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Enhancing Municipal Solid Waste Management in Addis Ababa, Ethiopia: Lessons from Warsaw's Municipal Waste Management Practices

Poprawa systemu zarządzania odpadami komunalnymi w Addis Abebie, Etiopia: Lekcje z praktyk zarządzania odpadami komunalnymi w Warszawie

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Keywords: *Municipal solid waste management |Addis Ababa | Warsaw | Comparative study*

Abstract
This article explores municipal solid waste management systems in Addis Ababa, Ethiopia, and Warsaw, Poland, with the aim of identifying gaps, highlighting best practices, and proposing improvements for Addis Ababa. Waste management is critical for addressing environmental and public health challenges, particularly in rapidly growing cities. Warsaw demonstrates an efficient system characterized by advanced infrastructure, high recycling rates, and robust public engagement. In contrast, Addis Ababa faces significant challenges, including limited waste collection, reliance on informal recycling systems, and dependence on the Koshe landfill.
The research adopts a comparative analysis, leveraging data from both cities to understand structural, policy, and operational differences. Findings reveal that while Addis Ababa has promising initiatives, such as the Reppie Waste-to-Energy Plant, systemic inefficiencies hinder its performance. Drawing insights from Warsaw, this thesis emphasizes the importance of enhancing public awareness, integrating informal waste systems, and modernizing waste processing infrastructure.
The study highlights the potential for Addis Ababa to transition toward a sustainable and efficient waste management system by adapting global best practices to its local context.

Słowa kluczowe: *Gospodarka odpadami komunalnymi stałymi (Addis Abeba -Warszawa). Studium porównawcze*

Streszczenie
Niniejszy artykuł analizuje systemy gospodarowania odpadami komunalnymi w Addis Ababa (Etiopia) i Warszawie (Polska) w celu zidentyfikowania luk, wskazania najlepszych praktyk oraz zaproponowania usprawnień dla Addis Ababa. Gospodarowanie odpadami odgrywa kluczową rolę w rozwiązywaniu wyzwań środowiskowych i zdrowotnych, szczególnie w szybko rozwijających się miastach. Warszawa reprezentuje efektywny system, charakteryzujący się zaawansowaną infrastrukturą, wysokimi wskaźnikami recyklingu i silnym zaangażowaniem społecznym. W przeciwieństwie do tego, Addis Ababa zmaga się z poważnymi problemami, takimi jak ograniczony poziom zbiórki odpadów, zależność od nieformalnych systemów recyklingu oraz uzależnienie od wysypiska Koshe.
W prowadzonym badaniu przyjęto metodologię analizy porównawczej, wykorzystując dane z obu miast, w celu zrozumienia różnic strukturalnych, politycznych i operacyjnych. Wyniki przeprowadzonych analiz wskazują że mimo obiecujących inicjatyw, takich jak Reppie Waste-to-Energy Plant, brak efektywności systemu utrudnia jego właściwe działanie. Czerpiąc inspirację z Warszawy, artykuł podkreśla znaczenie zwiększania świadomości społecznej, integracji nieformalnych systemów gospodarki odpadami oraz modernizacji infrastruktury przetwarzania odpadów.
W artykule wskazano na potencjał Addis Abab do transformacji w kierunku zrównoważonego i efektywnego systemu gospodarowania odpadami, poprzez adaptację globalnych najlepszych praktyk do lokalnych warunków.

1. Introduction

Municipal solid waste (MSW) refers to unwanted materials discarded as a result of human activity, including manufacturing, construction, packaging, and mining. Although commonly regarded as refuse, many of these materials retain residual value and can be recovered or repurposed [1]. MSW includes all solid materials discarded as useless or unwanted by-products and may also encompass substances that, by law, require safe disposal [6].

Rapid urbanization, population growth, economic development, and improved living standards have significantly increased both the volume and complexity of waste generation in cities. However, in many urban centers—particularly in African regions—the capacity of waste management systems has not kept pace with this growth. In Addis Ababa, for example, less than half of the solid waste produced is collected, and of that, approximately 95% is disposed of in unauthorized dumping sites or temporary open lots throughout the

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city [2]. Low-income neighborhoods are often the most affected, as they receive little or no waste collection services [6].

