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REGIONAL CASE STUDY

Investigating municipal solid waste generation and management in Ilorin for possible integrated waste-management system

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Abstract

The municipal solid waste generated in Ilorin is so enormous that the management method available cannot sufficiently cater for it. This is evident by the uncollected piles of MSW on the streets and the illegal disposal of wastes into water ways and undesignated sites. This study establishes the aggregate MSW produced in Ilorin and classifies it into categories, for an integrated management system. The aggregate MSW was established, using facts and figures obtained from collection processes without weighbridges. Sixty (60) samples of 240 L bin volume of MSW each, were sorted and characterized for the investigation. About 477,954 tons/year of MSW was estimated at the rate of 1.3 kg/capita/day. The population accountable for the waste generation, was estimated to be 1,154,883 people. About 3280 kg of MSW was characterized to give 50% recyclable, 39% compostable and 11% combustible categories correspondingly, without any component occurring twice. This implies, if recycling, composting, and incineration are integrated into waste-management system in Ilorin, the environmental pollution and land degradation consequences of inefficient and unscientific waste disposal would be ameliorated; thereby making the wastes to contribute to economic valuables than being a nuisance.

Graphic abstract

Extended author information available on the last page of the article

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Keywords Municipal solid waste · Recycling · Composting · Incineration · Integrated waste management

Introduction

The municipal solid waste (MSW) generated in Ilorin metropolis is so enormous that the available method of management cannot sufficiently cater for it. This is apparently evident by the uncollected piles of MSW on the streets and the indiscriminate disposal of wastes by people to the water ways. This study aims at establishing the aggregate of MSW generated and the categories of the components in the MSW streams, to be able to suggest other management methods that can be integrated into the existing system. The aggregate MSW generated was determined using the facts and figures obtained from collection processes without the use of weighbridges. Sixty (60) MSW samples of 240 L each, were sorted and characterized for the investigation. About 477,954 tons/year of MSW was estimated as the waste generated during this study, at the rate of 1.3 kg/capita/day. The population predicted as being responsible for the generation of the waste is 1,154,883 people. About 3280 kg of MSW fractions was characterized to give 50% recyclable, 39% compostable and 11% combustible fractions correspondingly, without any component being repeated in the categories. This implies, if recycling, composting, and incineration methods are integrated into Ilorin waste-management system, the environmental pollution and land degradation that would have resulted from inefficient and unscientific waste disposal method, would have been prevented; thereby making the wastes to constitute economic valuables other than nuisance.

There is a perception throughout the globe, that the consequential effect of municipal solid waste (MSW) on surface water, air, land and human health is growing on daily basis. The challenges, expenses and synergy required in an effective and sufficient waste-management methods, indicate there is a need for the involvement of multi-sectoral stakeholders at each phase of the MSW management procedures. Municipal solid waste management (MSWM) is a public service that is very complex and expensive to operate because of the technicalities involved. In most of the developing nations, up to 20 or 50% of the money budgeted by government for the running of municipalities is expended on MSWM and about 80–90% of the waste-management budget is spent on waste collection [1, 2]. UN-HABITAT and UNEP [2, 3] reported that MSW collection services, can only cover about 40–70% of the aggregate waste produced by ≤ 50% populace in the urban centers. Ogunjuyigbe [4], established that only about 74% of the MSW generated in the developing nations, are collected for disposal. Nevertheless, due to continuous growth in population, the quest for economic development and urbanization; waste generation increases, and the challenges associated with actualization of effective and efficient waste-management system is enormous.

There are notable problems associated with collection and disposal of MSW, in the waste-management systems of many nations of Africa [5, 6]. The insufficiency/ineffectiveness of the waste-management system of African nations, exposes the populace to environmental and health hazards, that are consequential effects of uncontrolled and uncollected wastes [7]. In Ilorin, the inadequacies of waste-management system, has encouraged unethical and indiscriminate disposal of wastes; into water ways, roadsides, undeveloped sites, and other undesignated places [8]. Olorunfemi and Odita [9] reported that MSWM system in Ilorin metropolis was inefficient because, of inconsistent policies on the part of the government, daily rise in demographic growth and absence of adequate and reliable waste data. UNEP [2], stated that waste aggregate reduction, recovery and reuse is achievable by adopting integrated municipal solid waste-management system (IMSWMs) approach. IMSWMs will promote recovery of beneficial materials, material recycling and energy production. Ashok [10], defines IMSWM as the waste-management system that embraces and applies the appropriate methods, technologies, and management procedures, to accomplish the set objectives and desire for a sufficient municipal solid waste management (MSWM).

Despite the recent development in different methods of waste-management system in the developed nations, like US [11], France, Germany, and UK [7]; to encourage waste reduction, recycling, and waste to energy; countries like Nigeria still engage in the traditional method of disposing the wastes generated, into dumpsites and landfills. North America and Europe have adopted waste-management method of composting food and other organic wastes. In New York City, the Sanitation Department collects > 10,000,000 kg of trash every day, and 1,700,000 kg of recyclable materials. Food residue/scraps and other organic wastes generated in New York city, are collected by a special pilot-program assigned to collect the garbage produced, for an ecofriendly compost making. In 2011, twenty-seven (27) states of European Union (EU) composted about 15% of the MSW generated. France, Germany and Spain composted about 18% of MSW generated, Netherlands composted 28% and Austria 34% [12].

Klinghoffer [13], reported that waste-to-energy (WTE) technology, has potentiality of disposing > 140 billion kg of US MSW, which is almost 35% of the requirement for 2030 WTE power generation projection. WTE has the potential of reducing the emission of greenhouse gases (GHGs) by > 140,000 billion kg on annual basis. The WTE industry was expanded, to be able to cover > 2% of US electrical power in 2030. In US there are eighty-seven (87) WTE facilities, which are used to process > 90,000,000 kg of MSW/day to generate 2.3 GW of electricity, to serve more than 2 million homes in US. In 2010 Austria recycled about 70% of its wastes and incinerated about 30% of the MSW generated; Germany recycled about 62% of its wastes and incinerated about 38%; while Belgium recycled 62% and incinerated about 37%. This compares to the recycling of 39% and incineration of 12% in UK [14]. Africa is coming behind other continents of the world, in adopting IMSWM technologies. In Nigeria, ≥ 14 billion kg of combustible MSW fractions are produced annually [15]. Insufficient knowledge in modern WTE technologies, resulted in disposing MSW resources into dumpsites/landfills. If WTE technology is practiced in Nigeria, the MSW produced could generate around 4400 GWh of electricity per annum and it would have ensured a scientific method of waste disposal; incineration of MSW in a controlled environment for WTE will promote clean and green environment [16]. In Lagos state of Nigeria, Waste Management Authority (LAWMA), has embarked on a pilot scheme that could convert fruit/organic wastes to electricity, via a 1500 VA generating plant at Ketu Market, to provide electrical power for the market environ [17]. Ghana has embarked on the construction of a 400,000 W hybrid of WTE power plant, at Atwima Nwabiagya of Ashanti Region; to convert the MSW produced to power [18]. Ethiopia has a WTE power plant that can convert 1,400,000 kg of waste generated per day to power of about 185,000 MW h. in a year [19].

