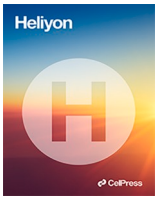
Heliyon 11 (2025) e41699

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Firsthand report on solid waste management practice in the major town of Addis Ababa-Adama economic corridor, Ethiopia

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ARTICLE INFO

Keywords:
Solid waste
Management practice
Waste generation
Waste composition
Recycling

ABSTRACT

Rapid population growth and economic development in Ethiopia have led to increased solid waste generation due to heightened consumption and a throwaway mentality. This has resulted in overcrowding, informal settlements, poor waste management, public health concerns, and environmental issues. Collecting accurate data on solid waste generation and composition in Ethiopia is challenging because of its limited scope and inconsistencies across the country. This assessment focuses on evaluating solid waste generation and composition in households, commercial establishments, and institutions located in the Addis Ababa-Adama corridor in the Oromia province. The research adopted a cross-sectional descriptive survey design, incorporating both qualitative and quantitative approaches to collect data the solid waste generation rates and composition from major sectors such as households, institutions, and commercial activities. The average generation rates of solid waste per household in the three towns were estimated to be 0.21 ± 0.10, 0.31 ± 0.19, and 0.19 ± 0.13 kg/day/person for Dukem, Bishoftu, and Mojo, respectively. Individuals with higher income levels produced higher amounts of solid waste per person. The average daily waste generation rate in the commercial sector was estimated to be 4.97 kg/day for Dukem, 38.34 kg/day for Bishoftu, and 3.29 kg/day for Mojo. Waste composition analyses revealed that the majority of waste generated was organic waste, with 65 %–69.5 %. A high fraction of organics in municipal solid waste (MSW) offers several advantages, including the production of biogas and compost. Small and medium enterprises are primarily responsible for waste collection, with collection efficiencies estimated at 70 %, 46 %, and 63.2 % for Bishoftu, Dukem, and Mojo, respectively. Uncollected waste ends up in open dumps or is burned.

1. Introduction

Rapid population growth, coupled with high demand for economic development, has placed immense pressure on resources [1]. The 21st century's rapid urbanization has transformed the world into cities and towns, improving quality of life but also negatively impacting the urban environment [2]. Urbanization increases solid waste generation due to increased consumption and a throwaway

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https://doi.org/10.1016/j.heliyon.2025.e41699
Received 8 October 2024; Received in revised form 29 December 2024; Accepted 3 January 2025
Available online 3 January 2025

mentality. In this regard, waste management is a significant environmental issue, especially in urban areas [3]. The UN predicts a 73 % increase in annual solid waste generation by 2050 due to population growth and urbanization, resulting in a projected global generation of 3.88 billion tons [4]. Africa is grappling with a significant waste management crisis, despite its relatively small waste volumes compared to developed regions, which is causing significant health and environmental issues [5]. Sub-Saharan Africa's annual waste volume surged from 81 million tons in 2012 to 174 million tons in 2016, with projections of 269 million tons by 2030 [6]. This region has experienced the fastest population growth since the 1980s [7]. Africa in general, only collects 55 % of annual municipal solid waste, with sub-Saharan Africa having a lower rate of 44 % [8]. Over 90 % of waste is disposed of in open dumpsites and uncontrolled landfills, with 19 of the world's 50 largest dumping sites located in this region.

Several research studies have been reported from various parts of the world, indicating waste generation and composition analysis. Accordingly, municipal solid waste generation and composition analysis in Asian, South American, and African countries have revealed significant variations.

For example, in Asian countries, the average waste generation ranges from 0.5 to 1.4 kg per person per day, with the exception of China [9]. The waste also characterized with high percentage of organic waste (ranged from 50 to 70 %) due to food waste and agricultural activities [10]. A recent review study on municipal solid waste in China showed that the amount of MSW that was generated ranged from 0.08 to 2.34 kg per person per day and averaged 0.73 kg per person per day [11]. Another study also report, In India, the per capita generation of solid waste ranges from 0.2 to 0.87 kg per capita per day [12].

In South America, the average solid waste generation is estimated to be 0.89 kg per capita per day. The major components of this waste include organic waste (52 %), paper and cardboard (13 %), and plastic (12 %) [13].

In Africa, specifically in sub-Saharan Africa, solid waste generation is approximately 62 million tonnes per year, with per capita generation ranging from 0.09 to 3.0 kg per person per day and an average of 0.65 kg per capita per day [14]. Given that an estimated 80–90 % of the municipal solid waste (MSW) generated in Africa is recyclable, it is perplexing that more than 90 % of this waste continues to be disposed of in landfills, often in uncontrolled or poorly managed dumpsites [15].

Rapid urbanization in Ethiopia, as in other sub-Saharan African countries, has led to overcrowding, informal settlements, poor