Inadequate solid waste management has been linked to numerous environmental and public health challenges. Poor practices contribute to blocked drainage systems, water and soil pollution through leachates, foul odors, air pollution from open burning, and increased risk of disease transmission—especially in underserved areas [6]. To address these concerns, the implementation of structured and sustainable waste management strategies has become critical [4].

Waste management encompasses the processes of collection, transport, treatment, disposal, monitoring, and regulation of waste materials [1]. Municipal solid waste management (MSWM), as a multidisciplinary field, involves the control of waste generation, storage, collection, transfer, processing, and final disposal. Its primary objective is to minimize adverse environmental and health impacts while promoting sustainable development and improved urban quality of life [3].

Addis Ababa, the capital city of Ethiopia with an estimated population of 3.8 million [7], faces significant challenges in MSWM. The city generates approximately 0.45 kg of waste per capita per day, with an average waste density of 330 kg/m³ [6]. Although around 75% of this waste is collected, only 5% is recycled and another 5% composted. Approximately 90% of the collected waste is disposed of in landfills, while the uncollected 25% is dumped in unauthorized locations [8]. These outcomes indicate a gap between current practices and the recommended waste management hierarchy, which prioritizes minimization, reuse, recycling, treatment, and disposal [4].

This study aims to evaluate the current state of MSWM in Addis Ababa by examining its historical development, system components, and implementation challenges. The composition and sources of municipal waste are assessed, along with ongoing efforts such as recycling, composting, and energy recovery. A comparative analysis with waste management practices in Warsaw, Poland, is also conducted to identify best practices and transferable strategies, recognizing that not all methods may be directly applicable due to contextual differences. Based on the findings, recommendations are proposed to address systemic gaps and support the development of an efficient, sustainable, and context-sensitive MSWM framework for Addis Ababa.

Fig.1. Location of Addis Ababa in Ethiopia

Rys. 1. Położenie Addis Abeby w Etiopii

2. Municipal Solid Waste Management

Waste refers to any material discarded after primary use, considered unwanted or unusable, and is an inevitable by-product of human activity. However, the definition of waste is subjective—what one person discards may be a valuable resource to another [10].

Historically, waste management was rudimentary. In ancient cities, waste was often dumped onto unpaved streets until Athens implemented the first known waste law in 320 BCE, marking the beginning of organized disposal [14]. In ancient Rome, property owners were responsible for street cleanliness, and organized collection occurred mainly during public events. Waste was typically discarded in pits outside city walls [14].

The decline of Rome ushered in centuries of poor sanitation. By the late 14th century, designated scavengers transported waste outside city limits. England institutionalized this system in 1714 by mandating official scavengers. In 18th-century America, cities like Boston and Philadelphia began waste collection, though disposal remained crude—Philadelphia, for instance, dumped waste directly into the Delaware River [14].

Technological progress in the late 19th century marked a turning point. Innovations like watertight garbage cans and durable collection vehicles emerged in the U.S., and the UK built its first incinerator in 1874. By the early 20th century, 15% of U.S. cities had adopted incineration, though many still relied on open dumping [14].

The 20th century saw further innovation with garbage grinders, compaction trucks, and pneumatic systems. Sanitary landfills began replacing open dumping to address environmental and health concerns, introducing classifications for hazardous and non-hazardous waste [14]. Developed countries later shifted focus to recycling and source reduction. Modern incinerators now capture energy from waste, with air pollution controls ensuring compliance with environmental standards [14].

Municipal solid waste (MSW) originates from households, offices, businesses, schools, and institutions. It primarily consists of food scraps, paper, plastic, textiles, metal, and glass. It may also include construction debris and minor hazardous waste like batteries or pharmaceuticals [22]. Rapid population growth, urbanization, and economic development have overwhelmed waste management systems, particularly in low – and middle-income countries [2].

