Solid waste recycling within higher education in developing countries: a case study of the University of Lagos

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Abstract

To create a truly circular economy requires a shift from the traditional view of waste disposal to one of resource management. This is particularly important in developing countries, where municipal waste generation is increasing, and efficient recovery of economic value from waste is rarely achieved. Conducted in the University of Lagos (UoL), Nigeria, this study investigated the efficiency of a recycling scheme with the goal of making recommendations to improve the process. UoL's recycling policy centers around source segregation of waste into color-coded bins. Waste audit was carried out using the output method and interviews were conducted with staff from the waste management team to understand practices on campus. Substantial contamination of colored bins with non-target material was observed. Organics (30%), mixed plastics (28%) and paper (24%) were the most abundant materials, hence have the greatest potential for recovery, and income generation, if segregation rates could be improved. Despite its recycling policy and infrastructure, 99% of UoL waste was going to landfill. Poor policy implementation results in low recovery rates. Targeted waste reduction and increased material recovery would enhance efficiency. Improved awareness of recycling benefits, in addition to policy enforcement, could serve as tools to increase stakeholder participation in recycling.

Keywords Municipal solid waste · Recycling · Waste characterization

Introduction

Municipal solid waste (MSW) recycling is a systematic approach to recovering unwanted and disposed materials and manufacturing them into new products of benefit to the end user [1]. Recycling schemes foster the idea of minimizing virgin-resource utilization and waste emissions from production and distribution through to disposal. It is important to understand the effectiveness of recycling to improve resource recovery. Effective recycling, in addition to waste reduction and reuse, remains key to sustainable waste management [2, 3], a concept that has been advocated for decades now and that has seen countries develop waste policies to manage increasing waste generation and conserve scarce natural resources.

In Nigeria, solid waste management policy guidelines, applicable to all sectors, were developed to ensure that waste generated is handled in such a way that more materials are recovered/recycled, thus minimizing potential risk to public health and the environment [4]. Furthermore, the guidelines encourage an institutional framework capable of achieving an efficient waste management system, as effectively managed solid waste prevents pollution and environmental degradation, which are cornerstones of environmental sustainability. Environmental sustainability in this context is an integrated approach to effective waste management that sees waste is properly managed to recover its economic value through reusing, recycling, and proper disposal, which encourages material longevity [5–7]. However, waste material recovery by institutions in developing countries has been poor, leaving the major role to the informal sector (scavengers who move from site to site to pick recyclable materials for personal gains) that does the work without minding the potential risks involved, as most of them do the work without any personal protective equipment (PPE) [8].

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To encourage environmental sustainability, research has used waste characterization to proffer recommendations on the best waste treatment and management options to explore [9–16]. The determination of various waste streams through waste audits helps to identify recoverable materials and even reduce the amount of biodegradable waste going to landfills, thereby mitigating potential risks posed by landfill sites. However, studies are often limited to the characterization of MSW based on the estimation of such wastes in urban areas, without a proper waste audit because of the cost implications of conducting such audits [17, 18].

While research on solid waste characterization at the household level is common, studies at higher educational institutions (HEIs) have been largely unexplored. However, as HEIs experience similar challenges in relation to effective waste management (e.g., inefficient recycling programs) as municipalities, and play a key role in achieving a sustainable society, they can be considered analogues to towns and cities. Given their population size and complexity of activities undertaken, these institutions contribute to high solid waste generation, much like municipalities [13, 19–21].

Of the studies that have focused on HEIs, several have shown that a higher percentage of waste generated is often organic waste, mixed plastics and paper. When assessing waste generation and composition across campus at the University of Tabriz, Iran, Taghizadeh et al. [22] found that the highest proportion of waste generated was organic waste (45%), followed by plastic (19%) and paper (14%). While Smyth et al. [23] determined that mixed paper was the largest component of the waste stream when characterizing waste at the St. George Campus of the University of Northern British Columbia (UNBC) in Canada (UNBC), this was followed by organic and plastic wastes. Zhang et al. [15] looked at waste characterization at the Longzi Lake Campus of Henan Agricultural University and found that about 79% of the waste from the institution was recyclable, which is similar to Adeniran et al. [24] that characterize waste at the University of Lagos, Nigeria, which also shows that 75% of waste generated at the UoL is recyclable. Of all these studies at HEIs, none focused on the efficiency of their institution's currently existing waste recycling policies.

The aim of this study was therefore to investigate the effectiveness of a recycling program at a HEI in a developing country. The University of Lagos (UoL), Nigeria, was used as a case study, to gain understanding of its waste management approach by examining the waste composition in the three main waste-generating activity areas (administrative, commercial and residential) on the university campus. Solid wastes from different colored bins in the administrative, commercial and residential areas were sampled and audited.

The findings will help to assess the university's waste management operational efficiency and inform a set of recommendations for a sustainable waste management approach within HEIs in the developing world.

Materials and methods

Case study area

Established in 1962, the University of Lagos (UoL) is one of the oldest HEIs in Nigeria. With an estimated daytime population of 87,000, the university generates on average 32.2 tons of waste per day [24]. The main campus, located at Akoka in the western part of Lagos State, is divided into 4 Zones, A–D (Fig. 1). Within these zones, waste is generated in three areas: administrative, commercial and residential. The administrative areas include offices and academic work spaces; the commercial areas include restaurants, photocopy centers, motor parks, and worship centers; and the residential areas host staff quarters and student hostels.

UoL's Department of Works and Physical Planning (DWPP) contracts two private waste companies to manage the university's waste. Waste is collected and transferred to the university's recycling center, where the contractors sort the recyclables manually. The DWPP monitors the activities of the waste contractors and organizes the university's waste management data. UoL's waste recycling policy aims to prioritize material recovery over landfilling, and has appropriate infrastructure to capture different waste streams for recycling, *i.e.,* color-coded bins to capture different waste streams (DWPP, personal communication, 14 December 2016).

During the data collection phase of the work, the DWPP assigned CM to the contractor responsible for Zones A and B, and permitted access to these areas only for waste sampling. Zones A and B, which contribute to over 70% of the total waste generated by the university, contain administrative, commercial, and residential areas. Both zones are dominated by residential areas (60 and 84%, respectively), but also have administrative (27 and 6%, respectively) and commercial (13 and 9%, respectively) areas [24].

