the Waste Potential of this Study with some Previous Studies (in w/W %).

Research and year	Chee and Sumiani (2014)	Adeniran et al. (2017)	Armijo de et al. (2008)	Smyth et al. (2010)	Tadele et al. 2015	This study
Recyclable	68	33.30	32	49.43	38.93	57.65
Potentially recyclable	24	41.70	34	21.61	57.43	38.93
Non-recyclable	8	25	34	28.20	3.64	3.42

Table 5. Tabular result of the ANOVA analysis.

		Sum of Squares	Df	Mean Square	F	Sig.
Polythene	Between Groups	235965.899	3	78655.300	72.344	<0.0001
	Within Groups	108724.749	100	1087.247		
	Total	344690.649	103			
Plastic	Between Groups	31708.688	3	10569.563	131.566	<0.0001
	Within Groups	8033.631	100	80.336		
	Total	39742.320	103			
Organic	Between Groups	798526.283	3	266175.428	232.944	<0.0001
	Within Groups	114265.668	100	1142.657		
	Total	912791.951	103			
Paper	Between Groups	901853.736	3	300617.912	703.544	<0.0001
	Within Groups	42729.106	100	427.291		
	Total	944582.842	103			

benefit. Inasmuch as the roles scavengers play in MSW management are very important, they could also be possible barriers to realizing higher percentage of organic waste for the functions discussed in this section. However, the university can curb this and other barriers by setting up an environmental taskforce that would monitor the environment against the unwanted actions of scavengers like ignorant burning of plastic wastes to extract the reinforcements, visit and collect organic wastes from the dumpsters, student's hostels, staff quarters and commercial centers and transport the wastes to specific areas of need within the university.

4.2. Polythene

Like seen for the case study, high quantity of polythene components (at 717.96kg daily) has also been justified by the report in Babatunde et al. (2013) about MSWs in Nigeria. The desire of individuals to have water in a portable form at a very reduced cost stimulated the increased preference for "sachet water" which is sold in almost all corners in the university and this is behind the high quantity of polythene bags. Another major contributing factor is the use of polythene bags known as "water proof" for packaging items from cafeterias and commercial areas. Yildiz et al. (2012) observed that polythene bags pose much environmental treats because most developing countries have increased polythene bag wastes generation with no or little recycling mechanisms. The university needs to make clean pipe-borne water readily available at strategic areas of the university especially at cafeterias/canteens, commercial areas, hostels, residential areas, offices and also propose and maintain constructive policies that will encourage and promote the use of water dispensers in some of the areas mentioned earlier. This will save cost and ease the labour in collection of MSW generally and also discourage the increased litter of sachet water and associated bags everywhere on campus. Summarily, the entire university populace will be attuned to saving cost coupled with cleaner environments. The possible barrier to this policy suggestion is that UNN is the owner and distributor of the dominant brand of sachet water on campus. If this is the case, UNN should consider recycling of the polythenes for reuse in packing of their water brand or consider handing over the business to independent entrepreneurs.

4.3. Plastics

Plastics are PET bottles used for packaging water, soft drinks and high density plastics mainly generated from broken and damaged household materials like buckets, bowls, etc. This waste category contributed about 189.25kg which is about 8.53% of the daily waste generated on campus. Paper waste is best managed by collecting them separately reusing them in the university for water packaging and could also be sold to the local

markets for their use in bottling locally made beverage drinks in Nsukka like Zobo, Soya beans and Qunu. A high volume of this waste category is unreported because the owners of these cafeterias collect the bottles and sell to the local re-users who come for them at will. When this high percentage that is reusable is removed from the stream, the university could consider recycling the rest. As reported by Espinosa et al. (2008), some universities have implemented reuse or recycle programs for their recyclable plastics. For optimal management of this waste category, separate containers should be provided at different waste collection sites on campus for early separation of plastic wastes from other waste components.