Global waste generation is projected to rise 73% by 2050, with middle-income countries experiencing the sharpest increase. This surge raises environmental alarms, particularly the emission of methane and carbon dioxide, prompting calls for integrated, sustainable solutions [23][24].

Since biodegradable waste contributes heavily to greenhouse gas emissions, modern strategies emphasize the "waste hierarchy": prevention, reuse, recycling, energy recovery, and lastly, disposal. This model supports the circular economy by preserving the value of materials and minimizing environmental harm [1][25].

primarily of food waste, paper, plastic, rags, metal, and glass, with additional components such as demolition and construction debris and small quantities of hazardous waste like light bulbs, batteries, automotive parts, and discarded medicines [22]. Increasing population, economic growth, urbanization, and improving living standards have intensified the challenge of waste management, leading to a decline in the effectiveness of solid waste collection and disposal systems [2].

Projections indicate a staggering increase in solid waste generation globally, driven by factors such as economic development, urbanization, and population growth. By 2050, the world is expected to generate 73 percent more MSW than in 2020, with high-income countries producing the most waste.

2.1. Essential Elements of Municipal Solid Waste Management

2.1.1. Generation and Composition

MSW generation depends on economic activity, lifestyle, and climate. For example, the U.S. generates ~2 kg/person/day, Canada 2.7 kg, Japan 1 kg, and Ethiopia's capital Addis Ababa only 0.45 kg [6][14]. Waste composition varies—some developing nations produce waste with over 70% organic matter and 50% moisture, requiring region-specific processing strategies [22][24]. Fig. 4 shows U.S. waste composition in 2013 [26].

2.1.2. Collection and Transfer

Collection is the costliest part of waste management, consuming up to 75% of total expenses. In many regions, waste is gathered using improvised containers or communal bins placed roadside. Techniques range from door-to-door pickup to indirect collection using skips or centralized bins. Trucks with compactors can reduce loose waste volume by over 50% [14][22].

Efficient route planning is crucial in large cities, factoring in haul distance, frequency, and waste type. Collection often occurs weekly due to rapid decomposition of food waste. Transfer stations consolidate waste for long-distance hauling, using trailers that transport up to 76 cubic meters to processing or disposal sites [14].

2.1.3. Treatment and Disposal

post-collection, waste undergoes treatment to reduce volume and extract reusable materials or energy. Sorting separates organic from inorganic matter using mechanical techniques based on size, density, and magnetism. Shredding produces a homogeneous mass for subsequent recycling, composting, incineration, or landfill disposal [14][26].

- **Recycling**:

involves collecting and processing materials like paper, plastic, metals, and electronics into new products. It conserves energy, reduces landfill use, and protects natural resources [27].

- **Composting**:

Biologically decomposes organic material (e.g., food, yard waste) into nutrient-rich soil amendments, enhancing soil fertility naturally [27].

- **Incineration**:

It also calls waste-to-energy, burns waste at high temperatures to produce heat or electricity. Though effective in reducing volume and generating power, it risks air pollution if not properly managed [27].

- **Landfilling:**

Places waste in lined, monitored sites to prevent environmental damage. Properly managed landfills include systems to capture methane and leachate, though mismanagement poses contamination risks [27].

Some waste types, such as hazardous or industrial by-products, require specialized chemical, physical, or biological treatments to neutralize harmful components before disposal industrial structure.

Such data is necessary and helpful to establish the municipality's solid waste to energy conversion facility. The region's municipal solid waste composition varies greatly; in certain middle-class and low-income nations, waste has an organic content of more than 70% and a moisture level of more than 50%. The waste composition of the United States of America, a developed nation, is depicted below as an example in Fig. 4 [26].