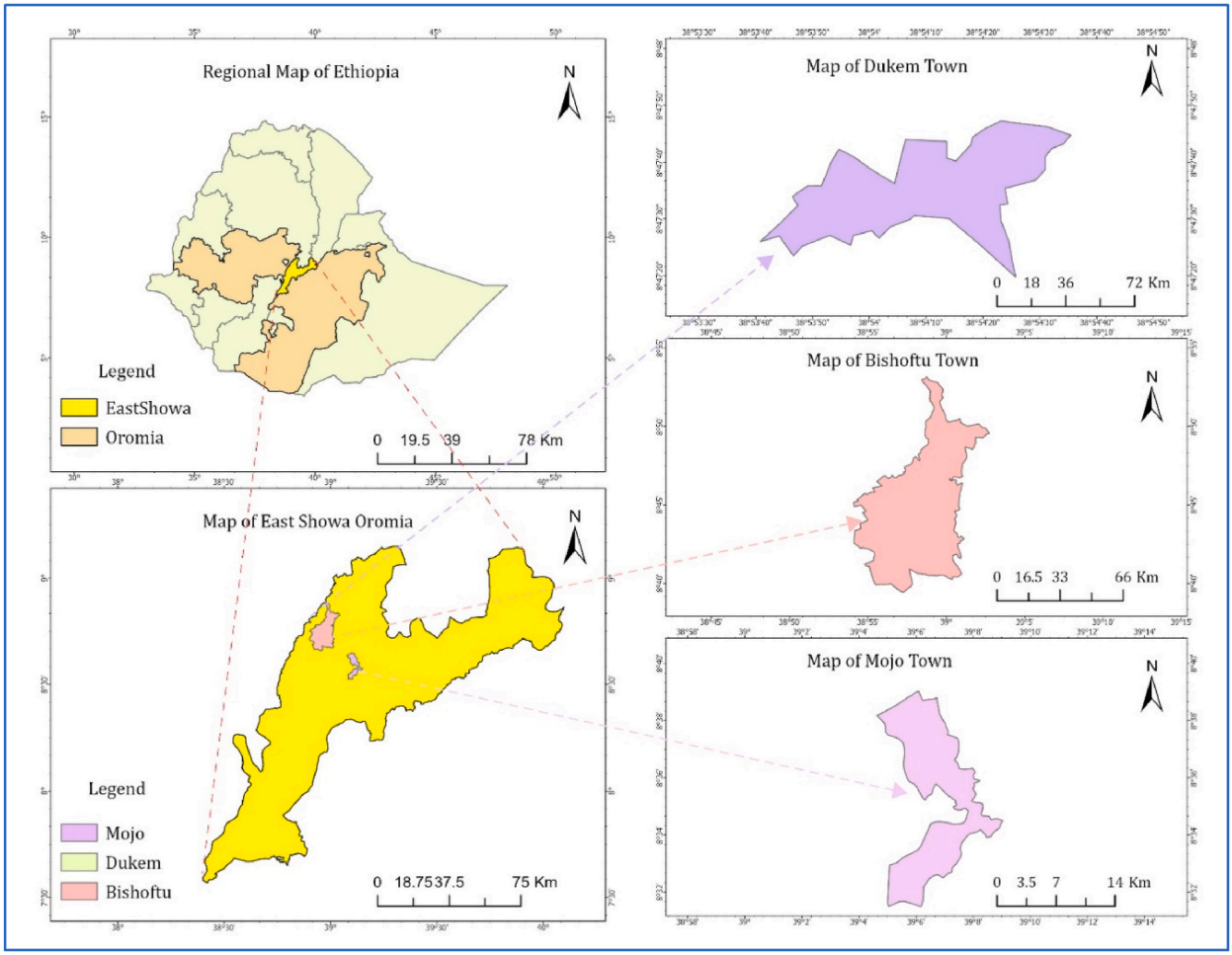

Fig. 1. Map of the study area (source: own elaboration).

waste management, public health, and environmental issues [16]. Ethiopia, a rapidly growing sub-Saharan African country and the second largest in population, is grappling with the issue of improper solid waste management, highlighting its need for improved waste management practices. Waste collection rates vary significantly between cities and rural areas, as well as among different urban zones. Research indicates that in Ethiopia, individuals generate between 0.28 and 0.83 kg of waste per person each day [17–20]. The country also faces a growing public challenge in waste management and controlling mechanism, with poor practices linked to various factors such as conventional transport, roadside waste dumping, water body waste disposal, irregular waste picking programs, infrastructure constraints, financial constraints, lack of skilled human resources, and unregulated landfills [21].

The collection of accurate data on Ethiopia's solid waste generation and composition is challenging due to its limited scope and consistency across the country. Furthermore, the study of solid waste management practices in Ethiopia is faced with challenges arising from limited availability of data, a focus on urban areas, and a scarcity of research studies and assessments. These factors hinder the understanding of waste management practices across the country and limit the availability of data-driven insights. This study mainly focuses on the assessment of current waste management practices in the towns of Dukem, Bishoftu, and Mojo. These towns are located in the Addis Ababa-Adama corridor (Addis-Djibouti import-export route) in the Oromia province. This corridor is a thriving economic area that spans across administrative borders (provincial and city). It serves as the main route for transporting goods from the seaport of Djibouti to the central and highlands of Ethiopia. The corridor is comprised of logistic hubs located between Addis and Adama, with the notable "Dry Port" in Mojo near Adama. These hubs are connected by two recently constructed routes: the Addis-Adama Express Highway and the railway line, in addition to the existing old highway. Over the years, the two main cities of Addis Ababa and Adama have experienced significant population growth. However, there has also been a noticeable increase in urbanization and extensive development in Dukem, Bishoftu, and Mojo, which are cities situated along this corridor. Though the corridor has significant economic advantages, to our knowledge, there is no comprehensive data regarding the solid waste management system, including a waste generation and compositional study. Therefore, the purpose of this study is to provide a current and comprehensive report that addresses this gap through an assessment that includes the evaluation of solid waste generation and composition from households, commercial establishments, and institutions as well as waste management practice.

2. Methodology

2.1. Description of the study area

Fig. 1 shows area maps of the study town within the Addis-Adama corridor. Each of the town is description is discussed below.

2.1.1. Dukem town

Dukem is a town in the Oromia special zone, 37 km from Addis Ababa, on the Addis Ababa-Adama expressway. It is surrounded by Bishoftu city, Gelan town, and four Akaki district peasant associations. The town, situated between 8°45′25"N and 8°50′30"N latitude and 38°51′55"E and 38°56′5"E longitude, spans an area of 9630.6 ha [23]. It is divided into four kebeles, which are the smallest administrative units below the district level in the Ethiopian government structure [22]. The estimated population of the town is 85, 839 with 23,884 households [24].