According to Oelofse [20], in 2007, only 61% of the household units in South African (SA) could access kerbside (garbage) collection services. In the same year, the Environmental (Ecological) Department of SA uncovered that, 54% of the waste that would have been conveyed for disposal was uncollected in the districts and the metropolitan. In 2012, CSIR uncovered that only 3.3% of South African populace recycled their domestic waste in 2010 [21]. The survey of 2010 also revealed that, greater than 73% of the urban settlers in South Africa did not have access to recycling facility; around 27% of them experienced some level of recycling and about 3.3% of them have the recyclables of their domestic wastes processed. Another study conducted by CSIR on SA revealed, that about 19 billion kg of MSW was produced in 2011; out of which 25% of the aggregate waste, were recyclables that include paper, glass, plastics, and tins. Nevertheless, not less than 2,000 households were surveyed, and it was observed that they lack access to disposal facilities [22]. In 2018, Akinwale [23] in Sahara Reports revealed that Twenty-six (26) recycling plants located in different cities of Nigeria to process plastic-wastes, were at different level of deterioration to another. In 2011, the subsequent investigation conducted by CSIR, uncovered that around 19 billion kg of MSW was generated in SA, with about 25% recyclables that incorporates paper, glass, plastics and tins [19]. Literatures have revealed that the rate at which developed nations embraced waste materials (as valuable black gold), as resource to be utilized in the production of other materials and energy is very high. The conversion of the MSW materials requires the processes in the IMSWM technology, that encompasses recovery, reuse and recycling of the waste components as shown in Fig. 1 [24]. Studies have uncovered that Nigeria as a nation, still engage in the traditional system of waste disposal into dumpsites and landfills as their major management method; whereby, many developed nations convert MSW as resource for economic development. If a metropolis like Ilorin embraces IMSWMs, it would serve a dual purposes of efficient waste management (due to composting and recycling processes) and energy recovery which are of economic values. Therefore, in this paper the MSW production capacity and rate of generation in Ilorin metropolis, was investigated; also, the available methods of management and eventually establish other methods that could be incorporated to the existing based on the rate of flow of the waste streams. The investigation adopted the random sampling method of the waste fractions as suggested by Abdellah [25] and Titiladunayo [8], the waste samples were collected from Eyenkorin/Lasoju dumpsite along Lagos-Ilorin express way. Ilorin waste-management system was not equipped with weighbridges, therefore the aggregate of waste generated was estimated using the facts and figures obtained from the capacities of the collection vehicles, the collection rate and the numbers of trucks used. The results of the investigation were used to appropriately state the possible waste-management methods that could further be engaged to ensure IMSWMs.

Description of Ilorin metropolis

Ilorin, the Kwara State Capital, has its geographical coordinates situated on latitude 8° 30′ 0″ N, longitude 4° 33′ 00″ E with altitude 290 m; it is located between South Western and middle belt of Nigeria. The map showing the major towns in Ilorin metropolis is presented in Fig. 2a [26]. The municipal zones in the city are Ilorin East, Ilorin South and Ilorin West. These municipals are represented in Fig. 2b–d [27]. The city is situated the North Central Zone of Nigeria, with the population capacity of 777,667 and 908,490 people as reported by the National Population Commission for 2006 and 2011 respectively [28]. Ibikunle [29], also predicted the population of the city to be 1,055,515 and 1,087,660 people for 2016 and 2017 discretely. The population census conducted in Nigeria in the year 2006, presents Ilorin as the seventh largest city in Nigeria by population rating. Ilorin city was selected for this investigation on the account of its recent growth in population, due to rise in birth rate and urban development. Ilorin East consists of 12 discretionary

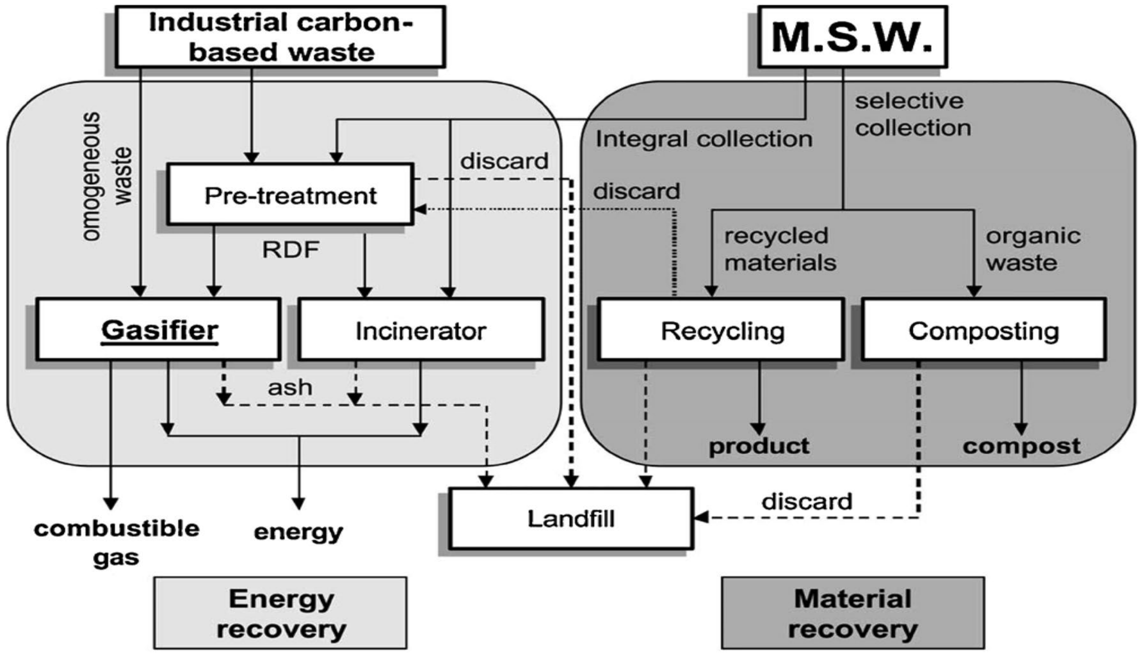


Fig. 1 Integrated municipal solid waste-management system [24]

wards with the land territory of 486 km^2, Ilorin West has 12 political wards and land region of 105 km^2, while Ilorin South comprises 11 appointive wards and land territory of 174 km^2. The map of Ilorin indicating some selected wards is shown in Fig. 2e [27].

The metropolis experiences a high-temperature weather condition at both dry and wet seasons. The wet season is usually the months of March to October of every year, while the dry season commences in November to February of the following year [30]. The average high temperature experienced in the metropolis between 1961 and 1990 is 32.5 °C, the daily mean temperature is 26.2 °C, the average low temperature is 21.2 °C and the average rainfall is 1185 mm [31]. The MSW components produced in Ilorin includes food waste, plastic bottle, paper, packaging box, nylon, plastic, grass/trimmings, wood, leather, bones, rags, toiletries (spent sanitary pads, toilet tissues and pampers), polypropylene-sacks, tins/metals, ceramic/glass, ash/sand, and excrement [32]. There were about ten dumpsites officially designated for waste disposal in Ilorin, but only Lasoju/Eyenkorin dumpsite was in operation during this investigation. The location of the dumpsite is not less than 25 km away from Ilorin, along Lagos–Ilorin express way; with a land area of about 20 acres filled with wastes.

MSW management system in Ilorin

Municipal solid waste-management system encompasses all the processes and policies involved in the organizing, financing, gathering/collection, movement, dumping and treatment of waste fractions for reuse and even energy recovery [29]. The notable techniques in the management of MSW involves, source reduction, disposal at dumpsite/landfill, composting, incineration, and recycling [33]. In Ilorin metropolis, the available MSW management methods embrace, disposal of waste to the dumpsite/undesignated-places, open burning, and recovery of materials for reuse (by scavengers). Composting and energy recovery were not practiced, but few individuals do engage in small scale shredding of plastic materials.

