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ORIGINAL ARTICLE

# Solid waste characterization and its recycling potential: Akure municipal dumpsite, Southwestern, Nigeria

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**Abstract**

This study was undertaken to characterize and determine the recycling potential of municipal solid waste brought to a centralized facility in Akure, Nigeria. The facility serves a population of over 350,000 people. For a year, waste brought to the municipal solid waste facility from three sources namely market, residential and curbsides were characterized and quantified monthly. Physical and chemical characteristics of the waste were determined using standard methods. Data obtained were analyzed using statistical analysis. The results showed that an average of 0.17 ton of waste is transported to the dumpsite from the three major sources every day. There were statistically significant differences in all the types of waste except paper brought from the three sources. The wastes transported from the three sources in the city to the dumpsite were mainly composed of paper at 17.3%, nylon at 26.6%, organic waste at 25% and sand at 18.9%. These obtained values were compared with waste generated in the same area from studies in the literature. The chemical conditions of the organic waste showed that it could be used for efficient composting. The usage of the recycling plant was not effectively maximized, despite the high (96%) recyclable potentials of the waste.

**Keywords** Akure dumpsite · Manual sorting · Recycling potential · Solid waste management · Waste characterization

## Introduction

The objectives of solid waste management in an area are to advance the environmental quality, safeguard its health, strengthen its technical and economic efficiency. However, achieving these objectives had become a difficulty confronting environmental protection agencies in Nigeria. Apart from the low level of public education on solid waste management [1], another barrier to achieving the objectives of solid waste management is the continual increase in the quantity of solid waste generated which is more than the capacity of the agencies. Population increase, swift urbanization and economic boom are some of the factors that result in the swift increase of solid waste in developing countries [2, 3]. These wastes are best disposed of by depositing them in open dumps with no environmental controls. This anthropogenic activity engenders gas emissions and leaching that affect the environment [4, 5]. Management of solid waste is normally seen as the main resolution making issue with respect to sustainable development in all local communities [6–8]. Hence for an effective solid waste management, the first and most significant stage is determining the composition and characterization of the wastes [9].

Procedures for solid waste characterization have been actualized for different applications. A common application is in determining the waste recycling potential [10–13], these include its potential for methane generation [14] and landfill mining [15]. It is used as organic fertilizer [16], animal foodstuffs [17] and other economically valuable materials [18]. Other applications of waste characterization are to determine its biodegradability [19], for a geotechnical purpose [20] and eventually for waste management plan [21–24]. Based on these applications, the type of information needed for a particular process differs. Although solid waste generation and characterization could be forecasted through prognostic tools and regression analysis [25], direct measurements for countries with developing economies is suggested due to the non-availability of data [26].

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Various waste characterization and quantification studies have been carried out in Nigeria. Among these studies are those in Abia State [27], Akwa Ibom State [28], Anambra State [29], Benue State [30], Delta State [31], Edo State [32], Lagos State [33], Nasarawa State [34], Ogun State [35], Oyo State [36, 37], Kano State [38], and Rivers State [39, 40]. To reduce the effect of the enormous waste generated in Ondo State, Nigeria and also benefit from its recycling potentials, the State Government in 2006 established an integrated solid waste recycling plant managed by the Ondo State Management Board [41]. This study is aimed at the physical and chemical characterization of the solid wastes dumped at the solid waste management facility of the State. The recycling potentials (which is the possibility of transforming waste materials into new and usable ones) are also determined. As a substitute to landfilling or open dump, recycling helps reduce greenhouse gas emissions. Unlike studies from other states in Nigeria [27–40] where waste characterization was done at the point of its generation/collection, characterization of wastes in this study was conducted at the point of disposal on the dumpsite. The data obtained from this study will decrease the expenses involved in the advancement of solid waste management in the State and also assist in developing regulations that will make the State achieve sustainable development goals.