Dukem, a rapidly growing urban center in the Oromia regional state, has experienced irregular and uncontrolled expansion, leading to fragmented development [25]. The town's proximity to Addis Ababa has resulted in increased investments and rapid economic and social development. Dukem has become an industrial urban center, known as the Eastern Industrial Zone, with industry concentrated in the Western and North Eastern areas and currently, there are 264 industries [24]. Major potential economic resources for local development include crop production, land, river resources, and quarry sites.

2.1.2. Bishoftu Town

Bishoftu town is one of the so-called railway towns of Ethiopia established following the construction of the Ethio-Djibouti railway in 1917 [26]. The town is located at 8°43′-8°45′ North Latitude and 38°56′-39°01′ East Longitude, covers 20,574 ha and is located at an altitude of 1850 m above sea level [27]. Bishoftu town, located in the Oromia National Regional State, lies approximately 47 km southeast of Addis Ababa. Positioned between the towns of Dukem and Mojo, it is situated along the Addis Ababa-Adama Road. The town covers an area of approximately 20,569 ha and is divided into nine urban Kebeles and five rural Kebeles. Moreover, the population of the town is estimated to be around 225,000 with a total number of households of 56,250 [28].

The town's economy is diversified through agriculture, manufacturing, tourism, and trade. The agricultural sector is a major contributor, while the manufacturing industry involves small-scale production [29]. Tourism attracts visitors to historical sites, natural attractions, and cultural events, contributing to the town's growth and development [30].

2.1.3. Mojo Town

Mojo town, located in the East-Shewa zone of Ethiopia, is an administration center and industry town in Lome Woreda. It spans 4532 ha and is located 70 km southeast of Addis Ababa. The town is situated between 1730 and 1890 m above sea level, with a latitude and longitude of 8°37′N 39°07′E [30]. The population of Mojo Town was estimated in 2021 to be 58,000 [30]. However, the 2022 Mojo Town census reported a total population of 93,264, with 48,578 males and 44,686 females. The Mojo Town administration currently has 10,552 legal households and is divided into two kebeles: Mojo Town Kebele 01 (OBO) and Mojo Town Kebele 02. Mojo Town's economic landscape is characterized by agriculture, manufacturing, construction, and commerce. Agriculture provides income and employment, while manufacturing and agro-processing contribute to food security and export revenues. Construction has surged,

attracting investment and jobs. The town's strategic location along the Addis Ababa-Djibouti railway line and the Mojo-Meki Industrial Zone further enhances its economic prospects.

2.2. Sampling

The current status of solid waste management practices in the three towns was investigated using a descriptive survey. This type of survey focuses on investigating the current status and practices of solid waste management in the town. The descriptive research design involves collecting both quantitative and qualitative information to describe the study. The study area was selected purposively. The research employed a cross-sectional descriptive survey framework, integrating both qualitative and quantitative techniques to collect information on the production rate and makeup of solid waste from households, institutions, and commercial entities.

The population in Dukem, Bishoftu, and Mojo town was estimated at 85,839, 225,000, and 58,000, with households ranging from 12,000 to 50,000, with an average of 4.5 people per household.

The statistical significance of results is determined by the sample size, which is reflected by the confidence level and margin of error. For a city with a population of 10,000–10,000,000, 370–384 households are needed to achieve a 95 % confidence level and 5 % margin of error. However, collecting waste samples from 384 households for 7 days may be unfeasible and costly. Therefore, it is suggested that 90 households be selected from average cities, with 10 households each from high, middle, and low-income groups, according to the UN Habitat Waste Wise Cities Tool [31]. In this regard, the household sample were considered in the three town 90 households (from each of 3 survey zones 30 high-income, 30 middle-income, and 30 low-income groups). Households were categorized into three income levels based on housing criteria, including income, house construction materials, ownership, finish work, and access to electricity, using a door-to-door survey. Illegal settlements, resettlement areas, and poor areas were included in this group. The most straightforward approach is the lottery method, which involves assigning a unique number to each household within the income group. From this well-mixed list, the sample households are chosen, ensuring that each household has an equal opportunity to be selected as a subject. For Dukem and Mojo town, a sample was proportionately chosen based on the population of each kebele located in the respective study town. In Bishoftu town, a multistage sampling method was employed, beginning with cluster sampling to divide the 14 kebeles into four geographic groups. From each group, a representative sample was then selected using simple random sampling. Furthermore, the analysis of solid waste generation and composition from various commercial units was conducted through representative sampling from categories including retail trade shops, wholesale trade shops, supermarkets, mini-markets, hotels, resorts, bars, restaurants, cafeterias, and repair services. Accordingly, about 20 and 35 commercial units were selected for Dukem and Mojo town, respectively. The number of commercial establishments in the two cities was 124 and 190, respectively, for the two towns. To determine the waste generation rate and composition for commercial activities, 16 samples were randomly analyzed from a total of 678 commercial centers. On the other hands to determine waste generation from institutions the institutions were stratified as governmental organizations, educational establishments, religious institutions, and service-providing institutions. In Dukem town, the study selected a diverse array of institutions, including 2 educational centers (1 kindergarten and 1 primary school), 2 religious institutions (1 mosque and 1 church), and 3 governmental institutions. In Bishoftu town, the selection comprised 3 educational centers (1 kindergarten, 1 primary school, and 1 secondary school), 2 religious institutions (1 mosque and 1 church), and 6 governmental institutions. Similarly, in Mojo town, the selected institutions included 3 educational centers (1 kindergarten, 1 primary school, and 1 secondary school), 2 religious institutions (1 mosque and 1 church), and 3 governmental institutions. This methodical selection process ensures a comprehensive and representative assessment of solid waste generation and composition across different types of institutions within the study area.