Materials and methods

In this study, the waste materials considered encompasses different waste fractions from households, markets and other commercial centers, institutions and public centers; but industrial wastes and hospital wastes were not included. An exploratory procedure for raw data accusation on MSW production was adopted as recommended by Abdellah [25], to acquire the necessary information needed on the MSW produced/day based on the capacity of collection trucks and the number of trips made by the trucks per day. The required information/data on the private partner contractors engaged, their assigned routes, zones, types, and numbers of trucks utilized; were collected from Kwara State Environmental Protection Agency (KWEPA). The information on population data was also collected from the National Population

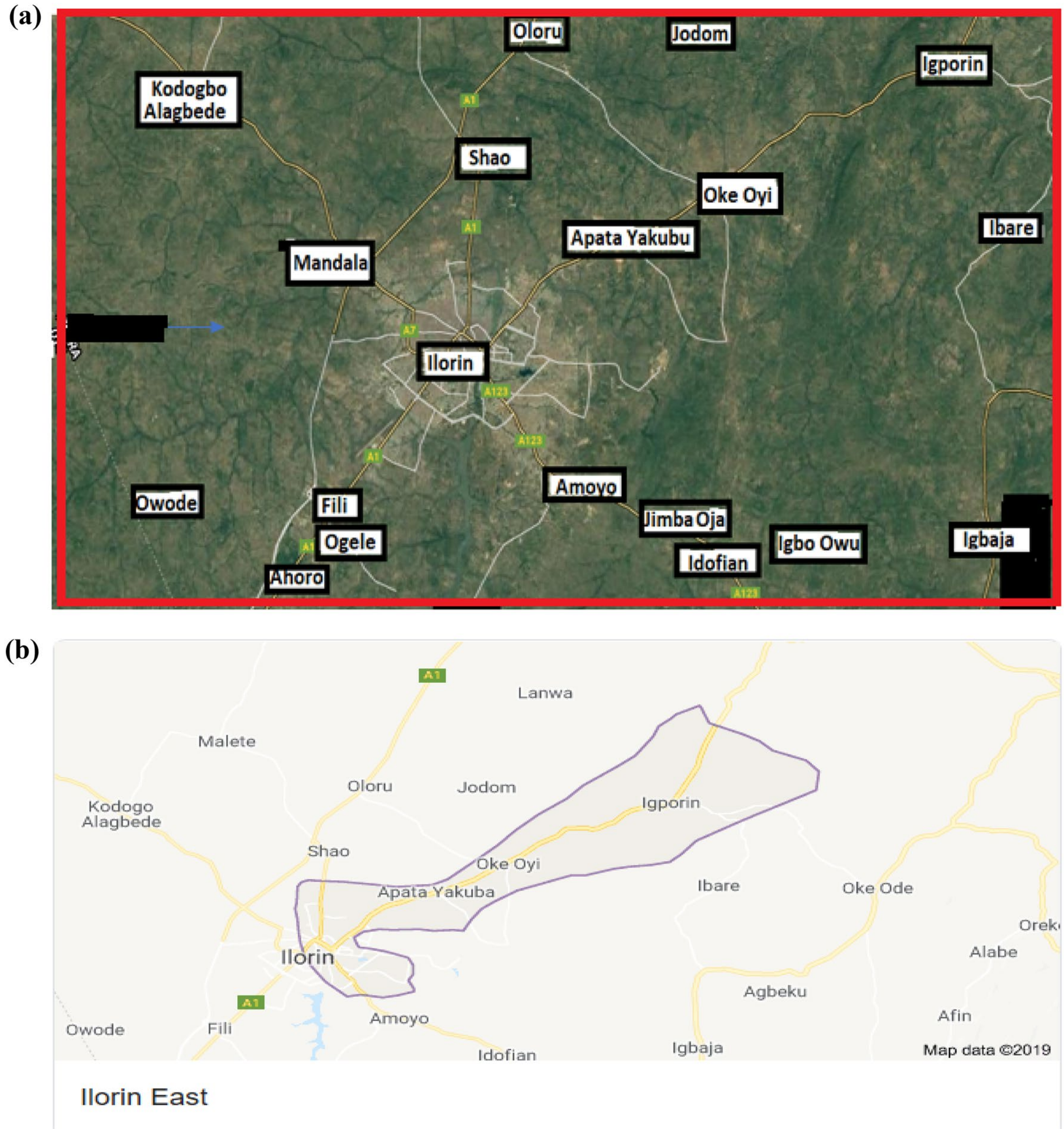


Fig. 2 **a** Map showing the major towns in Ilorin Metropolis (Google Map data [26]). **b** Map showing the towns in Ilorin East (KMLS [27]). **c** Map showing the towns in Ilorin South (KMLS [27]). **d** Map showing the towns in Ilorin West (KMLS [27]). **e** The map showing the political wards in of Ilorin metropolis (KMLS [27])

Commission (NPC) Ilorin office, to predict the population accountable for the waste generation and the generation rate per person per day.

Evaluation of the quantity of MSW generated per annuum

The amount of MSW produced in Ilorin was estimated based on collection facts, which composed of the number of collection trucks utilized, the capacity and the volume loading rate of each truck, the number of trips made by each truck/day. Kosuke and Ibikunle [29, 34], adopted the model presented in Eq. (1), to quantify the aggregated waste collected where weigh bridge was not available.

$$\mathrm{MSW}_{\mathrm{coll.}} = \sum_{j=1}^{365} \sum_{i=1}^{n} \left(C_{\mathrm{T}_i} \times V_{\mathrm{R}_i} \times \rho_i \times t_{n_{ij}}\right) \quad (1)$$

In Eq. (1), $\mathrm{MSW}_{\mathrm{coll.}}$ is the quantity of waste collected, n is the cumulative number of collection trucks, the capacity of truck, i (m^3 /truck) is C_{T_i}, the loading ratio of truck capacity $is V_{\mathrm{R}_i}$, density of waste loaded by truck $i is \rho_i$ (tons