Waste audit sample collection

A waste audit was conducted during December 2016 to establish the composition of the waste in the different colored recycling bins located in the three waste-generating areas on campus to determine if the university's recycling policy was being effectively implemented. The output method of analysis was used for the waste audit [17, 18]. This method examines solid waste composition from already disposed waste. An 'activities approach', as outlined in the Waste Audit User Manual: A Comprehensive Guide to the Waste Audit Process by the Canadian Council of Ministers
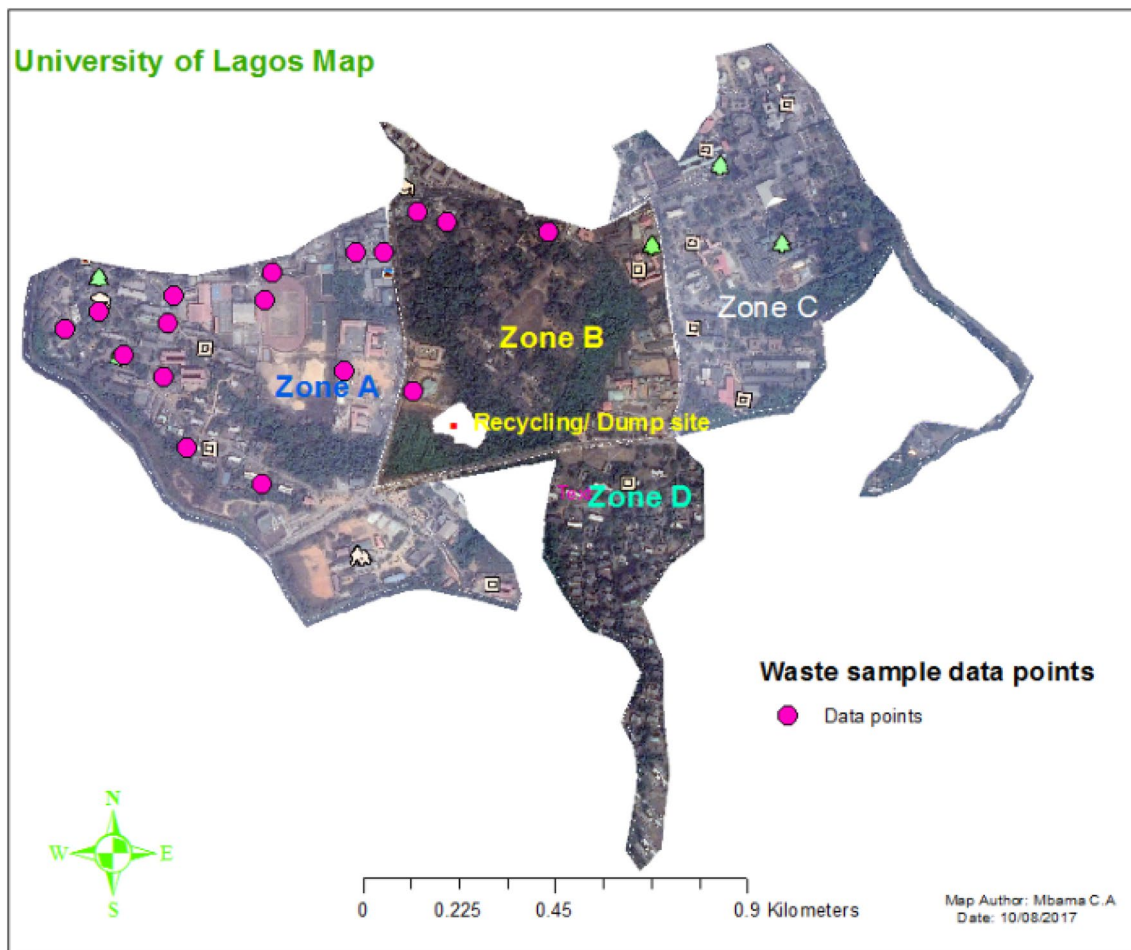
Fig. 1 Map of University of Lagos, Akoka Campus, showing the location of the four campus Zones (**A–D**) and the waste collection points (pink markers) within Zones **A** and **B**

of the Environment (CCME) [18], was also utilized. These methods track waste and recyclables within activity areas in institutions and separately audit the waste from each area.

The audit involved sampling waste from different colored bins in the administrative, commercial and residential areas. Once collected, the waste samples from each colored bin in each area were segregated into six different waste types: mixed paper and card; mixed plastic (with subsections for water sachets, single-use plastic bags and plastic bottles); cans; organic waste (with subsections for food and non-food waste); mixed glass; and non-recyclables. The volume of each waste type was measured; however, the measurement of the weight was used to assess the extent of contaminants in the colored bins.

As recommended by CCME (1996), representative waste samples were collected in a similar fashion to the quartering and dividing approach for representative sampling used by Tiew et al. [25]. One third of the waste contained in each of the 64 bins sampled across the three major waste-generating areas was collected. The DWPP indicated that there were 800 colored bins on the university campus, but colored bins were officially only located in the administration and commercial areas for collection of general waste and recyclable materials, not in the residential areas; people living in the residential areas are advised to dispose of their waste in black bin bags. However, during data collection, it was noted that some green and blue bins were located within residential areas, and therefore samples were also collected from these bins.

Tiew et al. [25] recommend sampling between 10 and 25% of the waste generated in any given area. However, it was not possible to reach the recommended minimum sample size of 80 bins, as the study was undertaken during university vacation when not all bins were in use.

Waste samples were collected with the help of UoL's waste haulage unit; the haulage unit provided a waste truck for sampling and transportation of the samples to the university's recycling center for storage until the audit was completed. The researcher employed a team of six assistants to audit the waste by separation and assessment; the

assistants included two students attending the university and four staff members from the waste contractor. The initial total weight of sampled waste was 259 kg; however, after segregation into six waste categories, mixed paper and cards (paper, cards, carton, etc), mixed plastic (plastic bottles, nylon including grocery and sachet water bags), cans (drink cans, food cans, etc.), non-recyclable (foil, sands, materials highly contaminated with oil, etc.), mixed glass (glass bottle, cup, wine, etc.) and organic waste (food, grasses, etc.), the estimated weight of sampled waste was 255 kg with an estimated volume of 49 m^3. The loss in weight resulted from emptying the liquid content of plastic containers.

Before completing the audit, a risk assessment for the study at UoL was completed, and strategies to minimize all identified risks were followed, *e.g.,* explaining the goal of the project to the waste audit assistants, presenting the risk assessment results and health and safety procedures, and providing PPE for the seven participants that conducted the audit (researcher, two students, and four waste contractor staff).

Data analysis

One-way ANOVA in IBM SPSS Statistics V24.0 was used to explore any significant difference in the waste composition between the four different colored waste bins from the three different waste-generating areas on campus; this software can be used to analyze and compare the variance between more than two groups [26]. Levene's statistical test was conducted to test the homogeneity of the variance across the three activity areas. Reinard's publication [27] indicated that this test better analyses the equality of error variance. In this investigation, appropriate analytical guidelines for the use of statistical software were used.