2.3. Waste generation, composition, and bulk density determination

Measurements were conducted at both the household and commercial levels to examine the rate of solid waste generation and its physical composition. These measurements followed the methods outlined in ASTM D5231-92 (2016) to ensure accurate and representative results. According to the method, it involved several techniques, including waste collection, manual sorting, weighing, and data recording.

The per capita waste generation (PCWG) for each household in the town was calculated using Equation (1) [31]. The number of family per household was estimated to be 6. Similarly, per facility waste generation from institutional (PFWGI) and per facility waste generation from commercial (PFWGC) were calculated based on equations (2) and (3). Data collection activities were conducted over 8 consecutive days. Ninety households were provided with 50 kg capacity plastic bags, each marked with a unique identification code, to collect their daily waste. The bags were collected every morning, weighed in situ, and recorded on a sampling sheet. All waste collected on the first day was discarded to avoid including previously accumulated waste. The following seven visits were made regularly, moving from one sample unit to another.

$$\text{PCWG (kg / person / day)} = \frac{\text{Total mass of wastes generated (kg) for consecutively 7 days}}{\text{number of days (7)*number of households*total number of family in the household}} \quad (1)$$

$$\text{PCWGI (kg / person / day)} = \frac{\text{Total mass of wastes generated (kg) for consecutively 7 days}}{\text{number of days (7)*number of institutional facility}} \quad (2)$$

$$\text{PFWGC (kg / person / day)} = \frac{\text{Total mass of wastes generated (kg) for consecutively 7 days}}{\text{number of days (7)*number of commercial facility}} \quad 3$$

Representative waste samples were collected, and the waste samples underwent manual sorting. The waste composition analysis involved distributing the waste onto a plastic sheet and meticulously separating it into predefined categories (11 different waste fractions) using standard methods (ASTM D5231-92 (2016)). The percentage of waste composition (PWC) for each waste fraction was calculated as shown in Equation (2).

$$\text{PWC (\%)} = \frac{\text{Mass of waste fraction (kg)}}{\textit{Total mass of the waste (kg)}} * 100\% \quad 2$$

The waste density was calculated using a 20-L bucket with a known volume. The sample density was determined using Equation (3).

$$\text{Density} = \frac{\text{Mass of the sample (kg)}}{\text{Volume occupied by sample (m}^3\text{)}} \quad 3$$

2.4. Evaluation of the existing solid waste management practice

Field observations were carried out to assess the spatial distribution of household solid waste management practices, including collection, segregation, and disposal. The study qualitatively evaluated the overall efficacy and efficiency of the town's solid waste management system, with particular emphasis on collection, transportation, and disposal processes. A purposive sampling method was employed to select municipal officers, scavengers (waste pickers), and all waste collectors and cleaners in the three towns.

3. Result and discussion

3.1. Waste generation and composition

3.1.1. Waste generation

As depicted in Fig. 2, the average generation rates of solid waste from each household in the three towns were estimated to be 0.21 ± 0.10, 0.31 ± 0.19, and 0.19 ± 0.13 kg/day/person for Dukem, Bishoftu, and Mojo towns, respectively. It was observed that the per person solid waste generation was higher among individuals with higher income levels with the range of 0.24–0.37 kg/person/day, followed by those with middle (0.17–0.31 kg/person/day) and low-income levels (0.15–0.19 kg/person/day). The solid waste generation rate in various cities and towns in Ethiopia ranges from 0.25 to 0.49 kg/capita/day [17]. Global average waste generation varies between 0.11 and 4.54 kg per person per day [32]. The bulk density of the household solid waste was in the range of 220–300 kg/m^3 in the three study towns.

The average daily waste generation rates for each commercial sector were estimated to be 4.97 kg/sector/day for Dukem town, 38.34 kg/day for Bishoftu town, and 3.29 kg/day for Mojo city. For example, the calculated average waste generation multipliers for different commercial sectors in Bishoftu town are presented in Table 1. The total amount of solid waste generated by all commercial sectors in the three towns was estimated to be approximately 13,687.3 kg/day for Dukem, 102,764.64 kg/day for Bishoftu, and 1060.6 kg/day for Mojo. Similarly, the mean generation rate of each category was multiplied by the total number of facilities/institutions in Bishoftu, as shown in Table 2. The average waste generated from each institutional sector in all three towns was calculated to be 6.2 kg/sector/day for Dukem, 10.4 kg/sector/day for Bishoftu, and 8.3 kg/sector/day for Mojo. Accordingly, the total solid waste generation from all institutions in the three towns was calculated to be 533.2 kg/day for Dukem, 1528.8 kg/day for Bishoftu, and 929.6 kg/day for Mojo. The higher generation rate in Bishoftu is associated with its diverse economic activities, several institutions, and large population size. Additionally, the town is well-known as a tourist destination in Ethiopia and offers various tourist-supporting facilities such as hotels, restaurants, and lodges.

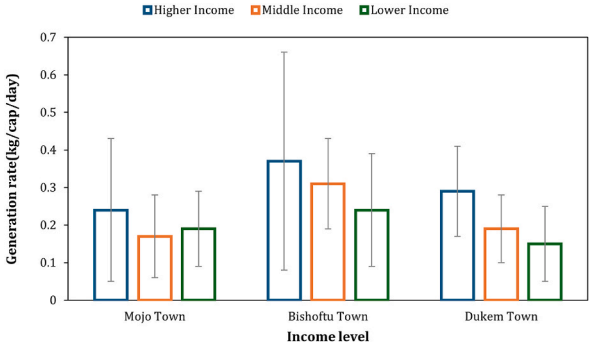

Fig. 2. Daily household solid waste generation rate with population income status (source: own elaboration).