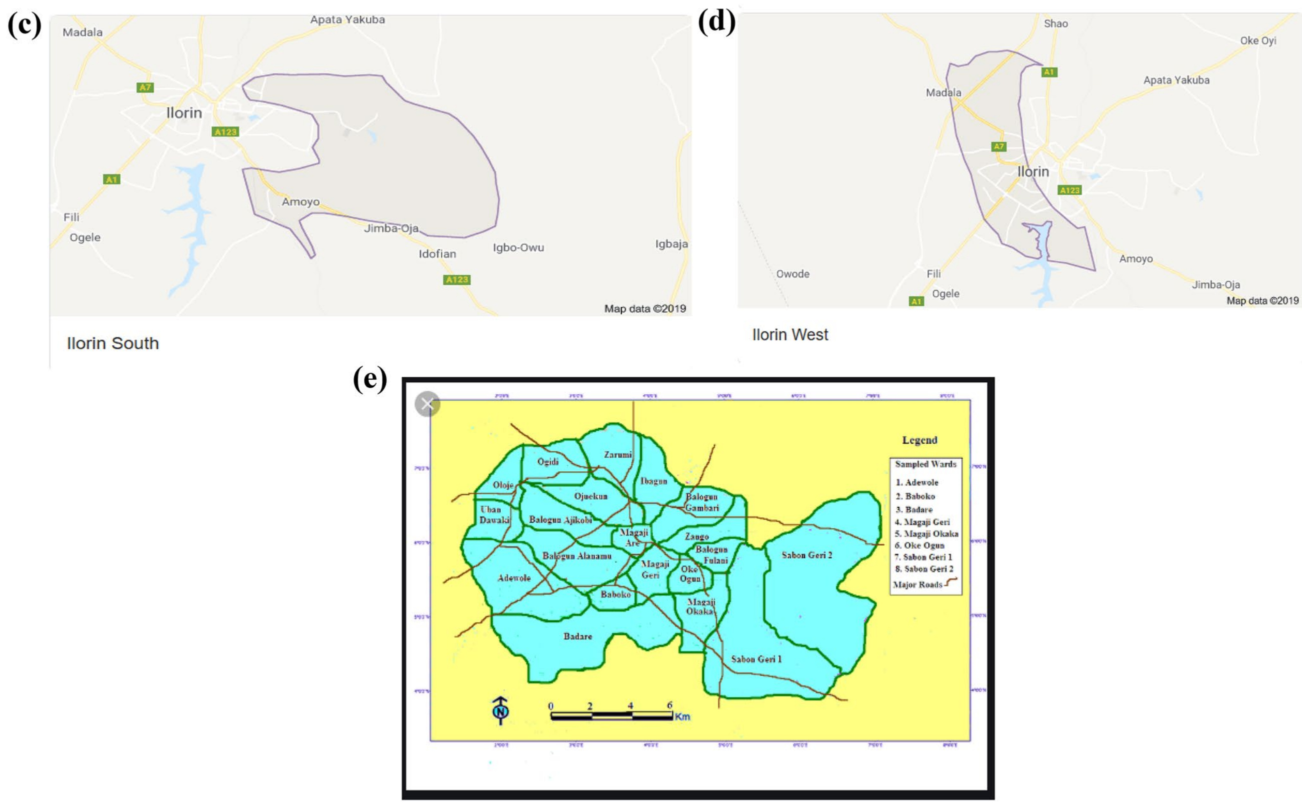


Fig. 2 (continued)

/m^3), and the total trips made by truck i on day j is $t_{n_{ij}}$ (trips/day).

Ogunjuyigbe [4], established that the quantity of waste collected in the developing nations, is just 74% of the total MSW generated. Therefore, the aggregate MSW generated in Ilorin was predicted using Eq. (2).

$$\mathrm{MSW}_{\mathrm{gen.}} = \sum_{j=1}^{365} \sum_{i=1}^{n} (C_{\mathrm{T}_i} \times V_{\mathrm{R}_i} \times \rho_i \times t_{n_{ij}}) \times \frac{100}{74} \tag{2}$$

Prediction of the population accountable for MSW generation in Ilorin

The population census of 2006 presented Ilorin to be 781,934 people which was used for the prediction of 2011 population, by the National Population Commission (NPC) [28]. The population of people responsible for MSW generation in 2016 to 2023, was predicted based on 2006 and 2011 population data from NPC office, using Malthusian model in Eq. (3), as adopted by Ibikunle [30].

$$P_t = P_{(t-1)} \times \mathrm{e}^{(K_p)t} \tag{3}$$

where

$$K_p = \left[\frac{P_{\mathrm{pr}}}{P_p}\right]^{\frac{1}{n}} - 1 \tag{4}$$

In Eq. (3), P_t is the estimated population of the year (t) of concern, $P_{(t-1)}$ is the population prior to the year of concern, K_P is the demographic growth rate/annum. In Eq. (4), p_{p_r} is the current population, while p_p is the former population and n is the number of years involved.

Determination of the MSW generation rate

The MSW rate of generation was estimated by applying Eq. (5), as suggested by Atta [35].

$$G_{\mathrm{R_i}} = 1000 G_{\mathrm{T_i}} / \left(P_i \times 365\right) \tag{5}$$

where G_{T_i} is the aggregate waste generated (tons/annum) in year i, G_{R_i} is the MSW rate of generation (kg/capita/day), P_i is the population in the year i.

Waste storage and collection system

In Ilorin metropolis, the Ministry of Environment and Forestry, Kwara State Environmental Protection Agency (KWEPA) and the Municipal Authority were responsible for MSW management activities of the city. Policies concerning environment and management of wastes are made by the ministry of environment, the policies are to be executed by KWEPA and the Local Government Authorities. The collection and transportation of MSW to the dumpsite was performed by KWEPA and some Private Partner Contractors of waste management. The waste collection system is divided into the social and commercial methods. KWEPA manages the Zones designated for social method of waste collection, while the Private Partner Contractors manage the section designated for commercial method of collection. Social Section of waste collection includes places like the central Oja-Oba (Emir's market), the environment of the Emir's, the traditional zone of the city and the Central mosque environment. The cost incurred on the management of waste in the social section, is a sole responsibility of the State Government. The Private Partner Contractors manage the zone considered for commercial method of waste collection, this area includes the Government Reserved Area (GRA) characterized by the middle-class members of the public, businessmen and other professionals; in this zone, every household is responsible for the financial implication of the wastes collected from their compounds.

In Ilorin, the MSW are stored in mild steel skip bins (otherwise called roro-bin); the roro-bin has a capacity of 8 m^3 (8000 L) and are located at strategic places within the zones designated for social management as indicated in Fig. 3a. Majority of these bins were used to their fullest capacity to the point of having other bales of wastes heaped around the skip container as shown in Fig. 3b. The rest of places in the zones, where roro bins were not provided, the wastes were indiscriminately deposited by roadsides/dividers for collection as shown in Fig. 3c. In the zone designated for commercial practice of waste collection system, MSW were stored in 200 L barrels in some houses, while in others, wastes were stored in skip rolling bins of 240 L before collection for disposal. Roro storage bins were in at least 110 strategic places in the city. MSW are collected in Ilorin by KWEPA, using different collection trucks (of capacities ranging from 15 tons with 8000 L to 30 tons with 22,000 L) that includes Compactor, Hino and Dino Tippers, and Arm Roller Trucks. The Private Partner Contractors use different kinds of collection vehicles with capacities ranging from 10 tons and 8000 L, to 13 tons and 13,000 L. The wastes were collected daily except on Sundays. Nevertheless, survey revealed that many piles of waste were left uncollected for days as shown in Fig. 3b, c.

Disposal of MSW

The ten (10) dumpsites originally approved by the government for Ilorin metropolis includes Airport road site of about 5 ha, Eyenkorin site of about 8 ha, Oko-Olowo site of about 20 ha, Asa-Dam road site of about 10 ha, Stadium-road site of about 10 ha, Ita-Nma site of about 4 ha, Taoheed road site of about 7 ha, and Madi dumpsite of about 5 ha (KWEPA). However, nearly all the designated dumpsites were closed; because some were already filled to their maximum capacity, secondly the people living in the villages that are close to other sites, revolted because they were exposed to different kinds of pollutions and hence prevented further deposition of wastes on the sites. The only officially approved dumpsite that was operational during this survey, was Lasoju Eyenkorin of about 20 acres shown in Fig. 4, located about 25 km away from the city of Ilorin along Lagos–Ilorin express way. Lasoju site being the only functional dumpsite, was filled with heterogenous components of MSW that were outspread and compressed in an unscientific way; the capacity of the site had also been exhausted. However, drainage and other facilities that are required to control seepage were not provided in the site. Heterogeneous MSW fractions (from different households, public places, various institution, market and commercial centers) were discarded together on to the dumpsite. There was no provision for greenhouse gases (GHGs) collection, waste components were periodically burnt; the leachate produced was neither collected nor treated, which stands to be a great source of pollution to the surface water in the city. The GHGs produced, the obnoxious odor, and the activities of rodents and domestic animals on the dumpsite, expose the populace in the vicinity to risk of health challenges.