Key interviewee discussion

A visit to the university's waste management facility (recycling center) was made, in addition to formal and informal discussions with university staff who have key roles with respect to waste management. The formal discussion posed structured questions to the waste management coordinator at the DWPP to gain insight into the university's waste management approach. Informal discussions took place with a waste haulage driver, four members of the cleaning staff, and a member of staff from the waste contractor involved in the manual sorting of recyclables at the university's recycling center. Open-ended questions included in the discussion with the DWPP waste management coordinator covered how the university's waste management system works, how much waste is generated, recycled, and landfilled monthly, and how often waste haulage is completed. The DWPP also

provided the university's waste generation data from October 2014 to October 2016.

The DWPP was initially contacted in September 2016 via email before the commencement of research work in December 2016. The initial e-mail contact was to inform the university about the key research aims, request assistance, and seek their consent to conduct the collaborative waste audit at the university.

Results

Solid waste management at the University of Lagos

Unless otherwise stated, all information about the university's waste management procedures was provided to the Department of Works and Physical Planning (DWPP) via email and interaction with a key DWPP officer. UoL's 2014 Waste Management Policy follows Nigerian guidelines [4]. The wastes are hauled to the university recycling center, where they are manually sorted to extract recyclables. University waste is hazardous, non-hazardous, and inert. The university's health clinic generates most of the hazardous waste, which is incinerated on-site. Inert waste is generated during construction or demolition at UoL, while non-hazardous waste, which is the focus of this research, is generated across the university.

The university recycles and has over eight hundred 300-L solid waste bins across campus: blue bins for mixed paper and cards, green bins for mixed plastics, red bins for cans, and black bins for residual/other waste. Upon implementing the waste management policy in 2014, UoL ran a waste management campaign that included waste and environmental management orientation for new students, regular awareness jingles on the university's radio station, color-coded waste bins and signage at strategic locations throughout the campus, and waste management awareness lectures with faculty officers and commercial operators.

Unofficially, some university staff pick up recyclables to sell and make extra income, and scavengers enter the campus to pick up recyclable wastes to sell too.

The DWPP also ensures the collation of waste management data, including keeping up-to-date records of waste management activities (daily generation, recycling, and disposal rates), and monitoring of the waste contractors' activities, to ensure that recyclable wastes are recovered, and residues are disposed of safely without posing a risk to the public. The university's solid waste data collected for 2014–2016 shows that about 11,500 tons of waste were generated on an annual basis, while the average daily waste generation was about 32.5 tons per day. Despite the commitment and efforts of the university's waste management team, the data show that an average

of 1% of the waste material is recycled, while about 99% is either used for land reclamation or sent to be landfilled (Fig. 2).

Waste audit

Sixty-four representative waste samples, amounting to approximately 254.5 kg/49 m^3 were collected from the colored solid waste bins spread over the three major waste-generating areas (Table 1). The mean, standard deviation, and margin of error (which shows the variance on the quantity of the wastes sampled) for the 64 waste samples were calculated; a standard deviation of 2.8 shows that the representative sample data values are similar, so the data are shown to be closely clustered to the mean, 4.0, which indicates that the sample is well distributed. This can be seen with the margin of error of 0.7%, which shows a good sample size that is representative.

Waste overview

The waste samples were separated into two categories: (1) general waste (black bins) and (2) recyclable waste (red, green, and blue bins). Once collected, samples were sorted at the university's recycling center. Figure 3 illustrates the waste content in these two categories and overall.

Organic waste (consisting of food and non-food waste) was the largest component of all the waste collected (30% by mass; 22% of the organic stream was food waste, while the remaining 78% included garden waste (leaves, branches, etc.). Organic waste was also the biggest component of the general waste stream (39%), but only the third largest component of the recyclable stream (21%), behind mixed plastic (33%) and paper and card (28%). The second and third largest components of all waste analyzed were mixed plastics (28%) and paper and card (24%). Limited amounts of mixed glass (2% of all waste collected) or cans (4% of all waste collected) were found in either waste stream. The most common plastics found among all waste sampled were

Fig. 2 Monthly waste disposed and recycled trend from October 2014 to October 2016 in Akoka Campus, University of Lagos
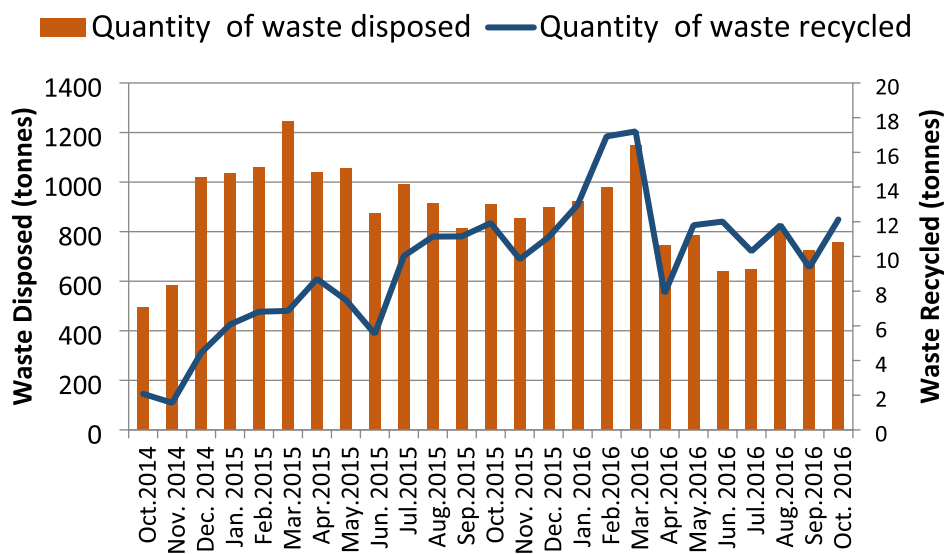
Table 1 Number and weight of waste samples collected from different colored waste bins in the administrative, commercial, and residential areas of Akoka Campus, University of Lagos from December, 2017

Generation area	Mixed paper Blue bin		Mixed plastic Green bin		Cans Red bin		General/other Black bin	
	Mass (kg)	No of samples	Mass (kg)	No of samples	Mass (kg)	No of samples	Mass (kg)	No of samples
Administrative	12.5	5.0	24.2	7.0	9.2	5.0	33.5	11.0
Commercial	33.5	5.0	33.1	6.0	8.6	5.0	50.0	8.0
Residential	5.2	1.0	4.3	1.0	0.0	0.0	40.6	10.0
Total	51.2	11.0	61.6	14.0	17.8	10.0	124.1	29.0
Total waste	254.5	(kg)						
No of waste Sample	64.0							