## Materials and methods

### Study area

The city of Akure, the capital of Ondo State, Nigeria, Africa is located in Latitude 7°15′0″ North and Longitude 5°11′42″ East as shown in Fig. 1. The population of the city was over 350,000 people as of 2008 [42]. The Akure Integrated Recycling Plant was commissioned by erstwhile Nigeria's President, Chief Olusegun Obasanjo on 14 June 2006 and began operations on the 1 December 2006. The design capacity of the plant for an 8 h daily production is 5 tons/day for organic fertilizer and 0.5 tons/day for plastic recycling. The plant consists of three units namely: (1) material recovery/quality control unit; (2) material processing; (3) production unit and marketing unit. The initial size of the facility is 7 ha. 6 ha of land is used as the dumpsite while the remaining 1 ha is used for the recycling plant. Presently, the dumpsite had covered more than 6 ha with a need for its rehabilitation [43]. A

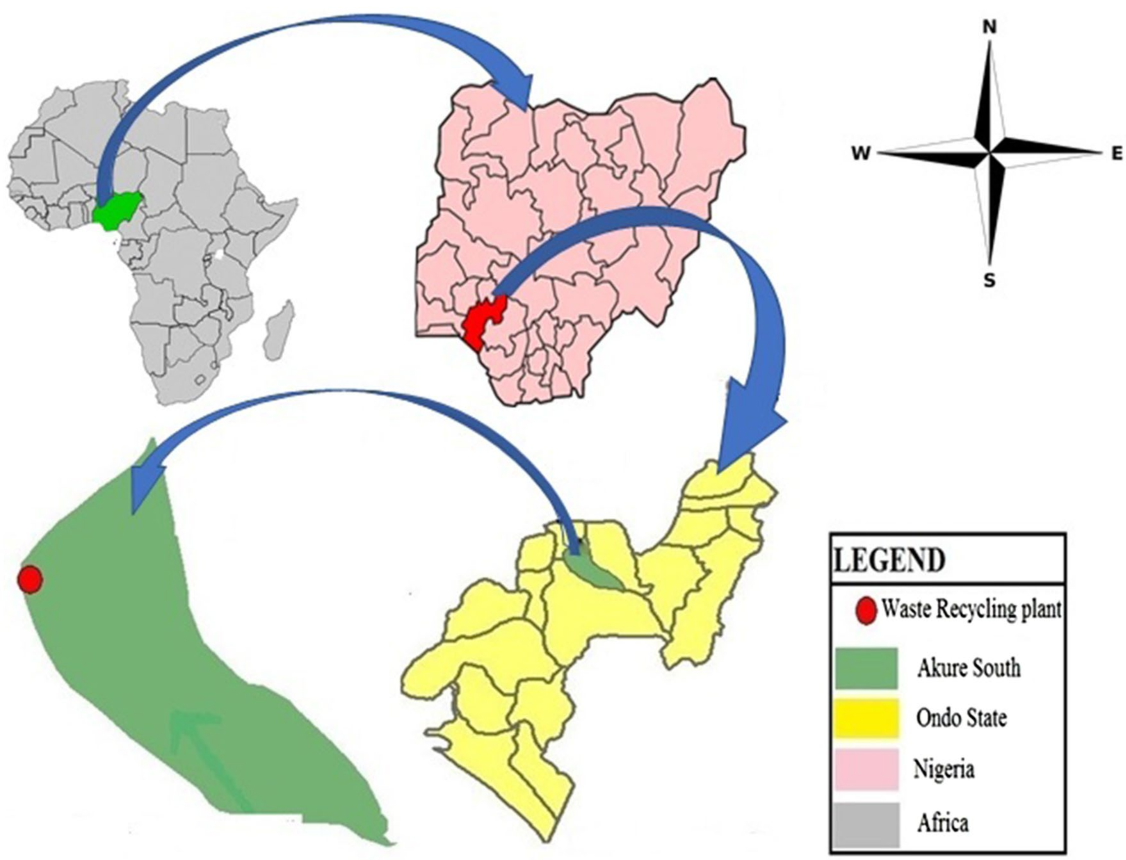


**Fig. 1** Map showing the location of the study area and the waste recycling plant

layout map showing the various sections of the integrated recycling plant is shown in Fig. 2.