4.4. Paper

Paper waste is generally low in the university's waste stream at 14.05% but dominant particularly at the academic areas of the university at 34.43%. Most of student course registrations and records are now done on the internet while some lecture notes are transmitted to students through softcopies. However, data are not currently available as regards to the quantity of papers reduced through these electronic alternatives, and this is an avenue for further research in Nigerian universities. Paper waste management must require a more commitment from the university through enacting a sustainable paperless policy where lecture notes, course registration by students, use of mails for memos, publication of student results, seminar papers are all done online and paper recycling/ reuse. This is achievable owing to the fact that the university already has wireless internet connections almost everywhere on campus. Due to the contamination after mixing with some organic wastes, paper wastes found in the waste containers are usually not fit for sale to recyclers. Because paper wastes have high reduction potential various prevention and reduction strategies can be used to minimize the generation rate of papers at source. Reuse is the first option of these strategies. The unused side of papers can be utilized to make rough copies of reports, internal memos and documents. This method should be coupled with e-mail as the main channel for communication of information, the use of printing machines that print on both sides to prevent or considerably reduce the disposal of paper wastes. To maximize the recovery potential of paper wastes in the campus, it is highly recommended to separate paper wastes and other major waste streams at the source to reduce the rate of contamination by other compostable waste categories. These strategies, if well implemented, will aide in cost saving as regards to waste management in the university especially from the academic/administrative blocks. A possible barrier to the suggested policies is that UNN might have some staff that might not be computer literate and this could hinder the policies to an extent. In this case, UNN should conduct compulsory

computer training for all the staff in this category for the policies to be sustainable.

4.5. Barriers and drivers

The barriers against proper waste management in the studied university, which other Nigerian universities should watch out against, are.

i. There is no known standard waste management policy in UNN.
ii. Currently, there is no separation at the source for compostable/organic waste from the other non-biodegradable wastes.
iii. The disposal practices of collecting wastes and openly burning the wastes are not only unsustainable but have adverse impacts on the environment in the form of green-house gas emissions, human health hazards, and social-economic stagnation.
iv. Single compactor vehicle which is currently used for disposal of daily waste generation is not enough leading to accumulation.
v. The culture of proper waste disposal is poor amongst waste generators in UNN.

The specific recommendations to drive improved management, which other Nigerian universities should replicate, are.

i. The university authority should develop zero waste policies for a sustainable environment by encouraging reduction at the point of generation, reuse of necessary categories like papers for packaging materials, papers for toilet uses, plastics for bottling drinking water, and recycling the unused ones. The university can recover energy for electricity generation from the estimated 51% biomass of the university waste which is capable of providing about 1.1MWh of electricity.
ii. Separate containers should be provided at dumpsters/collection sites for different waste categories especially for the four main waste categories and coloured or labeled bags should be provided to the staff and students residing on campus at nominal costs, and possibly little motivations, to encourage both the staff in the offices, quarters and students in the hostels to separate wastes.
iii. It is imperative to upgrade the existing open dumpsters and unsanitary landfill behind the university poultry farm to sanitary landfill. It has to be restricted to non-compostable wastes, inert wastes and other wastes that cannot be recycled, recovered or biologically processed.
iv. The daily collection routine should be upgraded by increasing the number of compactor vehicles, and a weighing bridge should be provided to ascertain the average quantity of waste collected and disposed-off daily at the open field.
v. The environmental unit of the university should set up a viable taskforce to monitor the dumpsters in the university and also different streets for improper waste disposal, and defaulters should be fined.
vi. Regular environmental campaigns should be conducted to sensitize the university community on the benefits derivable from these zero waste policies, and strategies for safer and cleaner environments.

5. Conclusion

The UNN campus generated a daily average of 2,218.66kg of solid waste during the 6-months study period with organic and polythene representing the largest portion at 32.36% and 34.29% respectively. The per capita generation of waste was about 0.06kg/day. As expected, the highest waste was generated during academic periods (April to June and September to January/February) at 2,604.77kg/day, lowest during Easter break at 1770.70 kg/day and intermediate during exam time at 2,332.16 kg. Analysis of variance showed the rate of generation and composition changed across differently dominated areas of the campus. A post hoc test revealed that the differences across differently dominated areas are due to the organic and polythene components, and not due plastic and paper components. Academic/administrative areas generated 763.29kg, staff residence areas generated 494.49kg, commercial areas generated 566.03kg and hostel areas generated 879.94kg. About 96.58% of the total waste was recyclable and 51.85% was biomass. If appropriate Waste to Energy (WtE) technologies are introduced, the university can generate about 1.1MWh of electricity per day. It was recommended that strategic policy framework and a total University community involvement and participation are imperative for reduction at the source of generation, recycling, re-usage and composting. The insightful understanding of the waste generation trends in the university, and how this should spur better sustainable strategies in the waste management on campus, is expected to stimulate similar studies in Nigerian universities.

Declarations

Author contribution statement

Collins O. Ugwu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Chigbogu G. Ozoegwu: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Paul A. Ozor: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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