Fig. 3 Composition of the general waste samples from black bins ($n=29$, 124.0 kg) and recyclable waste samples from green, blue, and red bins ($n=35$, 130.5 kg) at Akoka Campus, University of Lagos
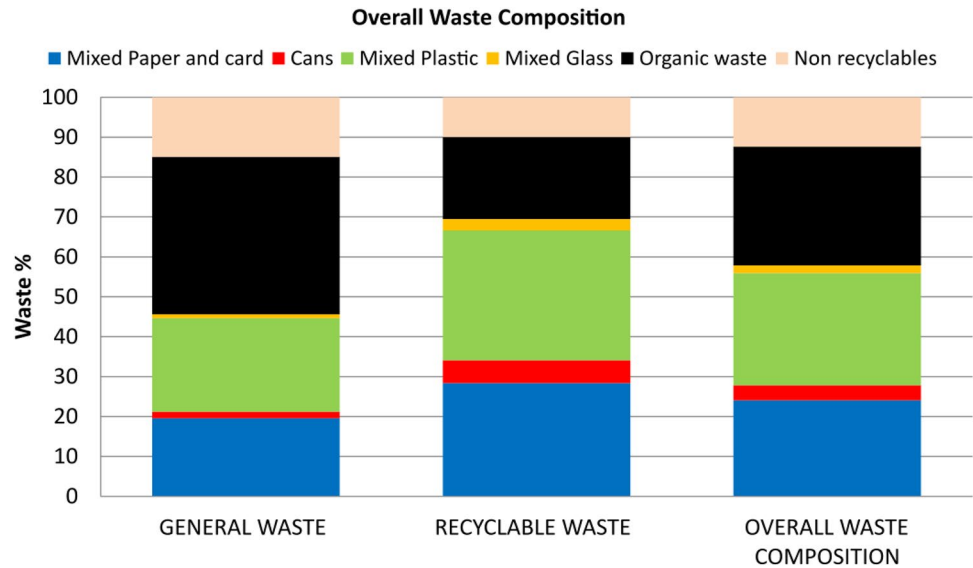
packaging (51%, 36.5 kg), composed of low-density poly ethylene (LDPE), e.g., water sachets, bin liners, carrier bags, etc.; the remainder were PET bottles (49%, 35.0 kg); this was also confirmed by visual inspection (Fig. 4). The high contribution from 'nylon' water sachets may be attributed to the low cost of this form of water, which is assumed to be safe for drinking [28, 29].

## Waste by area of activity

The composition of the general waste stream from the different waste-generating areas is shown in Fig. 5. Organic waste was a major component of waste in all areas, but the commercial area had the highest proportion (45%), followed by administrative (35%), and residential (36%). Mixed plastic made up 30% of the administrative area waste, but only 19% of that from the commercial area (Fig. 5). In the residential areas, just over a quarter of the general waste was composed of mixed paper and card (27%), while in the commercial area, waste had a much lower level of this material (11%). The other waste streams, *e.g.,* cans and mixed glass materials, were present in lower proportions (1–3%), except non-recyclable material, which ranged between 9 and 20% of the general waste stream across the three waste-generating areas.

Fig. 4 High LDPE content found during waste analysis sorting process; of the 71.5 kg of plastic waste sampled, 36.5 kg was 'nylon' sachet water and 35.0 kg was PET plastic bottles

Fig. 5 General waste composition across the three waste-generating areas (administration 33.5 kg, commercial 50.0 kg, and residential 40.6 kg) at Akoka Campus, University of Lagos

GENERAL WASTE COMPOSITION BY MASS (%)
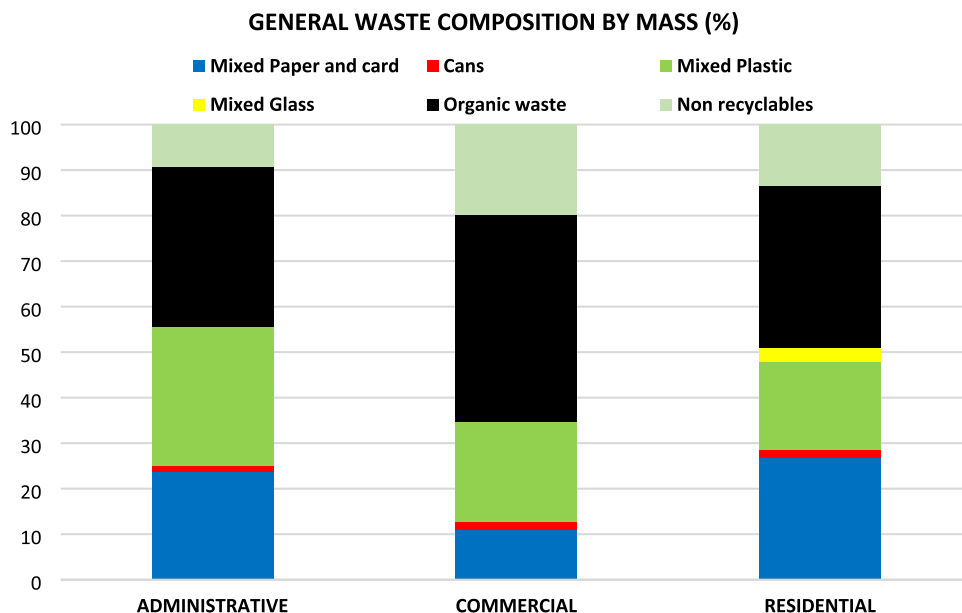
Differences in composition between the three areas were also noted in the recyclable waste stream (Fig. 6). The largest contributor to the recyclable waste stream in the administrative and residential areas was mixed paper and card (45% and 29%, respectively), while that in the commercial area was mixed plastic (33%). The administrative area also had a similarly high proportion of mixed plastics (32%). Compared with the general waste, there was a lower proportion of organic material in the recyclable waste stream.

However, there still exist similar patterns of organic material between the three waste-generating areas for both general and recyclable waste streams; for example, the commercial area had the highest proportion of organic material (e.g., 25% in the commercial area, and 14/17% in the administrative/residential areas, respectively, for recyclable waste streams). As with the general waste, there was a relatively small proportion of material from cans, mixed glass, and non-recyclable materials (10–16%) in the recyclable waste streams.