## Sample collection and segregation

The solid wastes brought to the dumpsite were collected for a period of 12 months. The collected wastes were sampled from three different sources of generation:

(a) Market: wastes originating mainly from the markets where goods are being sold.
(b) Residential: wastes emanating from 21 zones of residential areas in the city.
(c) Curbsides (non-specific wastes): wastes that are generated from offices and its environ.

Segregation was done once a month by picking a waste collection truck coming out of the three sources described above for each month. Figure 3a shows the waste from a market waste collection truck segregated into cartons and paper in Fig. 3b and into nylon and plastics in Fig. 3c. The workers were encouraged to segregate the wastes centrally and the various components of the solid wastes weighed. The mass and density of the sorted wastes were obtained by placing the wastes in a 0.5 $m^3$ container and using a 20 kg capacity Camry kitchen weighing scale. The recycling

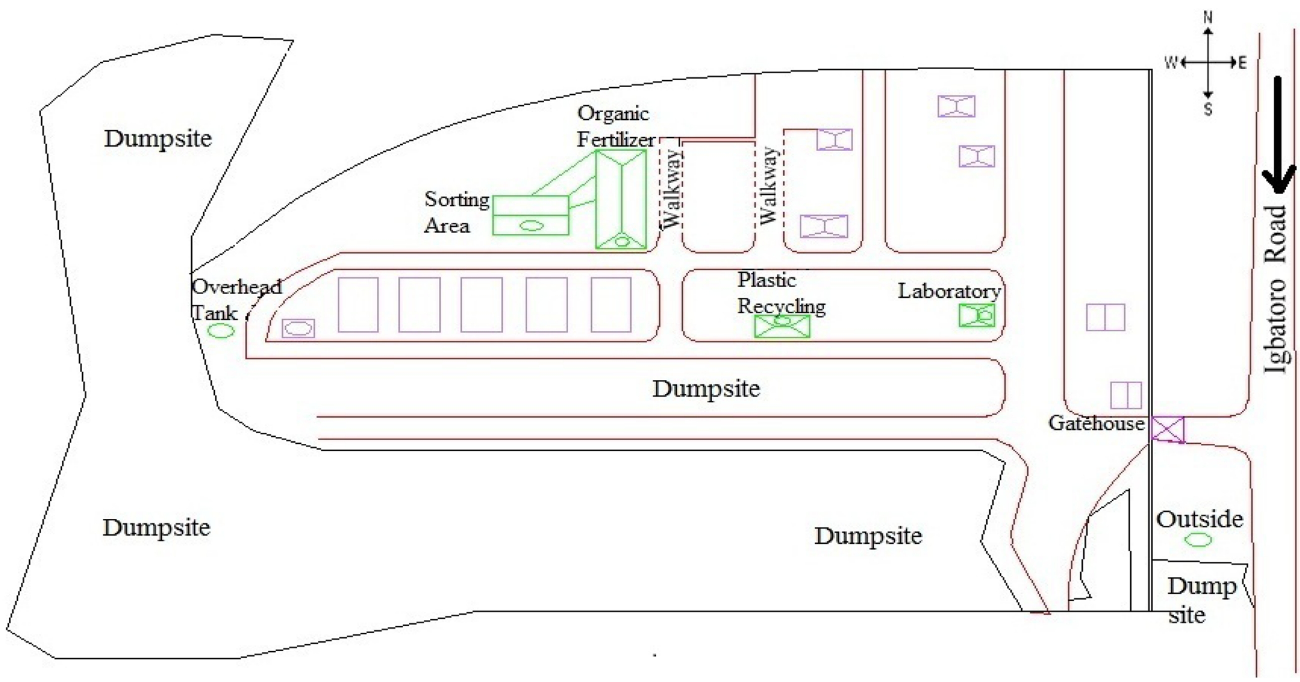


**Fig. 2** Layout map of the state waste recycling plant showing the dumpsite and the recycling plant


**Fig. 3** Wastes **a** from the market, **b** segregated into cartons and paper, **c** segregated into nylon and plastics

potential for the segregated wastes was determined using Table 1 modified from previous studies [11, 44].