Table 1
Daily commercial sector waste generation rate per facility (source: own elaboration).

Commercial sectors	Unit (kg/day)
Hotels	146.43
Restaurant	690.93
Cafeteria	6.74
Supermarkets	4.66
Mini market	0.926
Open market shop	1.4

Table 2
Daily Institutional sector waste generation rate per facility (source: own elaboration).

Institutional sectors	Unit (kg/day)
Governmental institutions	4.8
Educational centers	3.9
Religious institutions	1.7

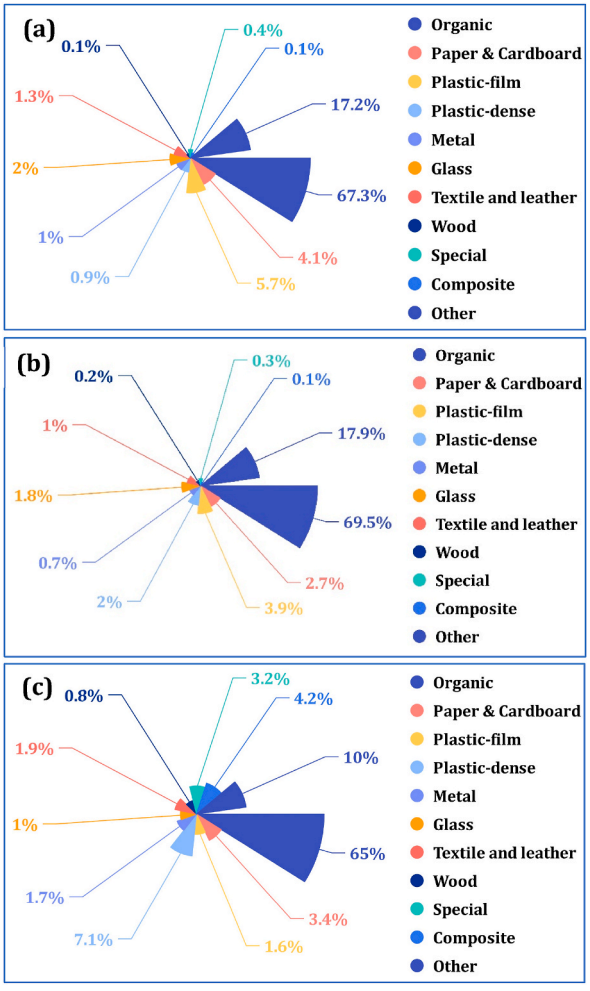

Fig. 3. Percentage composition of municipal solid waste in (a) Dukem town, (b) Bishoftu town and (c) Mojo town. (source: own elaboration).

3.1.2. Waste composition

Information and data on the physical composition of solid waste are essential for equipment and facility selection and operation. They are also important for evaluating the feasibility of resources and energy recovery, as well as for the analysis and design of waste disposal facilities. Solid waste composition varies from city to city and country to country, largely due to differences in standards of living, lifestyles, social and religious traditions, and eating habits. Furthermore, this analysis aids in identifying opportunities for recycling. This, in turn, supports the necessity of waste collection services that prioritize recyclable materials. Additionally, it assists in establishing a fair pricing system for mixed waste, thus promoting the implementation of waste recycling programs [33].

Waste composition analysis in the three towns showed that most of the waste generated was organic, including kitchen scraps, food waste, and yard trimmings, which accounted for 65 %–69.5 % of the total. This was followed by other waste, such as ash, sanitary pads, diapers, and inert materials, which comprised 10 %–17.9 %. Plastic waste, including plastic film and dense plastics, made up 5.8 %–8.7 %, while paper and cardboard accounted for 2.7 %–4.03 % (Fig. 3(a)–(c)). Other waste fractions, such as metals, glass, textiles, and leather, were present in small amounts, each below 2 %. Since organic waste constitutes more than two-thirds of the total waste generated in all towns, it is possible to recycle this biodegradable portion and utilize it as a valuable source of plant nutrients. This approach would prevent the loss of organic waste through improper disposal or inadequate treatment [34].

Furthermore, there is significant potential in utilizing plastic and paper waste to create a circular economy by recycling it. This would help reduce waste buildup in landfills and oceans, greenhouse gas emissions, and dependence on non-renewable petroleum resources for polymer production [35]. It would also allow for the recovery of the economic value of the material.

3.2. Solid waste management practice in the three towns

3.2.1. Bishoftu Town

The responsibility for the collection and disposal of solid waste in the town is assigned to the City Sanitation, Beautification, and Parks Agency, which oversees comprehensive waste management. Two types of waste collection services are employed: primary and secondary. Primary collection involves transporting waste from its source, predominantly households and commercial establishments, to nearby communal storage sites. A door-to-door collection system is utilized to collect household waste once a week, while waste from hotels, restaurants, and resorts is collected as part of commercial activities. Open market waste is collected thrice weekly, and waste from supermarkets and mini markets is collected twice weekly. The collected waste is then transported to the landfill by tractors, which make 3–5 trips daily.

Secondary collection entails transporting the accumulated solid waste from communal storage sites to final disposal sites, primarily conducted by various micro and small enterprises (MSEs). There are no established standard transfer stations in these towns, except for temporary communal storage sites. Waste transportation to the dumping site is mainly performed by tractors, skip loaders, and horse carts. Waste generated by institutions is generally managed independently, with exceptions for educational and religious institutions, as well as some governmental offices.

One management option is for households to store waste before transferring it to communal storage sites. According to data from the Bishoftu town waste management office, the majority of households (89 %) use polypropylene woven bags for temporary waste storage, about 7 % use plastic bags, and the remaining 4 % use plastic dustbins. Each household is expected to pay between 0.5 and 1 USD per month for this collection service to MSEs, with fees depending on family size and an agreement between the collector and the household head. The same fee structure applies to commercial services, though the payment system can vary for rural areas due to the distance between the collection area and the dumping site.