Contamination of recycling program bins

Blue bins designated for mixed paper and card recycling Almost half of the waste from the administrative (48%) and residential (49%) blue bins contained targeted paper and card material; however, only 11% of the waste in the commercial blue bins was paper and card (Fig. 7). In the commercial area, the paper waste stream had a high proportion of mixed plastic (47%) and organic (26%) contamination, while minimal contamination was found from

Fig. 6 Total recyclable waste composition across the three waste-generating areas (administration 45.8 kg, commercial 75.2 kg, and residential 9.5 kg) at Akoka Campus, University of Lagos
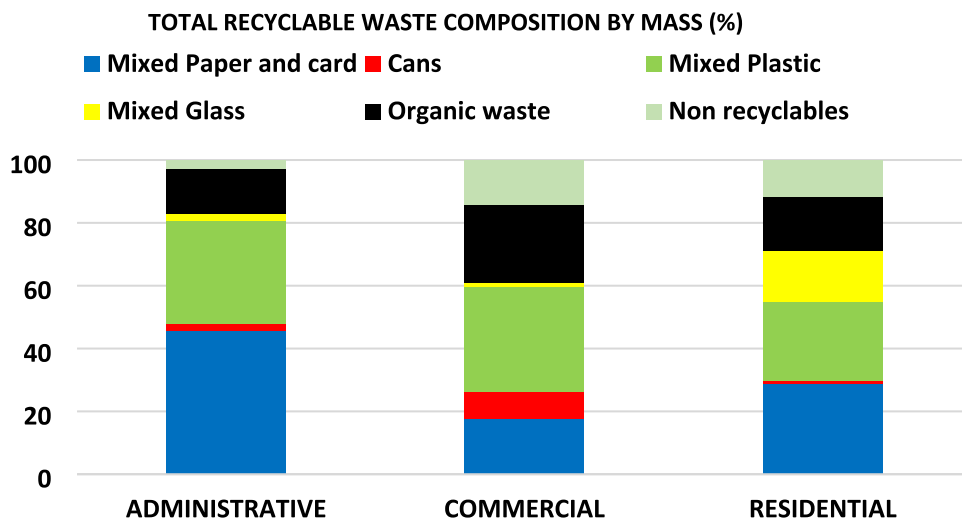

TOTAL RECYCLABLE WASTE COMPOSITION BY MASS (%)

Fig. 7 Composition of colored bins stratified by administrative, commercial, and residential waste-generating areas of Akoka Campus, University of Lagos. Mixed paper/card blue bin mass = administrative 12.5 kg, commercial 33.5 kg, residential 5.2 kg. Mixed plastic green bin mass = administrative 24.2 kg, commercial 33.1 kg, residential 4.3 kg. Can red bins mass = administrative 9.2 kg, commercial 8.6 kg, residential no bins present
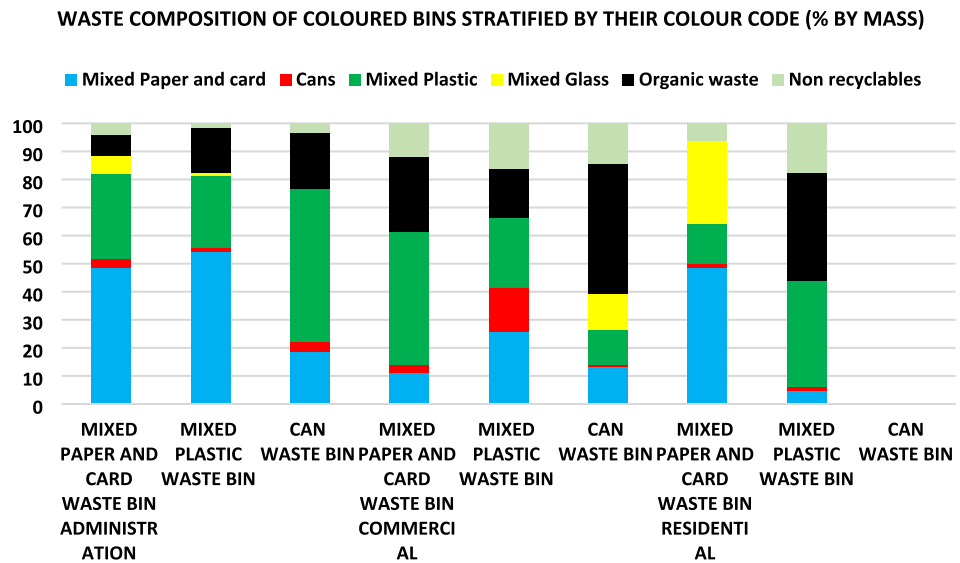
non-recyclable material (12%) and cans (3%). Among the administrative and residential waste, the most abundant contaminants were mixed plastic (30%) and mixed glass (30%), respectively, with minimal contamination from the other waste streams. No organic waste was found in the residential blue bins.

Green bins designated for mixed plastics recycling A quarter of the waste sampled from the administrative and commercial green bins contained target mixed plastics; however, a higher level was found in the residential green bin samples (38%) (Fig. 7). The plastic waste stream had a high proportion of paper and organic contamination. For instance, contaminants in the residential green bins were 38% organic waste (mainly food waste) and 18% non-recyclable material. Over half of the material (54%) in the administrative green bins was non-target paper and card, with some contamination from organic materials (16%). A high level of mixed paper and card (26%) was found in the plastic waste from the commercial green bins, followed by 16% cans contamination in the same area.

Red bins designated for can recycling Very little target material was present in the red bins located in the administrative and commercial areas (1% and 2%, respectively); no red bins were present in the residential area because, under the current official recycling policy of UoL, the residential area should have no colored recycling bins. The cans waste stream had a high proportion of plastic contamination, (54%) in administrative area, and organic (46%) in commercial areas. Organic (20%) and non-recyclable (15%) materials were also found in the administrative and commercial areas, respectively, among the waste in the red bin. As with the other recyclable streams, minimal glass and

non-recyclable material were found (1–13%). Additionally, despite not being a waste stream under investigation, approximately 5 kg of electrical waste (primarily electrical wires) was found in a red bin from the commercial area during the waste audit.

Data analysis

The one-way ANOVA result showed that across the three waste-generating areas (administrative, commercial, and residential), there was no significant difference in the waste composition in the blue mixed paper bin samples ($p = 0.507$). Same for the green mixed plastic bin ($p = 0.539$) and red cans bin samples ($p = 0.474$) across waste-generating areas, when each of the mean of the targeted waste stream was compared with mean of the contaminants in each of the waste bins. However, only the general waste (black bin) showed a significant difference ($p = 0.003$).

Discussion

As part of its 2014 waste management policy, the UoL introduced a recycling scheme with more than 800 colored bins. Despite some success with waste infrastructure, such as waste bins, haulage trucks, and the recycling center, the university still faces challenges, including efficient management to explore economic and environmental benefits. Analysis of the university's data showed that only 1% of waste materials are recovered at the recycling center, the rest is landfilled. This is similar to Adeniran et al. [24] who found that 99% of UoL waste is not recycled.

The waste characterization analysis found that 88% of the university's waste could be diverted from landfill; 30%

composted, and the rest recycled (Fig. 3). These findings are similar to those of Adeniran et al. [24] who investigated waste management at the same university and found a recycling potential of 75%. They are also in line with similar research on waste streams at other HEIs. Smyth et al. [23] determined that 70% of UNBC's waste stream could be diverted from landfills through recycling, composting, and waste reduction programs. Ezeah et al. [21] and Taghizadeh et al. [22] found that over 80% of waste from Wolverhampton and Tabriz universities could be managed by reduction, recycling, and composting/landfill diversion.