### Physicochemical analysis of organic waste

The physical parameters of the solid waste samples that were analyzed include the moisture content, pH and density. The moisture content (which is the percentage of the sample weight lost during drying) of the waste was determined by weighing an empty moisture can ($W_0$). About 200 g of the grab samples in triplicates was added to the moisture can and weighed ($W_1$). The moisture cans and samples were then dried in the oven for 24 h and thereafter cooled in a desiccator. The cans with the dry samples were finally weighed ($W_2$) and the moisture content calculated from Eq. 1 is the difference in recorded weights [45].

$$\text{Moisture content} = \frac{(W_1 - W_2)}{(W_1 - W_0)} \times 100\%. \quad (1)$$

The Dwyer model WPH1 waterproof pH meter calibrated with standard buffer 7.0 and 4.0 using the Electrometric pH determinations method [46] was used in determining the pH of the waste suspension. The chemical parameters analyzed were nitrogen, phosphorus, and carbon percentages in the waste and they were determined using the standard methods for the examination of water and wastewater [47]. The data gotten were analyzed using analysis of variance (ANOVA) at 5% level of significance.

**Table 1** Recycling potential for waste sub-categories

| Waste sub-categories | Recycling potential | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Paper and cardboard | | | |
| Colored bond paper, newspaper, magazines, cardboard | × | | |
| Plastics | | | |
| PET and HDPE container | × | | |
| Recyclable resins and plastic bags (nylon) | | × | |
| Organic | | | |
| Food waste, leaves and grass, tree branches | | × | |
| Organic, various types | | | × |
| Textile | | | |
| Clothes and other textile materials | | | × |
| Metal | | | |
| Aluminum, tin, metal, various types | × | | |
| Glass | | | |
| Glass green, amber and clear | × | | |
| Other | | × | |
| Construction/demolition | | | |
| Gravel, rocks, wood and other | | × | × |

*1* waste for which there exists a recycling market, *2* recyclable waste for which there does not exist a local market, *3* non-recyclable waste

## Results and discussion

### Characterization of solid wastes

The result of the segregation of the solid wastes brought from the three sources showed that the type of waste transported to the dumpsite include paper/carton, nylon, organic wastes, leaves and garden trimmings, plastic, textiles, wood, metal, can/tins, sand, ash and bottles, tyre and bones. The percentage composition by mass of these characterized wastes is presented in Table 2. The average mass and standard deviation of the waste from the three sources per month is shown in Fig. 4.

From the results in Table 2, the most transported waste from the market were organic wastes at 30.2%, this could be attributed to the type of commodities being sold and consumed in the market. For the residential area, the most transported waste was nylon at 27.1% which was closely followed by organic waste at 25.4%. The curbsides had sand at 30.1% to be the most transported waste to the dumpsite. The combination of waste from the three sources on the dumpsite in Table 2 and the specific mass of this waste shown in Fig. 4 revealed that paper, nylon, organic waste and sand were the main types of waste transported from the city (Akure) to the dumpsite. Average monthly mass of paper, nylon, organic waste and sand was 814 kg, 1260 kg, 1180 kg and 888 kg respectively. The average monthly mass of the total solid waste disposed on the dumpsite is 4711.9 kg (5.2 ton). The average amount of solid waste brought to the dumpsite is about 157 kg per day (0.17 ton/day), which is less than the design capacity of the recycling plant for organic waste. The *P* value which indicates an evidence against the null hypothesis was also determined and presented in Table 3. The *P* values showed that there was no statistically significant difference in the quantities of paper brought to the dumpsite from the three waste sources, there was a significant difference in quantities of the other types of wastes. The recycling potential of the characterized wastes was also evaluated as shown in Fig. 5. 20% were recyclables (with existing recycling market), 76% were potentially recyclables (with no existing recycling local market) and 4% were non-recyclable. From the current recycling potential, the recycling plant is adequate in its operational capacity for wastes disposed on the dumpsite. Although separation/sorting of recyclable wastes is done on the dumpsite. Separation at the point of generation will be difficult due to the waste generation culture of the populace, improper planning of waste generation