Sampling and characterization of MSW

The on-site characterization of MSW generated in Ilorin metropolis was carried out for the period of 8 months. The first stage of the study included the months of May–August 2019 (for wet season), while the second stage included the months of November 2019 to February 2020 (for dry season).

The heterogeneous character of MSW constituted challenges that made the determination of the constituents in a waste stream a difficult task. As a result of this, more indiscriminate and universal procedures based on habitual perception and random sampling methodology, was used to determine the waste composition [36]. Sharma [37] suggested 30 samples, for a comprehensive characterization compared to 15 samples suggested by EC SWA-Tool [38] for stratification.

The sampling method engaged was in accordance with ASTM D5231 standard method of random sampling and quartering, as adopted by AbdAlqadar [39]. In this study, 60 samples were considered from Eyenkorin/Lasoju dumpsite; to avoid mistake that may occur due to inadequate parent representation of the waste streams. Various MSW subsamples were collected randomly from 12 different heaps of

Fig. 3 **a** Map of Ilorin Metropolis showing locations of Dumpsters (Roro bins). **b** Roro-bin located beside Bulletin Construction Company Ilorin. **c** Piles of uncollected MSW deposited by road along Emir's Road

Fig. 4 Lasoju Eyenkorin dumpsite along Lagos–Ilorin Express way (Ibikunle [29])

wastes on the dumpsite and were pooled together for characterization [40, 41]. The total number of 180 subsamples collected from the parent wastes were thoroughly mixed using shovel. The mixed waste components were heaped into a cone-like shape, sliced into four portions [42, 43]. Two of the four (4) slices that were diagonally opposite were discarded, while the remaining two portions were further mixed to collect 240 L bin volume of MSW [8, 38]. This procedure was repeated 64 times to obtain the samples that could adequately represent the parent waste materials for proper investigation.

The characterization of the MSW into different fractions was performed based on the American Society for Testing and Materials (ASTM D5231). Every of the 240 L bin of waste taken as a parent sample shown in Fig. 5a, was poured on the screening table (of 1.5 m by 3 m dimension with 10 mm by 10 mm mesh) shown in Fig. 5b recommended for heterogeneous MSW [8, 41]. Each sample collected was screened, sifted, and manually segregated into different components that are in turns put into different receptacles. Each receptacle containing individual waste fraction, was weighed, and the results recorded. The first solid-waste-characterization study undertaken by the World Health Organization [44] in 1980, provided an in-depth characterization of MSW in Instanbul, whereby waste generated in each month of the year was analyzed. In this paper, characterization of wastes was investigated for eight different months, bearing in mind that months of May to August is the raining/wet

Fig. 5 **a** Taking the weight of a typical sample of MSW. **b** Sieving and sorting MSW fractions on the screening-table

season of the metropolis and November to February of the following year is the period of dry season.

Results and discussion

This section presents the summary of the rate of generation (kg/capita/day of MSW, the amount of waste generated in tons/annum, the quantity of MSW collected, the availability of the collection vehicles and the population of people accountable for the waste production. The details of physical characterization of the wastes are provided and the classification of the waste components into categories that include recyclables, compostable and combustibles; to project the current waste-management system in Ilorin to an integrated municipal solid waste-management system (IMSWMs).

The aggregate MSW generated and the availability of collection trucks

There were about thirty (30) trucks provided by Kwara State Government MSW, for the collection of MSW produced in Ilorin metropolis. Due to age, wear and tears, and inadequate maintenance, only 50% were functional during this study, with total capacity of 330 tons and 258 m^3 as presented in Table 1. The predicted quantity of MSW generated, based on collection facts, is shown in Table 2. In Ilorin metropolis, weigh bridge facility was not available in the MSW management system to estimate the quantity of waste collected. The quantity of MSW collected, was estimated to be 353,686 tons/year by adopting the mathematical model that was suggested by Kosuke and Ibikunle [32, 34]; compared to 267.8 million tons of MSW generated in US by about 328.5 millions of people at rate of 2.18 kg/capita/day in 2017 [45] and 32.2 million tons of MSW generated in UK by about 66.96 millions of people at rate. Adopting the fact established by Ogunjuyigbe [4], concerning the ratio of waste collected to the quantity of waste generated in the developing nations; MSW generated in Ilorin was estimated to be 477,954 tons/year as presented in Table 2. This can be used as a management tool to properly plan for an efficient waste-management system. Having known the quantity to cater for, the municipality will be able to make a projection for the type of storage system required, the appropriate collection system and the methods that are desirable for efficient management to ensure a hygienic environment.

The population of people responsible for MSW production

The population accountable for the generation of MSW in Ilorin metropolis is presented in Table 3. The population for 2011 was projected by the National Population Commission based on 2006 census data. The population for 2016–2023 was predicted for the purpose of this study based on 2006 census data, using Malthusian modified model [30, 46]. Population data is very important while trying to determine the MSW generation rate (kg/capita/day). The population growth rate of Ilorin was determined to be 0.03. The growth in population rate is due to increase in birth rate, and

Table 1 MSW collection trucks, availability and capacity

Kinds of truck	Number available	Number on road	Number off road	% Availability	Capacity/truck (tons)	Capacity/truck (m^3)
Scania compactor	5	2	3	40	30	22
Hino tipper	10	5	5	50	25	22
Dino tipper	10	5	5	50	20	16
Mazda arm roller	5	3	2	60	15	8
Total	30	15	15	50	90	68

Table 2 The quantity of MSW generated/year based on collection facts

Types of truck	No of trucks utilized/day	Capacity/truck (tons)	Loading volume ratio /truck (V_{R_i})	Capacity, C_{T_i} (m^3/truck)	Trips/truck/day ($t_{n_{ij}}$)	MSW collected (tons/year)	Estimated quantity of MSW generated/ collection (tons/year)
Scania compactor	2	30	0.95	22	2	41,610	56,230
Hino tipper	5	25	0.95	22	3	130,032	175,719
Dino tipper	5	20	0.95	16	3	104,025	140,574
Mazda arm roller	3	15	0.95	8	5	78,019	105,431
Total	15	90	3.80	68	13	353,686	477,954

Table 3 Ilorin Metropolis population prediction for 2016–2023

Demographic centers	2011	2016	2017	2018	2019	2020	2021	2022	2023
Ilorin east	241,040	280,050	288,579	297,381	306,414	315,764	325,372	335,292	345,503
Ilorin south	243,120	282,466	291,068	299,947	309,057	318,488	328,137	338,142	348,440
Ilorin west	424,330	493,002	508,016	523,511	539,412	555,872	572,785	590,248	608,224
Total	908,490	1,055,518	1,087,663	1,120,839	1,154,883	1,190,124	1,226,294	1,263,682	1,302,167

migration of people from rural area to urban centers. This also helps in determining the aggregate of waste generated per year.