Organic (30%), mixed plastic (28%), and mixed paper (24%) wastes represented the higher proportion of compostable and recyclable materials of the overall waste sampled (Fig. 3). This varied from the findings of Smyth et al. [23], where mixed paper and card (29%) represented the highest proportion of the UNBC campus waste, followed by non-recyclables (28%) and organic materials (22%). This could be due to geographical and cultural differences, as both have been found to be factors influencing waste composition [30]. The current findings highlight the three major waste streams that could be recovered from the study area, namely plastics, paper, and organic waste; these streams should be the primary focus for sustainable waste management in the university. These streams have also been highlighted in the literature as being the main waste streams identified in HEI [22, 23, 31].

Non-recyclable material, to be disposed of either through incineration or landfilling, made up about 12% of the waste across the case study area, a value almost half that found by Adeniran et al. [24] at the same campus. While this study only sampled waste from Zones A and B on campus, Adeniran et al. [24] sampled from all 4 campus zones, which will have increased the number of samples from residential structures, and may explain the difference found in residual waste material, as residential areas, under the current official recycling policy, have no colored recycling bins.

At 30% (Fig. 3), all three areas of the campus generated a high volume of organic waste. Of this, 43% came from the commercial area, which is where most cafeterias and canteens are located. Mixed plastic waste made up 28% of the total waste stream in the study areas (Fig. 3). Staff and students rely heavily on plastic packaged food and drinks, especially sachet water, which is affordable and portable. A lower composition of paper (24%) than plastic may be attributed to the waste audit being conducted during the vacation period, when teaching activities were reduced, hence a limitation to the study; the findings show waste generation is lower during student vacation. The university generates between 496 and 1250 tons of waste per month, with peak generation during the teaching semester and lower generation when distance learning students are on campus or students are on vacation (Fig. 2). The high proportion of mixed plastic

and paper is similar to previous research showing 50–90% of HEI solid wastes are mostly mixed paper, mixed plastic, and food waste that could be recycled or composted [31, 32].

Contamination (non-target material) in colored recycling bins across campus indicates staff and students using the system. This investigation showed that the UoL has a recycling policy that should encourage recovery from major waste streams, but waste is generally collected together by the haulage unit, regardless of the waste streams, and stakeholder (staff, students, and visitors) recycling engagement does not align with the university's overall recycling strategy.

No significant difference was detected in the waste samples from the blue ($p = 0.507$), green ($p = 0.539$), and red ($p = 0.474$) bins, respectively, across the waste-generating areas when comparing the mean of the targeted waste stream to the mean of the five contaminant waste streams, indicating there was no proper segregation of materials in these colored bins. General waste (black bin) was significantly different ($p = 0.003$) from the five contaminants across the three waste-generating areas. The significance level was further analyzed using ANOVA's Tukey post hoc test, which revealed that Tukey's honest significant difference (HSD) was still less than 0.05, indicating that staff and students only use the black bin as they should, and thus there is no significant difference in the waste composition of the black bins across waste-generating areas. People on campus are using all bins, regardless of color, as general waste bins and not segregating their waste properly, resulting in low material recovery. This will increase the environmental and economic costs of management; for example, 99% of UoL's waste is sent to landfills, whereas revenue could be generated by selling high-quality recovered waste.

Based on the waste composition analysis, the university has the opportunity to not only recover/recycle waste (e.g., the high volume of mixed plastic and paper has high recycling potential), but also reduce and reuse (the 3 Rs of waste management). Although the 3Rs are a voluntary approach to the waste management [34], they would encourage efficient waste minimisation at the university, e.g., if drinking water quality fountains were installed by the university, it would minimize the use of 'nylon' sachet water and plastic bottled water, thus preventing generation of these waste materials. More so, another method to reduce the high presence of plastic waste, especially carrier bags, would be to charge for single-use plastic bags. This could be implemented on campus to minimize such usage in favor of re-usable bags. Schemes such as this have been successful in western countries like the United Kingdom, resulting in an 81% reduction in the volume of single-use bags distributed between 2010 and 2012; bag usage per capita per month decreased from 9.7 plastic bags in 2010, to 1.8 bags in 2012 [35, 36]. Such measures could be adopted nationwide in developing countries to enhance behavioral change [34].

The audit result has also shown the need to establish recycling, as provided in other areas of the campus, in the residential areas, i.e., staff quarters, as there are significant recyclable wastes (plastics and paper wastes) generated in these areas. This could be the reason other colored bins (blue and green bins) were found in the residential area despite the area being advised to dispose of its waste in black bin bags.

The recycling policy has to be enforced to ensure that high-quality recyclable materials of economic value are recovered, as suggested by Armijo de Vega [31]. Currently, the research shows that an average of only 1% of waste materials is recovered because of the lack of engagement with the recycling policy. The materials that are recovered are often manually sorted at the university's recycling center after collection, and having less than 10 staff, results in a poor recovery rate. If source segregation is maximized through message specific public awareness programs, more recyclables can be recovered.

Previous research has found that some staff members are engaged in unauthorized waste recycling on campus [24], while waste pickers/scavengers also enter the campus and undertake unofficial recycling of university waste. To ensure that revenue potential from waste materials is returned to the university, there not only needs to be enforcement of the recycling policy but also control mechanisms in place to prevent unofficial recycling of campus waste materials at the individual or departmental level, i.e., recycling of waste by individuals or departments other than the university's authorized waste contractors. Alternatively, to maximize a high material recovery rate, the waste contractors could work collaboratively with waste pickers to create a win–win situation. These workers could be a great ally to ensure that high levels of recyclable materials are recovered [33].

The waste audit result showed that organic wastes are the largest waste stream generated at the university, which suggests that biological treatment methods such as anaerobic digestion (AD) or composting may be viable management options. AD has the advantage of not only generating energy through creation of methane, but also fertilizer could be created from relatively small-scale facilities [37]. One ton of organic waste has the potential to generate between 100 and 150 kWh of electricity [38]. However, composting also remains a good option for treating organic waste in developing countries to produce organic fertilizer considering the cost effectiveness of setting up a simple composting system, in addition to the temperature advantage the weather provides [39].

At UoL, collection of segregated organic material should be enforced as part of the recycling policy, with particular focus on the commercial areas (i.e., cafeteria) and residential areas, i.e., staff quarters, as these areas generate more organic waste (33% and 32%, respectively). As composted materials can be used to enhance crop productivity, revenue could be generated by selling on the compost [40, 41].

The result shows that the non-recyclable waste category only makes up a small portion of the waste stream (12%) compared to other waste categories. Some energy recovery may be possible from this material via incineration, but this is not really a viable option as construction of energy recovery incinerators is expensive—unless it could be shipped to a pre-existing facility, but transportation has environmental costs [42]. Although waste landfilling may appear to be a cost-effective waste management option, it is ranked last in the waste management hierarchy due to its high environmental impact [43].