**Table 2** Percentage composition of characterized recyclable solid waste

| Waste type | Market (%) | Residential (%) | Curbsides (%) | Total dump-site wastes (%) |
|---|---|---|---|---|
| Paper | 15.8 | 17.3 | 17.9 | 17.3[1] |
| Nylon | 28.6 | 27.1 | 22.7 | 26.6[2] |
| Organic wastes | 30.2 | 25.4 | 17.7 | 25.0[2] |
| Leaves | 3.5 | 2.8 | 1.9 | 2.8[2] |
| Plastics | 1.7 | 1.6 | 1.5 | 1.6[1] |
| Textiles | 3.4 | 5.4 | 1.9 | 3.6[3] |
| Wood | 0.9 | 0.9 | 0.8 | 0.9[2] |
| Metals | 0.2 | 0.1 | 0.0 | 0.1[1] |
| Cans/tins | 0.0 | 0.3 | 0.6 | 0.3[1] |
| Sand | 10.3 | 17.4 | 30.2 | 18.9[2] |
| Ash | 2.8 | 0.8 | 2.8 | 1.9[2] |
| Bottles | 2.1 | 0.5 | 1.5 | 0.8[1] |
| Tyre | 0.0 | 0.4 | 0.0 | 0.1[2] |
| Bones | 0.5 | 0.0 | 0.5 | 0.1[2] |
| Total | 100.0 | 100.0 | 100.0 | 100.0 |

Superscript numbers denote recycling potential.

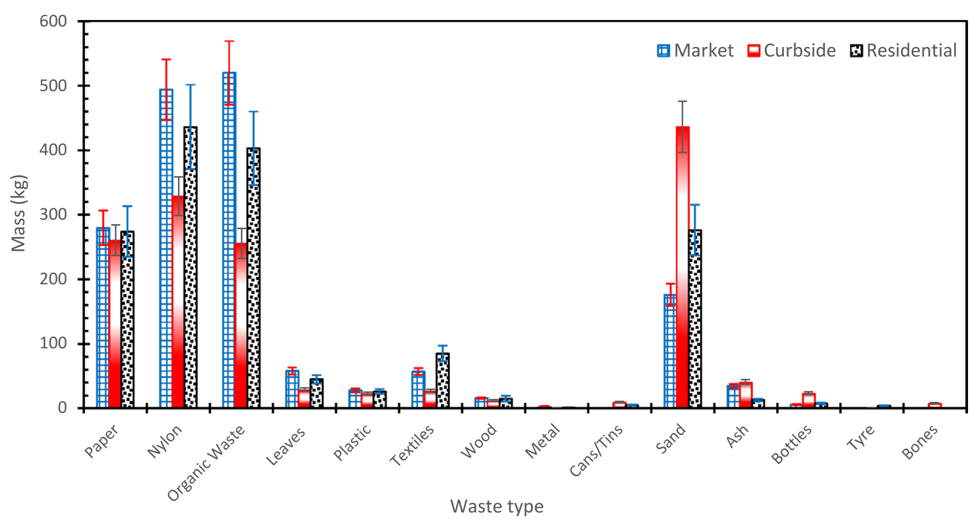


**Fig. 4** Average monthly mass of characterized wastes from the three sources

sources and non-institutionalization of waste management activities in the study area.

The potentially recyclables were also separated like the recyclables and stored for possible future demand.

## Physicochemical properties of the organic waste sample

The result of the average monthly value of the physicochemical properties of the organic waste is presented in Table 4. The density ranges from 229.3 to 248.5 kg/m$^3$ with a significant difference in the values, the residential areas had the highest. The moisture content ranges from 64.1 to 72.5% with no significant difference in the values, the residential areas had the highest. The pH ranges from 4.8 to 5.1, an indication of a slightly acidic waste, with no significant difference in the values. The chemical properties of the organic waste showed that the percentage carbon of the waste was the highest followed by the percentage of nitrogen and phosphorus. There was no statistically significant difference in the values for the three sources.