Fig. 2: Waste Management Hierarchy [25]
Rys.2. Hierarchia postępowania z odpadami [25]

3. Municipal solid waste management practice in Addis Ababa

3.1. Municipal Solid waste management history in Addis Ababa

Addis Ababa, founded in 1886, has grown into Ethiopia's political and economic center. Initially, low population and rural habits allowed open-air dumping without major issues. However, with urban expansion and rising waste volumes, sanitation deteriorated. In response, a municipal council was formed in 1909, and national sanitation policies emerged with the 1948 health system and the 1950 Ministry of Public Health (Proclamation No. 147). The city charter in 1954 strengthened municipal oversight [8].

From 1994–2003, solid waste management was handled by the Environmental Health Department under the City Health Bureau. Bureaucratic inefficiencies hindered progress, prompting restructuring under the Sanitation, Beautification, and Parks Development Agency (SBPDA) in 2003. This decentralized management to kebeles and sub-cities, improved regulation, landfill oversight, and public education [28].

In 2018, the Addis Ababa Cleansing Management Agency (AACMA) replaced the Recycling and Disposal Project Office (Proclamation No. 58/2018). AACMA coordinates with Community Management Offices (CMOs) at the sub-city and Woreda levels. As of 2023, AACMA employs 304 people across 15 directorates. Its Service Provision Department oversees collection, recycling, and landfill operations, with the Landfill Administration being the largest unit [36].

3.2. Sources, Composition, and Volume of Waste

Solid waste is generated from households, industries, hotels, hospitals, and street sweeping. Between 2016–2020, household waste made up 71% of the total, followed by street sweeping (10%) and commercial sources (9%) [6]. Waste in Addis Ababa is 63.1% organic, 19.4% recyclable, and 17.5% other, reflecting limited packaging and high food waste in developing countries [3][22][29].

Table 1. Waste Composition of Addis Ababa [36]
Tabela 1. Skład (morfologia) odpadów Addis Abeby [36]

Waste Component	Percentage (%)
Food	52.8
Paper	5.0
Textile	2.2
Plastic	9.6
Glass	1.3
Metal and Aluminum	1.3
Leaves/grass	10.3
Diapers and sanitary napkins	7.1
Other (leather,wood,rubber,bone,ceramic)	3.0
Ash/Fine waste	6.1
Miscellaneous	1.2
Total	100

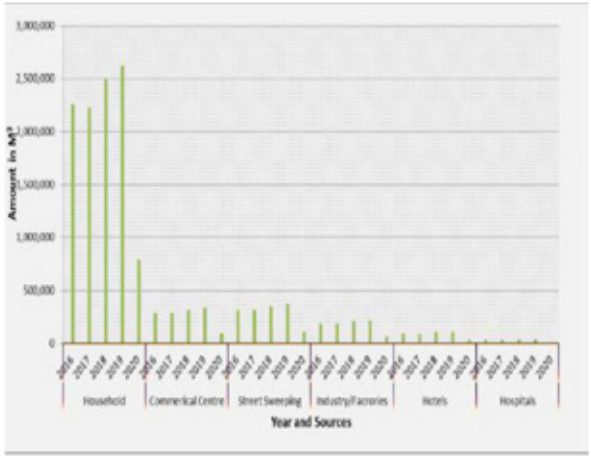

Fig. 3. The generation of solid waste in Addis Ababa (2016–2020) (M3) [6]
Rys. 3. Wytwarzanie odpadów stałych w Addis Abebie (2016–2020) (M3) [6]

3.3.Collection System

About 3,300 tonnes of solid waste is produced daily, but only 75% is collected. Collection is funded via water bills, with households paying 20% and commercial entities 42.5% of the total [8] [29]. Waste is managed via three systems: primary, secondary, and street sweeping.

- **Primary Collection:**

Handled by ~520 Micro and Small Enterprises (MSEs), each covering 800–1,000 households. Waste is collected door-to-door using pushcarts or trucks and moved to transfer depots [8][29].

Fig. 4. Primary Collectors
Rys. 4. Zbiórka odpadów

Fig. 5. Garbage container and transfer depot
Rysunek 5: Kontener na odpady, stacja przeładunkowa

- **Secondary Collection:**

Managed by sub-cities and the Solid Waste Management Agency using 140 trucks (only 97 operational). Waste is hauled to the Reppi landfill; transport involves compactors and container trucks with 8–80 m³ capacity. About 57% is moved by the government, 21% by private firms, and 22% is outsourced [28].