Previous studies in Ethiopia show that only 40–50 % of the waste generated is collected, largely due to the exclusion of impoverished communities from the collection system [36]. Additionally, the solid waste collection efficiency in three Ethiopian cities was recorded as follows: Addis Ababa at 70 %, Hawassa at 80 %, and Bahir Dar at 57 % [37]. Comparing the waste collection coverage in Bishoftu town to that of other cities in Ethiopia, it appears to be better. Approximately 70 % of the daily generated waste is collected, but there are still areas, such as rural kebeles, where the collection system is not effective due to the distance from the dumping site and financial issues within the community (Fig. 4). Most of the remaining uncollected waste (13.3 %) is typically burned or illegally

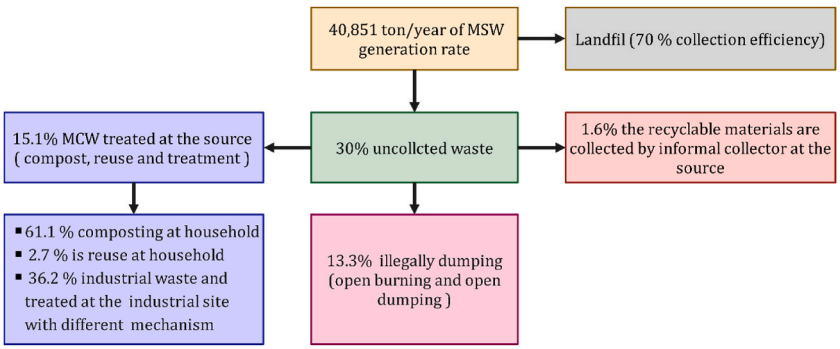

Fig. 4. Municipal solid waste flow of Bishoftu town (source: own elaboration).

disposed of in open areas, while food waste from hotels and restaurants is usually sold to pig farmers before being transported to the dumping site. The city has very low material recycling rates, approximately 1.6 %. The primary method of waste treatment at the source is composting, which is facilitated by the presence of agricultural businesses in the city. Despite the relatively high collection rate in Bishoftu town compared to other cities, challenges remain that hinder the overall effectiveness of waste management. The inconsistent waste collection in the rural kebeles often leads to unsightly litter and health hazards, as the community struggles to manage waste disposal effectively. Moreover, the limitation of financial resources not only affects the collection system but also the community's ability to invest in sustainable waste management initiatives.

The burning of uncollected waste and illegal dumping poses environmental concerns, contributing to air pollution and the degradation of local ecosystems. The practice of selling food waste to pig farmers reflects an informal approach to waste management, with potential benefits for both the farmers and the reduction of waste volume. However, this system lacks regulation and oversight, which can lead to public health risks if it is not managed properly.

Furthermore, the low recycling rate of only 1.6 % indicates that there is significant room for improvement in promoting material recovery and recycling practices within the city. Engaging the community, implementing educational programs about the benefits of recycling, and establishing more formalized recycling facilities could enhance the overall waste management strategy.

To bolster waste treatment at the source, the practice of composting could be further encouraged. With the agricultural businesses in the area, there is an opportunity to develop a more robust composting program that not only reduces organic waste destined for landfills but also provides valuable compost for local farmers. This circular approach could strengthen the connection between waste management and sustainable agriculture, ultimately fostering a more resilient community.

The solid waste collected from Bishoftu Town is currently disposed of at a final landfill site in Burda Kebele, located approximately 3 km from the city, without any further waste separation. This designated landfill site covers 11 ha and is encircled by mountains. It comprises two cells, each designed to operate for 10 years. The first cell has been in use since 2019 and is equipped with a geo-membrane cover and a leachate collection system.

Three microenterprises at the landfill site, along with one outside it, sort recyclable and reusable materials. Due to the absence of recycling facilities in Bishoftu Town, the collected recyclable materials are sold to processing facilities outside the town, including those in Addis Ababa.

In the cities, there are informal waste collectors (scavengers) who collect and recover reusable and recyclable waste from various sources, such as households, commercial establishments, streets, and bins. They then sell these materials through intermediaries to recycling industries. The exact number of informal waste pickers in the town is unknown. Additionally, there is a compost plant located in the landfill site that is managed by three MSEs. The plant was initially designed with a capacity of 60 tons per year, but it is currently operating below capacity due to market issues.

3.2.2. Dukem town

In Dukem town, the Solid Waste Management Office is available under the city municipality. However, the town does not have a separate annual budget for solid waste management. Instead, it is operated as one department within the municipality service. The Solid Waste Management Office is responsible for overseeing all aspects of solid waste management in the town. There are currently four micro and small-scale enterprises involved in solid waste collection services. Each of these enterprises is organized under the municipality's solid waste management office through an agreement. Additionally, each kebele has its own micro and small-scale enterprise, which hires waste collectors under its supervision. Micro and small-scale enterprises play a crucial role in the collection and transportation of solid waste. They collect waste from residential and commercial properties using a door-to-door method. After being collected, waste is transferred to the disposal facility. The frequency of solid waste collection varies by commercial unit. Some people have their waste collected every two or three days, whereas the bulk have it picked up once a week. The cost of these services varies according to the sort of commercial activity. Small commercial providers impose a minimum monthly fee of approximately 0.9 USD, whilst others charge based on the amount of waste produced. The collected wastes are transported to the disposal site directly by the truck with 1–2 trips per day. The waste collection efficiency in the town is currently only 46 % which is very low(Fig. 5). The remaining waste, approximately 54 %, is either illegally disposed of, treated and reused at the source, or collected by informal