## Comparison of solid wastes composition

The knowledge of wastes composition permits for prescribing strategies in separating and collecting wastes for recycling. The results of this study had made known: (1) the volume of waste brought to the Akure dumpsite; (2) the high

**Table 3** The *P* value for an average monthly mass of characterized wastes from the three sources

| Waste type | *P* value (< 0.05) |
|---|---|
| Paper | 0.65 |
| Nylon | 0 |
| Organic Waste | 0 |
| Leaves | 0 |
| Plastic | 0.03 |
| Textiles | 0 |
| Wood | 0.05 |
| Metal | 0 |
| Cans/Tins | 0 |
| Sand | 0 |
| Ash | 0 |
| Bottles | 0 |
| Tyre | 0 |
| Bones | 0 |

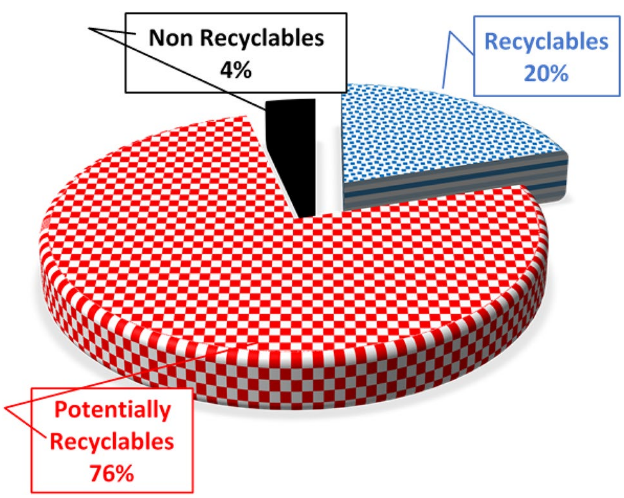


**Fig. 5** Percentage of waste (by mass) according to the recycling potential

recycling potential of the waste; and (3) the potential (usage) of the recycling plant could be effectively maximized. Figure 6 shows the composition of solid waste generated in Akure from various studies [16, 48, 49] compared to the one brought to the dumpsite in the present study. The pattern of waste flow in this study is such that after waste generation, some of these wastes (those not disposed indiscriminately) are collected in dustbins which maybe scavenged or recycled indirectly. The remaining wastes are afterwards transported to the dumpsite by the waste disposal agents. It is at this point that the waste characterization was carried out in this study.

From the composition of solid wastes generated in the city of Akure in 2005, 2014 and 2015 compared to the ones brought to the dumpsite in Fig. 6, it could be observed that apart from sand, plastic and nylon wastes, all other forms of wastes that actually arrive at the dumping site were very much lower than the ones reported in the previous studies. The reduction may be attributed to the fact that there are a lot of informal recycling activities and indiscriminate waste disposal going on in Akure. Also, the wastes characterized in the studies [16, 48, 49] were done at the point of generation/collection unlike the characterization in this study that was done at the point of disposal/dumping. However, the increment in the sand and soil-like waste may be attached to the amount of waste from the curbsides brought to the dumpsite. For the plastic and nylon, the increase could be due to the high usages of plastic and nylon in present times compared to the periods where these previous studies were undertaken.

### Chemical conditions of organic wastes for efficient composting

Composting is the aerobic decomposition of organic waste under controlled conditions by microorganisms into a soil-like material called compost. The controlled conditions in the organic waste include an adequate supply of oxygen; a level of carbon to nitrogen ratio; appreciable moisture content; good temperature and pH levels. The chemical conditions of organic wastes segregated in this study alongside the recommended chemical controlled conditions needed for efficient composting [50] are presented in Table 5.

The chemical conditions of the segregated organic waste from the three different sources on the dumpsite in Table 5 showed that not all the recommended values for efficient composting were met. For the carbon to nitrogen ratio, only organic waste from curbsides met the recommended values. The carbon to nitrogen ratio in the organic waste from the market and residential sources will increase with the addition of wastes (e.g. straw) that are rich in carbon and the carbon is in a form that can easily decompose. For the moisture content, only organic waste from the market met the recommended values. The moisture content of organic wastes from other sources (residential and curbsides) will reduce by little drying of the waste, although this may not be necessary as moisture content tends to decrease as composting increases. The pH values of the organic wastes (from the three sources) will increase with an addition of small quantity of lime, ashes or any other alkaline additive thoroughly mixed with the waste.