Waste audit results from recycling bins at universities can help identify the "wrong" waste and tailor strategies to reduce its presence in bins. Adapting the use of waste audit in assessing the composition of recycling bins also help to evaluate the effectiveness of the recycling programs, and hence a better way to reintroduce and implement strategies to enhance the recycling rate as well as improve environmental sustainability.

Efficient waste collection plays a key role in waste management, and this is particularly relevant where segregated wastes require separate collections for each stream. Therefore, there is need to collect colored waste bins for different waste categories separately by the haulage unit to maximize recovery efficiency. Research has shown that over 60% of waste management budgets are used for waste collection and transportation [44, 45]; however, much of this cost ends up in the payment of salaries and fuel. To minimize the cost of waste collection, it is essential that GIS routing of the university's activity areas be completed to identify the shortest route during waste collection to plan the waste collection of different colored bins efficiently. Routing using GIS has been found to be an efficient and cost-effective approach for waste collection and transportation. For instance, it has been used in the past to optimize waste collection/bin positions in Sfax, Tunisia [46]. Kallel et al. [46] developed three optimal scenarios using an ArcGIS Network Analyst tool to compare with the system's base scenario to understand and improve the efficiency of waste collection. The findings showed that up to 57% of time could be reduced and 48% of fuel consumption could be saved when waste collection was optimized [46]. Similarly, Malakahmad et al. [47] conducted a pilot study in which five routes for waste collection were chosen in different parts of Ipoh city. When the routes were optimized, it took up to 22% less time to collect waste than usual. This meant that the optimized routes were better for collecting waste, thereby saving time, fuel costs, truck air pollution emissions, etc. For the UoL, this could potentially reduce the cost of waste collection and transportation.

Raising awareness of the benefits of waste recycling can serve as a tool to increase stakeholders' (academic and

non-academic staff, students, and visitors') participation at the university. Desa et al. [48] looked at environmental awareness and education as a key approach to solid waste management, and found that awareness campaigns on inefficient recycling and communication strategies such as focusing on environmental education, *i.e.*, recycling, have proved to be beneficial and enhance wider participation in recycling [48, 49]. More so, increasing knowledge-based campaigns on waste-related environmental and health issues can foster positive attitude change toward safe waste management practices [50–52].

Conclusion

This research has investigated recycling practice at a typical HEI in a developing country to improve knowledge, which is necessary for proper and effective sustainable waste management practices.

The results helped to evaluate the level of recycling performance at the University of Lagos, and the process can be adopted by other universities, especially in developing countries where the level of recycling practice is low. The present result shows that the level of contamination across colored waste bins remains a big challenge despite the university's recycling policy and efforts to provide recycling facilities across the campus. Results indicate that material recovery of organic waste, mixed plastic, and mixed paper could be maximized in the management approach, indicating more opportunity from these three waste streams; further analysis on this will be presented in future publications.

Staff and students are not following university policy with respect to discarding their waste material, as no significant difference was found between the waste compositions of the blue, green, and red bins in the waste-generating areas. If source separation could be maximized and waste collection and transportation routes be optimized, they could potentially reduce the high environmental and economic cost of waste management for the university, as more revenue could be generated through marketing of recovered waste materials with less time, and fuel consumption by haulage trucks, thereby saving time and cost of waste management at the university. The result will help to develop more strategies to reduce the presence of waste contaminants across targeted materials.

The benefits of waste recycling are enormous, including economic gain, which could potentially reduce the operational cost of the process. Hence, a number of waste management options such as reduce, reuse, recycle, and compost could be explored, and most importantly, awareness could be created to understand the benefits of waste recycling and enforcement could serve as a tool to increase stakeholders' (academic and non-academic staff, and students')

participation at universities. Finally, there should be an introduction of recycling bins in residential areas. Separate bins for organic waste materials should also be introduced, while composting of such waste should be adopted instead of sending it to landfills so that potential environmental risks, e.g., greenhouse gas (GHG) emissions, are minimized.

Data availability The dataset generated and/or analysed during the current study is included within the article, however, any further data enquiry is available upon reasonable request from the corresponding author.

References

1. Hopewell J, Dvorak R, Kosior E (2009) Plastic recycling: challenges and opportunities. Philos Trans R Soc Lond B Biol Sci 364(1526):2115–2126
2. Ferreira B, Monedero J, Marti JL, Aliaga C, Hortal M, Lopez AD (2012) The economic aspects of recycling, post-consumer waste recycling and optimal production. Enri Damanhuri, IntechOpen. https://doi.org/10.5772/34133. Available at: https://www.intechopen.com/books/post-consumer-waste-recycling-and-optimal-production/the-economic-aspects-of-recycling [Accessed 22/12/2018].
3. Kam H, Baharum M, Chua S (2016) A review of commercial waste recycling policy in Malaysia. Int J Environ Sustain Dev 15(4):404–422
4. Federal Ministry of Environment (2005) Policy guidelines on solid waste management. Abuja, Nigeria, Pages 1–14
5. Morrissey AJ, Browne J (2004) Waste management models and their application to sustainable waste management. Waste Manage 24(3):297–308
6. Otegbulu AC (2011) Economics of green design and environmental sustainability. J Sustain Dev 4:2
7. Bailey J, Pena M, Tudor T (2015) Strategies for improving recycling at a higher education institution: a case study of the University of the West Indies, Cave Hill Campus, Barbados. Open Waste Manag J 8:1–11

8. Marshall R, Farahbakhsh K (2013) Systems approaches to integrated solid waste management in developing countries. Waste Manag Pergamon 33(4):988–1003

9. Hoang PC (2005) Audit of solid wastes from hotels and composting trial in HaLong City, Vietnam. Master Thesis, Department of Civil Engineering, University of Toronto, Toronto, Canada.

10. Byer PH, Hoang C, Nguyen TT, Chopra S, Maclaren V, Haight M (2006) Household, hotel, and market waste audits for composting in Vietnam and Laos. Waste Manag Resour 24:465–472

11. Coggins PC (2009) Waste composition and analysis. In: Smith SR, Cheeseman, C Blakely N (eds) Waste management and minimisation. Encyclopaedia of Life Support Systems, United Nations Education, Science, and Cultural Organization

12. Mbeng LO, Phillips PS, Fairweather R (2012) Waste characterization as an element of household waste management operations: a case study in Limbe, Cameroon. Open Waste Manag J 5:49–58

13. Ishak NR, Mahayuddin SA, Mohamed MR (2015) Generation and composition of solid waste in University Campus. In: Proceedings of the Colloquium on Administrative Science and Technology

14. Gallardo A, Edo-Alcón N, Carlos M, Renau M (2016) The determination of waste generation and composition as an essential tool to improve the waste management plan of a university. Waste Manage 53:3–11

15. Zhang D, Hao M, Chen S, Morse, S (2020) Solid waste characterization and recycling potential for a University Campus in China. Sustainability 12.