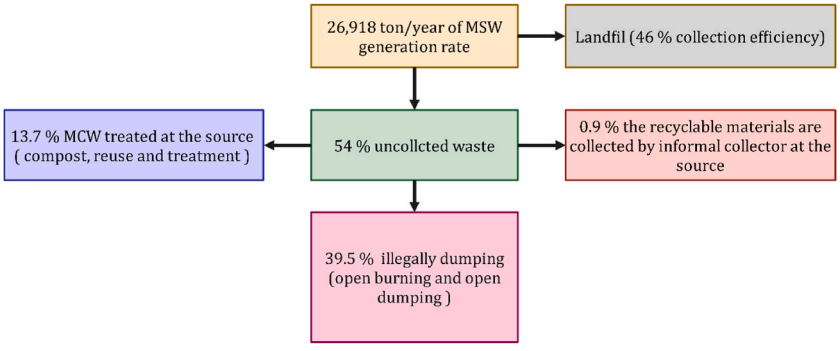

Fig. 5. Municipal solid waste flow of Dukem town (source: own elaboration).

recyclable waste collectors. However, the rate of illegal dumping is notably high, at about 39.5 %. Additionally, only 0.9 % of the waste material undergoes recycling. This situation underscores the critical challenges facing waste management systems, where the lack of adequate infrastructure and enforcement mechanisms allows for such a high incidence of illegal disposal. Many communities grapple with insufficient access to proper waste collection services, leading individuals to resort to dumping their waste in vacant lots or natural areas. This not only poses severe environmental hazards but also impacts public health by attracting pests and contaminating local water sources.

The meager recycling rate of 0.9 % highlights an urgent need for increased awareness and education surrounding recycling practices. Oftentimes, people are unaware of what materials can be recycled or lack access to recycling facilities. Consequently, many recyclable materials end up in landfills, exacerbating the issue of waste accumulation.

To address these challenges, a multi-faceted approach is essential, encompassing improved collection systems, robust legal frameworks to deter illegal dumping, and community engagement initiatives designed to promote recycling. Collaboration among stakeholders, including government agencies, businesses, and non-profit organizations, is vital to foster a culture of responsibility and sustainability, thereby transforming waste from a burden into a valuable resource for communities.

Most rural areas lack waste collectors, leading residents to dispose of their waste in rivers and water bodies. The main reasons for this illegal disposal include a lack of awareness regarding proper waste management, cultural constraints that prioritize sustainable waste management less, the absence of door-to-door waste collection services, and the scarcity of public waste collection skip points.

The disposal site is residence to six micro and small-scale enterprises that collect recyclable and reusable waste. Their major function is to sort and separate recyclable and reusable items. Similar to Bishoftu, because there is no recycling facility in the town, the collected recyclable waste is sold to a recyclable waste processing enterprise outside of town.

There are informal waste collectors, also known as scavengers, in the town who work to collect and recover reusable and recyclable waste from various sources, including households, commercial sectors, and industries, as well as from the streets. From field observations, it can be seen that the town's commercial and industrial recyclable waste is mostly collected by private collectors who operate informally. Additionally, there are informal waste collectors who gather recyclable waste from disposal sites. These collectors sell recyclable waste to intermediaries, who then distribute it to recycling industries. Unfortunately, a comprehensive estimate of the number of informal waste pickers in the town is unavailable.

The current solid waste disposal site in use by the town is an open field located near Dukem River. It is an unmanaged landfill site that lacks cover and compaction. Additionally, the site is characterized by poor road infrastructure, making it unsuitable for vehicles, especially during the rainy seasons when the problem is greatly exacerbated. It is generally described as an open and unsanitary landfill site. The current disposal site has been functioning since 1997 due to delays in the establishment of the municipality solid waste management office.

3.2.3. *Mojo Town*

Currently, Mojo Town's municipal solid waste management primarily focuses on collecting, transporting, and disposing of solid waste. However, it is not effective in properly collecting, sorting, transporting, and disposing of waste from improper landfills. The town collects waste from its origins and transports it directly to final disposal places. This emphasizes the significance of implementing sustainable solid waste management practices in Mojo Town, such as waste prevention, reduction, reuse, recycling, and proper disposal. In conclusion, Mojo Town's solid waste management system has been recognized as lacking in several essential components. Fig. 6 depicts the flow of municipal solid waste management techniques in Mojo Town.

In Mojo Town, five small and medium-sized enterprises are responsible for collecting waste from households and marketplaces. However, data collected from town residents indicates that there is an inconsistent schedule for waste collection and disposal from households. Approximately 65 % of the solid waste in Mojo Town originates from residential areas.

The town has a waste collection efficiency of about 63.2 % (Fig. 7). Although skip points are managed by the town administration,

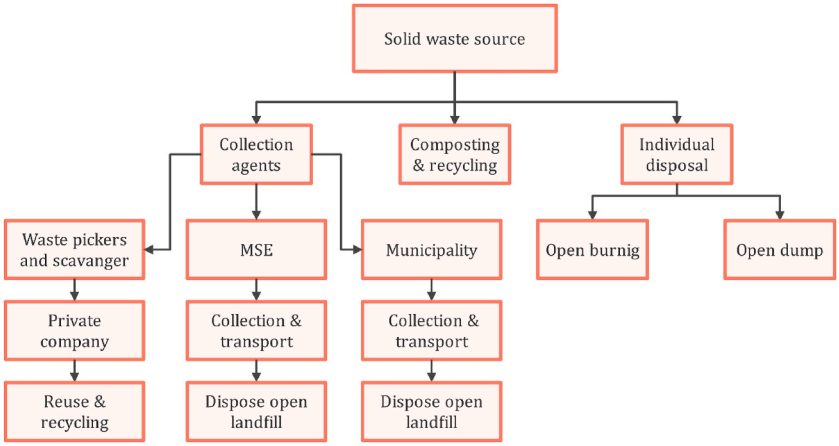

Fig. 6. The flow of municipal solid waste management practices in Mojo town (source: own elaboration).