Estimated proportions of MSW components via characterization

The characterization study of eight months, consists of two (2) batches per week, making the total of eight (8) batches in every month. The characterization was conducted to investigate the waste components produced in the seasons, the percentage by mass of each component and the generation rate (kg/capita/day). The different waste constituents identified involve packaging box, propylene sack, nylon, plastic bottle, rags, paper, leather, rubber, grass/garden trimmings, tins, glass/ceramics, sand/ash, cow dung, excrement, toiletries, bones, wood, and others. The results of the wet season (May–August) MSW characterization study, presented in Table 4 shows that in month of May, about 401 kg of MSW was investigated, and the waste components distribution in Table 5, reveals that packaging box (carton) was 11.4% by proportion and volume of 0.22 m^3, followed by tins/metals 11.3% with 0.22 m^3, nylon 11.2% with volume 0.21 m^3 and the least is leather with 0.27% rubber with volume 0.01 m^3. The results of characterization for the month of June in Table 4, reveals about 405 kg of MSW, having 13.2% food residue with 0.25 m^3 volume as the highest fraction, followed by 12% packaging box (carton) with 0.23 m^3 volume, 10.9% nylon with volume of 0.21 m^3 and the least fractions are leather and rubber with 0.25% as presented in Table 5. The reason for having food residue as the highest waste fraction in the month of June, could be because of the availability of newly harvested food crops. Leather waste is very rear to come by in the metropolis because leather is highly treasured as valuable economic resource. The results of waste characterization for the month of July in Table 4

Table 4 Combined characterization for the 8 months

MSW fractions	MSW monthly characterization wt. (kg)								Total wt. (kg)	Mean	Vol. m^3	kg/capita/day
	May	June	July	Aug	Nov	Dec	Jan	Feb				
Food residue	31.9	52.8	58.6	113	14.7	33.0	20.1	23.1	347	43.4 ± 32.0	1.53	0.14
Wood	4.70	5.60	8.00	3.10	1.80	3.40	4.00	4.50	35.1	4.38 ± 1.86	0.16	0.01
Paper	21.5	16.5	32.5	27.4	14.8	32.1	28.3	19.3	192	24.1 ± 6.94	0.89	0.08
packaging box	45.9	48.1	51.5	63.0	12.6	49.6	25.7	19.2	316	39.5 ± 17.9	1.42	0.13
Grass/trimmings	23.0	25.7	36.4	39.0	19.9	9.70	8.90	11.1	174	21.7 ± 11.7	0.81	0.07
Texiles (rag)	21.6	27.4	21.5	60.4	27.2	47.1	35.2	29.7	270	33.8 ± 13.6	1.25	0.11
Toiletries	33.7	22.8	25.6	16.9	20.9	14.2	15.1	31.1	180	22.5 ± 7.24	0.88	0.07
Feaces	6.50	14.5	4.60	5.90	1.60	11.6	5.00	7.10	56.8	7.10 ± 4.10	0.27	0.02
Cow dung	5.90	14.5	10.3	4.50	8.90	12.1	5.70	3.50	65.4	8.18 ± 3.91	0.31	0.03
Nylon	44.9	43.9	41.1	44.5	59.0	73.2	72.2	54.8	434	54.2 ± 12.9	2.10	0.17
poly—sack	24.7	15.2	26.1	33.4	23.2	30.3	27.2	29.8	210	26.2 ± 5.54	1.01	0.08
Plastic bottle	20.1	24.8	23.3	22.8	31.8	54.6	33.4	23.0	234	29.2 ± 11.2	1.11	0.09
Rubber	1.10	1.00	0.80	1.00	1.90	1.30	3.20	2.00	12.3	1.54 ±0.79	0.06	0.01
Leather	1.30	1.00	0.00	0.40	1.10	0.70	2.00	3.90	10.4	1.30 ± 1.21	0.05	0.00
Glass/ceramics	7.90	10.3	9.60	8.60	10.4	10.0	20.4	13.7	90.9	11.4 ± 4.03	0.44	0.04
Bones	7.60	8.60	3.20	2.20	3.10	7.00	4.80	4.00	40.5	5.06 ± 2.37	0.19	0.02
Tins/metals	45.2	17.2	22.9	21.1	8.00	27.3	16.9	7.50	166	20.8 ± 12.0	0.76	0.07
Sand/ash	13.9	14.8	11.2	15.0	12.1	10.6	15.3	13.1	106	13.3 ± 1.79	0.51	0.04
Others	40.2	41.1	45.1	38.1	23.0	51.6	51.7	49.5	340	42.5 ± 9.49	1.60	0.14
Grand total	402	406	432	520	296	479	395	350	3280		15.4	1.30

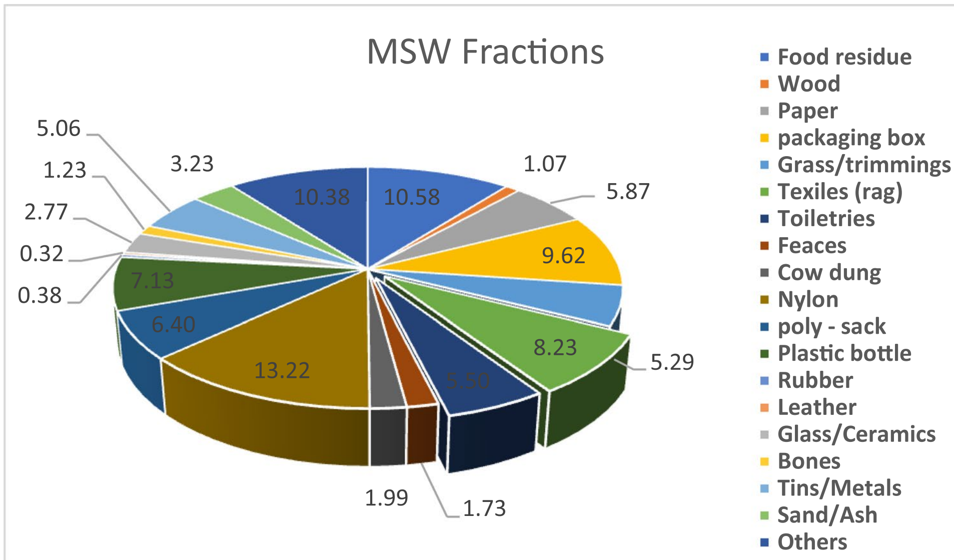
Table 5 The percentage distribution of MSW components for 8 months

Waste fractions	wt. (kg)	Vol. (m^3)	Municipal solid waste weight% in the months							
			May	June	July	Aug	Nov	Dec	Jan	Feb
Food residue	347.2	1.54	7.95	13.2	13.6	21.7	4.96	6.89	5.09	6.59
Wood	35.05	0.16	1.17	1.4	1.85	0.6	0.61	0.71	1.01	1.27
Paper	192.4	0.9	5.36	4.12	7.52	5.27	5	6.7	7.16	5.52
Carton	315.6	1.42	11.4	12	11.9	12.1	4.26	10.4	6.51	5.49
Grass/trimmings	173.7	0.8	5.73	6.4	8.42	7.5	6.72	2.02	2.25	3.16
Textiles (rag)	270.1	1.25	5.38	6.83	4.97	11.6	9.19	9.82	8.91	8.49
Toiletries	180.3	0.88	8.39	5.69	5.92	3.25	7.06	2.95	3.82	8.89
Excrement	56.8	0.27	1.62	3.62	1.06	1.13	0.54	2.42	1.27	2.03
Cow dung	65.4	0.33	1.47	3.62	2.38	0.86	3.01	2.53	1.44	1
Nylon	433.6	2.08	11.2	10.9	9.51	8.55	19.9	15.3	18.3	15.7
Poly-sack	209.9	1	6.15	3.79	6.04	6.42	7.84	6.32	6.89	8.52
Plastic bottle	233.8	1.12	4.99	6.19	5.39	4.38	10.7	11.4	8.44	6.57
Rubber	12.3	0.06	0.27	0.25	0.19	0.19	0.64	0.27	0.81	0.57
Leather	10.4	0.05	0.32	0.25	0	0.08	0.37	0.15	0.51	1.11
Glass/ceramics	90.85	0.45	1.97	2.45	2.22	1.65	3.51	2.08	5.16	3.92
Bones	40.45	0.19	1.89	2.14	0.74	0.42	1.05	1.45	1.22	1.14
Tins/metals	166.1	0.76	11.3	4.29	5.3	4.06	2.7	5.7	4.27	2.14
Sand/ash	106	0.51	3.45	3.69	2.59	2.88	4.09	2.21	3.87	3.75
Others	340.3	1.6	10	10.3	10.4	7.32	7.77	10.8	13.1	14.15
Grand total	3280	15.37	100	100	100	100	100	100	100	100