## Conclusions

The study investigated the characterization (which in turn determined the recycling potential) and the physicochemical properties of wastes brought to the Akure dumpsite (which

**Table 4** Physicochemical properties of organic waste from the three sources

| Parameter | Waste source | Average | Standard deviation | *P* value (<0.05) |
|---|---|---|---|---|
| Nitrogen (%) | Market | 3.4 | 0.7 | 0.15 |
| | Curbsides | 2.1 | 0.8 | |
| | Residential | 2.7 | 0.6 | |
| Phosphorus (%) | Market | 0.08 | 0.04 | 0.58 |
| | Curbsides | 0.13 | 0.14 | |
| | Residential | 0.05 | 0.03 | |
| Carbon (%) | Market | 52.08 | 1.5 | 0.99 |
| | Curbsides | 52.07 | 1.8 | |
| | Residential | 52.24 | 1.4 | |
| pH | Market | 4.8 | 0.5 | 0.88 |
| | Curbsides | 5.1 | 1.0 | |
| | Residential | 4.9 | 0.6 | |
| Moisture content (%) | Market | 64.1 | 0.9 | 0.50 |
| | Curbsides | 71.7 | 5.9 | |
| | Residential | 72.5 | 1.6 | |
| Density (kg/m$^3$) | Market | 229.3 | 13.8 | 0.00 |
| | Curbsides | 247.1 | 5.9 | |
| | Residential | 248.5 | 4.9 | |

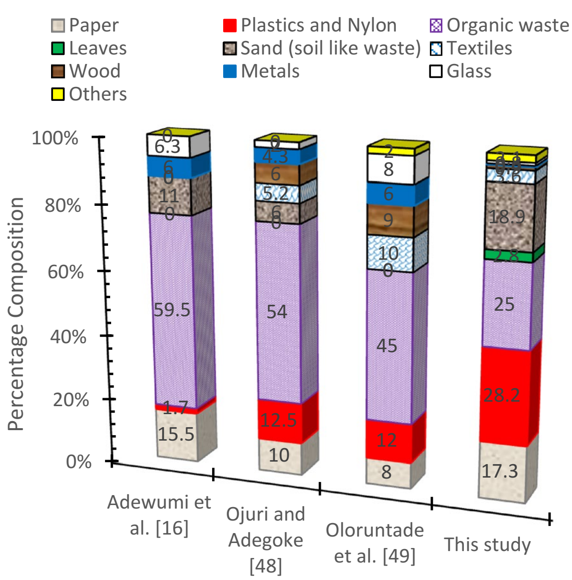


**Fig. 6** Comparison of solid waste composition in Akure

contains a recycling plant). About 814 kg, 1260 kg, 1180 kg and 888 kg of paper, nylon, organic waste and sand, respectively, were the main wastes disposed at a monthly average on the dumpsite. An average monthly mass of 4711.9 kg (5.2 ton) solid waste was disposed on the dumpsite. The average amount of waste was calculated as 0.17 ton per day, providing a good source of raw material for the establishment of a recycling plant. About 95% of the wastes transported to the dumpsite were recyclable/potentially recyclable. The chemical properties of the wastes (organic waste) showed that with little or no alterations, the controlled conditions required for composting were met. The usage of the recycling plant can be effectively maximized by transporting more of the generated organic waste in the city to the dumpsite. Regulations against indiscriminate waste disposal and informal recycling activities should be made by the government.

**Table 5** Chemical conditions of organic waste required for composting

| Parameter | Market | Residential | Curbsides | Recommended value | References |
|---|---|---|---|---|---|
| Carbon to Nitrogen ratio | 15.3:1 | 19.4:1 | 24.8:1 | 20:1–40:1 | Rynk et al. [50] |
| Moisture content (%) | 64.1 | 72.5 | 71.7 | 40–65 | Rynk et al. [50] |
| pH | 4.8 | 4.9 | 5.1 | 5.5–9.0 | Rynk et al. [50] |

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