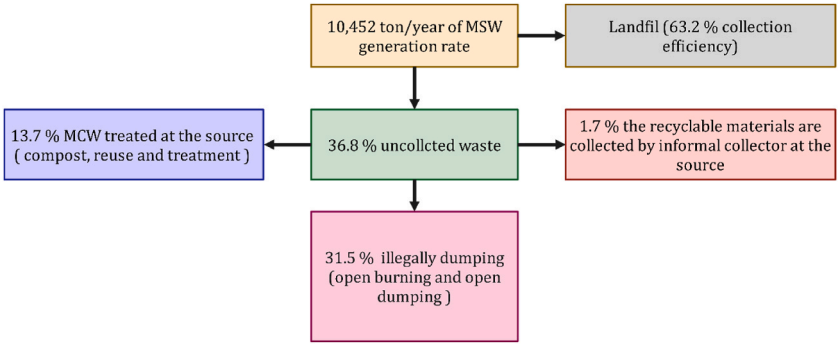

Fig. 7. Municipal solid waste flow of Mojo town (source: own elaboration).

there are no designated waste collection transfer stations apart from these skip points.

In terms of waste recycling and reuse processes in the town, some materials, such as glass and plastic, are reused. For example, Fig. 7 shows that just 3.5 % of waste is processed at the source through composting and reuse.

Mojo city's solid waste management practices need improvement. To achieve this, clear and regular waste collection schedules and effective communication with residents are essential. The town's waste collection efficiency can be increased by expanding the fleet of collection vehicles and enhancing the capacity of small and medium-sized enterprises. Additional waste transfer stations are needed for better waste handling, sorting, and transportation. Expanding recycling programs, particularly for glass and plastics, and promoting composting can reduce waste volume. Community-based recycling centers and household separation of recyclables should be encouraged. Promoting composting at both household and community levels is crucial due to high organic waste content. Strengthening regulatory frameworks, public awareness, and education campaigns can foster a culture of environmental responsibility. Engaging schools, religious institutions, and local organizations in these efforts can help spread awareness and improve waste management practices in Mojo city.

Mojo town had an open landfill located around 6.7 km to the south. This landfill had been operating for approximately 7 years and covered a total area of about 3.5 ha. Unfortunately, the landfill was unmanaged and lacked any cover or compaction, allowing waste from various sources, such as manufacturing industries like the tannery industry, to be dumped there. Consequently, this led to significant pollution of the nearby river and the surrounding population.

4. Conclusion

The rapid urbanization in Ethiopia, as in many other countries in sub-Saharan Africa, has led to overcrowding, the formation of informal settlements, inadequate waste management, public health issues, and environmental hazards. As the second-most populous country in the region, Ethiopia faces significant challenges in managing solid waste due to its growing population. This underscores the urgent need for improved waste management practices nationwide.

However, acquiring accurate statistics on solid waste generation and composition in Ethiopia is difficult due to low coverage and discrepancies among regions. Similarly, analyzing waste management techniques is complicated by a lack of comprehensive data, a concentration on urban areas, and limited research, all of which limit our understanding and impede data-driven insights.

This study assessed waste management practices in Ethiopian towns, particularly focusing on solid waste generation and composition from households, commercial establishments, and institutions. The main results revealed daily solid waste generation rates per person of 0.21 ± 0.10 kg/day in Dukem, 0.31 ± 0.19 kg/day in Bishoftu, and 0.19 ± 0.13 kg/day in Mojo. Higher-income individuals generate more waste. Household solid waste bulk density ranged from 220 to 300 kg/m^3. Waste generation rates from the commercial sector were 4.97 kg/day in Dukem, 38.34 kg/day in Bishoftu, and 3.29 kg/day in Mojo. The dominant waste composition was organic (65–69.5 %), followed by other wastes such as ash, sanitary pads, diapers, and inert materials (10–17.9 %), plastics (5.8–8.7 %), and paper/cardboard (2.7–4.03 %).

These findings suggest a high potential for establishing a circular economy through composting, biogas production, and recycling of plastic and paper. However, current waste collection efficiency ranges between 40 % and 70 %, with a significant portion of waste being illegally dumped. The implementation of the circular economy concept in these towns is inadequate and requires significant improvement. Enhanced waste management strategies, community engagement, and sustainable practices are essential to mitigate environmental impact and promote public health. These efforts will help transform waste management into a more efficient and environmentally friendly system, benefiting both urban and rural populations in Ethiopia.

CRediT authorship contribution statement

Shimelis Kebede Kassahun: Writing – original draft, Supervision, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Berhanu Assefa:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Kristina Henzler:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Julia**

Weißert: Writing – review & editing, Supervision, Project administration, Funding acquisition. **Martin Oteng-Ababio:** Writing – review & editing, Project administration, Methodology, Conceptualization. **Mahelet Admassu:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Ikram Mohammed-Amin:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Genanew Tesfahun:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Ethical approval

Not applicable.

Data availability statement

Data will be made available on request. For requesting data, please write to the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported as a part of the project “SuCCESS24 - Sustainable Cities, Circular Economy, Sub-Sahara Africa 2024”, which has been funded by The DAAD (German Academic Exchange Service) and BMBF (Federal Ministry of Education and Research). The authors would like to express our thanks to Institute for Sanitary Engineering, Water Quality and Solid Waste Management,(ISWA) University of Stuttgartfor all support and project management needed for this study. The authors also gratefully acknowledge the School of Chemical and Bio Engineering of Addis Ababa Institute of Technology at Addis Ababa University.

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