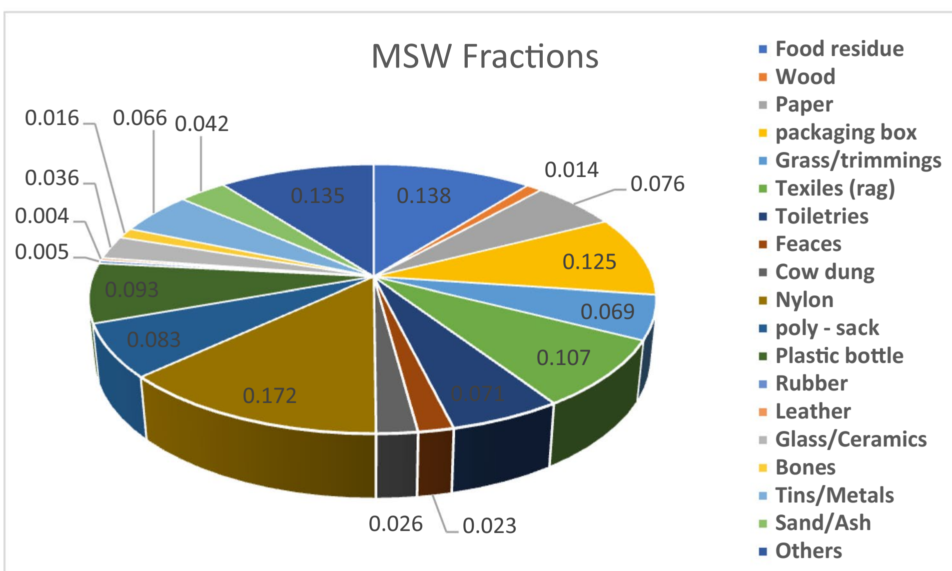
shows the quantity of waste analyzed to be 432 kg and the proportion of waste components in Table 5 presents 13.6% of food residue with volume of 0.26 m^3, followed by 11.9% of packaging box (carton) with 0.23 m^3 volume, 10.4% of other-biogenic fraction with volume of 0.20 m^3 and the least of all the waste components is rubber with 0.19%, while leather does not occur at all in the waste streams. The waste characterized for the month of August was about 520 kg, which is larger than any of other months, composed of 21.7% of food waste with volume 0.42 m^3, as the highest fraction; followed by 12.1% packaging box (carton) having volume of 0.23 m^3, 11.6% rag with volume of 0.22 m^3 and the least is 0.08% of leather.

The results of MSW characterization for the dry season presented in Table 4 (November–February), reveals that about 296 kg of MSW was characterized in the month of November, having nylon as the highest proportion of 19.9% with volume of 0.38 m^3, followed by plastic bottle of 10.74% with volume 0.21 m^3, 0.37% textile (rags) with 0.18 m^3 and the least is leather with 0.37% with volume of 0.01 m^3 as presented in Table 5. The characterization data for the month of December in Table 4, shows that about 479 kg of MSW was analyzed, having 15.3% of nylon as the highest proportion with 0.29 m^3, followed by 11.4% plastic bottle with 0.22 m^3, 10.8% others with 0.21 m^3 and the least is leather of 0.15% as in Table 5. The reason for nylon waste as the highest proportion followed by plastic bottle, is because of the high climate temperature of the region during dry season which prompt high rate consumption of water packed in nylon sachets and plastic bottles. The least fraction is leather with 0.15%, leather is highly treasured in Ilorin because it is used for shoes, bags, and different ornamental materials; thereby making the discarded leather to be scarce. The characterization for the month of January as presented in Table 4, shows that 395 kg of MSW was characterized to give 18.3% nylon with volume of 0.35 m^3 as the highest fraction, followed by others with 13.1% and 0.25 m^3, 8.91% with 0.19 m^3 of rags and the least is 0.51% with 0.01 m^3 of leather as presented in Table 5. The characterization for the month of February was 347 kg in Table 4, having nylon of 15.8% with 0.03 m^3 as the highest constituent, followed by others with 14.2% and 0.27 m^3, toiletries of 8.90% with 0.17 m^3 and the least is rubber with 0.58% and volume of 0.01 m^3 presented in Table 5. The combined physical characterization of MSW for 8 months in Table 4, shows that 3280 kg of MSW having bin volume 15.36 m^3 with generation rate of 1.30 kg/capita/day was investigated. The generating rate is compared to 0.75 kg/capita/day reported concerning Ilorin in 2016, by Ibikunle et al. [30], 0.66 kg/capita/day for urban areas and 0.7–1.8 kg/capita/day for developed nations [47]. EPA [48] reported that 267.8 million tons of MSW was generated in US by about 328.5 million of people, presenting a generating rate of 2.18 kg/capita/day in 2017 and 32.2 million tons of MSW generated by about 66.96 million people in UK, at the rate of 1.33 kg/capita/day in 2016 [49]. The waste streams comprised, 13.22% nylon fraction with 2.1 m^3 volume generated at the rate of 0.172 kg/capita/day compared to 9.60% reported by Olorunfemi and Odita [9] for commercial area of Ilorin in 1986. The food residue of 10.58% with volume of 1.53 m^3 and generation rate of 0.13 kg/capita/day is also compared to that of 28.3%, reported by Olorunfemi and Odita [9] for residential area of Ilorin in 1991 and the 15.2% of food waste estimated from the total waste generated by US in 2017 [48]. Followed by 10.38% other-biogenic fraction, with volume of 0.51 m^3 and 0.042 kg/capita/day rate of production; the least was 0.34% of leather fraction with volume of 0.05 m^3 and production rate of 0.004 kg/capita/day. The distributions of the waste generated, and the rate of generation are presented in Figs. 6a, b respectively. In UK, about 6.6 million tons of household food waste was estimated per annum in 2018 [49]. The reason for higher food waste in the developed nations than the underdeveloped and developing nations is because, there is a greater rate of food production in the advanced nations more than others, hence there is food surplus thereby allowing food waste and processing of reasonable quantity as animal feeds [49].

In Table 6, the MSW streams of Ilorin was categorized into biogenic and non-biogenic components. About 65% of the aggregate waste generated was categorized to be



(a)



(b)

Fig. 6 **a** The municipal solid waste distribution for 8 months. **b** MSW rate of generation distribution for 8 months biogenic fractions and about 35% of the aggregate waste was categorized as non-biogenic fractions. Table 7 reveals that about 53.5% of the MSW fractions in Ilorin with generation rate of 0.69 kg/capita/day (with nylon, plastic bottle and poly sack inclusive) was categorized as combustible waste for energy recovery via incineration, while 44.5% of the waste with generation rate of 0.58 kg/capita/day was categorized as recyclables (with carton inclusive) and about 38.7% with rate of generation 0.50 kg/capita/day was categorized as compostable. If recycling is combined with composting in Ilorin waste-management system, only 16.7% of the aggregate waste will be dumped and if waste incineration (for energy recovery) is combined with composting, it implies only 7.79% of the waste will be available for disposal. But if recycling and incineration is combined, only 2.0% of the waste generated will be disposed. If incineration and composting are combined, that means only 7.79% of waste will be discarded. The classification of waste components into categories without replication, is presented in Table 8. The combustible fractions take 10.85% of the total waste with generation rate of 0.144 kg/capita/day compared to 12.7% of 268 million tons of US MSW combusted for energy production in 2017 [50], 10% of MSW in England and 17.3% of MSW in Europe [51]. The recyclable takes 50.4% with rate of generation 0.66 kg/capita/day compared to 35.2% of US MSW, 55% of household and commercial wastes in Taiwan and 77% of US industrial wastes recycled in 2017 [52], also 45.5% of household wastes of UK was recycled in 2017 [53]. About 38.71% of the waste characterized with 0.5 kg/capita/day are compostable, compared to 10.1% of 268 million tons of US MSW composted in 2017 [50]. If energy recovery via incineration, recycling and composting methods of IMSWMs are adopted in Ilorin virtually all the wastes shall be utilized; thereby putting an end to traditional waste disposal method and its consequential effects.