16. Elemile OO, Sridhar MKC, Oluwatuyi OE (2019) Solid waste characterization and its recycling potential: Akure municipal dumpsite, Southwestern, Nigeria. J Mater Cycl Waste Manag 21:585–593

17. Sharma M, McBean E (2007) A methodology for solid waste characterization based on diminishing marginal returns. Waste Manage 27(3):337–344

18. ASTM D5231–92 (2016) Standard test method for determination of the composition of unprocessed municipal solid waste. In: ASTM International, West Conshohocken, PA.

19. Acurio G, Rossin A, Teixeira PF, Zepeda F (1997) Situation of the municipal solid waste management in Latin America and the Caribbean. In: Pan-American Organization, Washington, DC, USA.

20. Schmieder T (2012) Food waste at the University of Leeds—maximising opportunities. Earth Environ 7:201–231

21. Ezeah C, Fazakerley JA, Roberts CL, Cigari MI, Ahmadu MD (2015) Characterisation and compositional analyses of institutional waste in the United Kingdom: A case study of the university of wolverhampton. J Multidiscip Eng Sci Technol (JMEST) 2(7).

22. Taghizadeh S, Ghassemzadeh HF, Vahed MM, Fellegari R (2012) Solid waste characterization and management within university campuses case study: University of Tabriz. Elixir Pollut 43:6650–6654

23. Smyth DP, Fredeen AL, Booth AL (2010) Reducing solid waste in higher education: the first step towards 'greening' a university campus. Resour Conserv Recycl 54:1007–1016

24. Adeniran AE, Nubi AT, Adelopo AO (2017) Solid waste generation and characterization in the University of Lagos for a sustainable waste management. Waste Manage 67:3–10

25. Tiew KC, Kruppa S, Basri NEA, Basri H (2010) Municipal solid waste composition study at Universiti Kebangsaan Malaysia Campus. Aust J Basic Appl Sci 4(12):6380–6389

26. Kim HY (2014) Analysis of variance (ANOVA) comparing means of more than two groups. Restor Dent Endod 39(1):74–77

27. Reinard JC (2006) Communication research statistics. In: Language Arts and Discipline, Pages 1–600

28. Dada AC (2011) Packaged water: optimizing local processes for sustainable water delivery in developing nations. Global Health 7:24

29. Miner CA, Tagurum YO, Hassan Z, Afolaranmi TO, Bello DA, Dakhin A, Zoakah AI (2015) Sachet water: prevalence of use, perception and quality in a community of Jos South Local Government Area of Plateau State. Jos J Med 8(3):33–40

30. Mihai FC (2012) Geography of waste as a new approach in waste management study. Pap Dimit Cante Geograph Semin 33:39–46

31. Armijo de Vega C, Ojeda-Benitez S, Ramirez-Barreto E (2008) Solid waste characterization and recycling potential for a university campus. Waste Manage 28:521–526

32. Baldwin E, Dripps W (2012) Spatial characterization and analysis of the campus residential waste stream at a small private Liberal Arts Institution. Resour Conserv Recycl 65:107–115

33. Colombijn F, Morbidini M (2017) Pros and cons of the formation of waste-pickers' cooperatives: a comparison between Brazil and Indonesia. Decision 44:91–101

34. Tangwanichagapong S, Nitivattananon V, Mohanty B, Visvanathan C (2017) Greening of a campus through waste management initiatives: experience from a higher education institution in Thailand. Int J Sustain Higher Educ 18(2):203–217

35. Thomas GO, Poortinga W, Sautkina E (2016) The welsh single-use carrier bag charge and behavioural spillover. J Environ Psychol 47:126–135

36. Poortinga W, Sautkina E, Thomas GO, Wolstenholme E (2016) The English plastic bag charge: changes in attitudes and behaviour. Cardiff Welsh School Arch School Psychol Cardiff Univ 1(1):1–44

37. Lin L, Xu F, Ge X, Li Y (2018) Improving the sustainability of organic waste management practices in the food-energy-water nexus: a comparative review of anaerobic digestion and composting. Renew Sustain Energy Rev 89:151–167

38. Braber K (1995) Anaerobic digestion of municipal solid waste: a modern waste disposal option on the verge of breakthrough. Biomass Bioenergy 9(1–5):365–376

39. Jara-Samaniego J, Pérez-Murcia MD, Bustamante MA (2017) Development of organic fertilizers from food market waste and urban gardening by composting. Ecuador PLoS One 12:7

40. Mu D, Horowitz N, Casey M, Jones K (2016) Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the US. Waste Manage 59:476–486

41. Kawai K, Liu C, Gamaralalage PJD (2020) Composting. In: CCET guideline series on intermediate municipal solid waste treatment technologies

42. Banister D, Anderton K, Bonilla D, Givoni M, Schwanen T (2011) Transportation and the Environment. Annu Rev Environ Resour 36:247–270

43. Zhang C, Xu T, Feng H, Chen S (2019) Greenhouse gas emissions from landfills: a review and bibliometric analysis. Sustain 11:2282

44. Chalkias C, Lasaridi K (2009) A GIS-based model for the optimization of municipal solid waste collection: the case study of Nikea, Athens, Greece. WSEAS Trans Environ Dev 5:10

45. O'Connor DL (2013) Solid waste collection vehicle route optimization for the city of Redlands, California. Master's thesis, University of Redlands. Retrieved from http://inspire.redlands.edu/gis_gradproj/201. [Accessed on 15/11/2017].

46. Kallel A, Mohamed MS, Moncef Z (2016) Using GIS-based tools for the optimization of solid waste collection and transport: case study of Sfax City, Tunisia. J Eng 20:1–7

47. Malakahmad A, Bakri P, Mokhtar M, Khalil N (2014) Solid waste collection routes optimization via GIS techniques in Ipoh City, Malaysia. Proc Eng 77:20–27

48. Desa A, Abd Kadir N, Yusooff F (2012) Environmental awareness and education: a key approach to solid waste management (SWM). A Case Study Univ Malaysia. https://doi.org/10.5772/48169. ([**Accessed23/02/2019**])

49. Prestina A, Pearce KE (2010) We care a lot: formative research for a social marketing campaign to promote school-based recycling. Resour Conserv Recycl 54:1017–1026

50. Mamady K (2016) Factors influencing attitude, safety behaviour, and knowledge regarding household waste management in guinea: a cross-sectional study. J Environ Public Health. https://doi.org/10.1155/2016/9305768

51. Yusuf R, Fajri I (2022) Differences in behavior, engagement and environmental knowledge on waste management for science and social students through the campus program. Heliyon. https://doi.org/10.1016/j.heliyon.2022.e08912

52. Schanes K, Dobernig K, Gözet B (2018) Food waste matters—a systematic review of household food waste practices and their policy implications. J Clean Prod 182:978–991