Recovery of recyclables

MSW generated in Ilorin comprises heterogenous mixture of waste fractions. The sorting of the waste generated into the corresponding component fractions from source was not encouraged in the city. The recovery of recyclables components from the heaps of heterogenous waste dumped on the site, was performed by the scavengers that trade locally in recyclables. The scavengers in Ilorin metropolis are so committed and diligent to the extent they made huts with rags and polypropylene materials beside the dumpsite for their accommodation as in Fig. 7a, though this could make them be prone to diseases causative agents. Scavenging is the only method of materials recovery in Ilorin and the major materials recovered are presented in Fig. 7b–f. The recyclables recovered are sold to junk dealers, which in turn sells them to companies that use them as raw materials.

Open burning of MSW

The waste-management system of Ilorin lacks enough facilities and the modern technology required for efficient management, which resulted in uncollected piles of wastes constituting nuisance in the streets as in Fig. 3b, c. This encourages many people to indulge in indecent and indiscriminate disposal of MSW into water ways and undesignated places, as well as engage in burn their household wastes openly as in Fig. 8.

Conclusion

The MSW generated in Ilorin is very huge and disposal into dumpsite is the only management method practiced. This method is quite incapacitated to cater for the enormous waste produced, which is evident by uncollected

Table 6 Categorization of MSW into biogenic and non-biogenic fractions

Biogenic fractions	wt%	kg/capita/day	Non-biogenic fractions	wt%	kg/capita/day
Food residue	10.6	0.14	Nylon	13.2	0.17
Wood	1.07	0.01	Poly-sack	6.40	0.08
Paper	5.87	0.08	Plastic bottle	7.13	0.09
packaging box	9.62	0.13	Rubber	0.38	0.01
Grass/trimmings	5.29	0.07	Leather	0.32	0.00
Textiles (rag)	8.23	0.11	Glass/ceramics	2.77	0.04
Toiletries	5.50	0.07	Tins/metals	5.06	0.07
Excrement	1.73	0.02			
Cow dung	1.99	0.03			
Sand/ash	3.23	0.04			
Bones	1.23	0.02			
Other-biogenic	10.4	0.14			
Total	64.7	0.84	Total	35.3	0.46

Table 7 Categorization of waste fractions with some components repeated

Combustible fractions	wt. (kg)	wt%	kg/capita/day	Recyclable fractions	wt. (kg)	wt. %	kg/capita/day	Compostable fractions	wt. (kg)	wt%	kg/capita/day
Wood	35.1	1.07	0.01	Carton	316	9.62	0.13	Food residue	347	10.5	0.14
Paper	192	5.87	0.08	Nylon	434	13.2	0.17	Grass	174	5.29	0.07
Carton	316	9.62	0.13	Poly-sack	210	6.40	0.08	Others	340	10.4	0.13
Rag	270	8.23	0.11	PET bottle	234	7.12	0.09	Toiletries	180	5.49	0.07
Nylon	434	13.2	0.17	Rubber	12.3	0.37	0.00	Excrement	56.8	1.73	0.02
Poly-sack	210	6.40	0.08	Ceramics	90.9	2.77	0.04	Cow dung	65.4	1.49	0.03
PET bottle	234	7.13	0.09	Tins/Metals	166	5.06	0.07	Sand/Ash	106	3.23	0.04
Rubber	12.3	0.38	0.00								
Leather	10.4	0.32	0.00								
Bones	40.5	1.23	0.02								
Total	1754	53.5	0.69	Total	1463	44.5	0.58	Total	1269	38.71	0.50

piles of wastes, left on the streets for days. This study reveals that 1,154,883 people were responsible for 477,954 tons of MSW per annum at 1.3 kg/capita/day rate of generation. Only 50% of the collection trucks provided by the government were functional, thereby rendering waste collection system deficient and inadequate. The classification of waste fractions into categories, reveals 64.7% biogenic components with rate of generation 0.84 kg/capita/day, 35.3% non-biogenic fractions with 0.46 kg/capita/day. Categorizing the waste fractions into groups with some components replicated/repeated in combustible and recyclable categories, 53.5% is classified as combustible with generation rate of 0.69 kg/capita/day, recyclable takes 44.5% with 0.58 kg/capita/day and 38.7% recyclable with 0.50 kg/capita/day. This implies, if recycling and composting methods are incorporated into the waste-management system of Ilorin, only 16.7% of the aggregate waste will be dumped and if waste incineration (for energy recovery) is combined with composting, it implies only 7.79% of the waste will be available for disposal. But if recycling and incineration are combined, only 2.0% of the waste generated will be disposed. If incineration and composting methods are combined, only 7.79% of waste will be discarded. Nevertheless, if the waste components are categorized without replication, the combustible fractions give 10.9% of the total waste generated at rate of 0.14 kg/capita/day, the recyclable takes 50.4% with generation rate of 0.66 kg/capita/day and 38.7% compostable with 0.50 kg/capita/day. If recycling, composting and energy recovery via incineration methods of waste management are adopted in Ilorin, virtually all the wastes shall be utilized; thereby putting an end to unscientific traditional waste disposal method and its consequential effects.

Table 8 Categorization of waste without repeated fractions

Combustibles	wt%	kg/capita/day	Recyclables	wt%.	kg/capita /day	Compostable	wt%	kg/capita/day
Wood	1.07	0.01	Paper	5.87	0.08	Food waste	10.6	0.14
Bones	1.23	0.02	Carton	9.62	0.13	Grass	5.29	0.07
Rag	8.23	0.11	Nylon	13.2	0.17	Toiletries	5.50	0.07
Leather	0.32	0.00	Poly-sack	6.40	0.08	Excrement	1.73	0.02
			PET bottle	7.13	0.09	Cow-dung	1.99	0.03
			Rubber	0.38	0.00	Sand/ash	3.23	0.04
			Ceramics	2.77	0.04	Others	10.4	0.13
			Tins	5.06	0.07			
Total	10.9	0.14	Total	50.4	0.66	Total	38.7	0.50

Fig. 7 **a** Scavenger's hut on the dumpsite. **b** A heap of tins waste. **c** Piles and bales of tins waste. **d** A heap of PET bottles. **e** Piles of PET bottles. **f** Glass bottles (Ibikunle [29])

Fig. 8 Dumping into undesignated site with open burning of waste

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Author contributions RAI: conceptualization, data curation, formal analysis, funding, investigation, methodology, project administration, resources, validation, visualization, writing—original draft and editing.

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Compliance with ethical standards

Conflict of interest The author declares no conflicting or competing interests with anyone whatsoever, that could have appeared to influence the work reported in this paper.

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