Fig. 6. Secondary Collectors
Rys. 6.Transport odpadów

- **Street Sweeping:**

Operated by sub-cities, especially in high-waste commercial zones like Merkato and Piassa. Sweepers collect and transport waste to transfer depots, aided by city subsidies [28].

Fig. 7. Street Sweepers
Rys. 7. Zamiatanie ulic

3.4. Processing and Disposal

Waste processing is minimal, with only 10% reused or recycled—5% informally. "Koraleos" (informal collectors) buy recyclables from households and sell to registered middlemen, who supply recycling firms. MSEs also sort recyclables at transfer depots, but poor separation practices persist [8].

Fig. 8. Informal re-use material collector (koraleo)
Rys. 8. Nieformalny zbiórka odpadów – materiałów do ponownego wykorzystania (koraleo)

The city's only landfill, "Reppi" or "Koshe," active since 1964, spans 25 hectares in Kolfe Keraniyo. It uses open dumping, posing environmental and health risks. Over 200 scavengers work daily on-site, complicating landfill operations [8].

3.5. Ongoing initiatives in waste management.

3.5.1. Recycling and Composting Initiatives in Addis Ababa

Recycling in Addis Ababa is growing but remains challenged by limited infrastructure and minimal government support. Only about 5% of collected waste is recycled, handled by both formal and informal actors. Informal collectors contribute significantly by recovering plastics, cardboard, and metal from streets. Enterprises like Kubik recycle plastic waste into building blocks for affordable infrastructure, collaborating with IPDC and GIZ's NatuReS program to empower SMEs in waste segregation and business skills development [30]. In the paper sector, Penda-Paper, based in Addis Ababa, promotes circular economy solutions and works with Bakken & Bæck to digitize waste-paper recycling [30]. For PET recycling, COBA Impact Manufacturing processes PET and HDPE into reusable flakes, adhering to international standards while supplying materials for polyester Fiber production [30]. In metal recycling, Ethiopia's steel sector includes about 130 companies, recycling 360,000–480,000 tons annually (30–40% of its waste metal). However, high costs and poor segregation limit the sector's efficiency [33]. Despite 70 total recycling enterprises in the city, only a small portion of recyclable waste is processed. Of 10 plastic recyclers, just two use advanced methods; only a fraction of waste is handled by around 15 paper recycling firms [34][35].

3.5.2. Composting Initiatives

About 60% of Addis Ababa's household waste is biodegradable. In 2020, a composting program collected organic waste from the Nifasilk sub-city market, distributing 326,240 kg to 104 cooperatives between November 2020 and February 2021 [8]. Nevertheless, composting covers only about 5% of total waste. By 2020, 1,015 tonnes had been composted, involving over 1,000 households. Primary actors like Integrated Bio Economy (IBE) and Birhane Clean and Environmental Sanitation Association focus on turning waste into compost for agriculture. Though the private sector's involvement is still limited, opportunities exist in hospitality and urban agriculture if waste is sorted at the source [30].

3.5.3. Waste-to-Energy (WTE) Initiative

The Reppi landfill (Koshe), active since 1964, reached 9.5 million m³ by 2002. In 2018, the Reppie WTE plant—Africa's first—was established nearby to incinerate 1,400 tons/day and supply 50 MW, or 30% of Addis's power demand. Operated by EEP, the plant receives waste free from the AACMA in a mutually beneficial exchange [36]. However, due to technical issues and poor waste quality (74.3% moisture content), it now processes only ~600 tons/day. Incineration rates dropped from 56% in 2020 to 22% in 2022, worsened by a faulty transformer and delays in part replacements. Additionally, ash residues rose from 16% to 22%, reducing energy conversion efficiency [6][30][36].

Fig. 9. Reppie waste-to-energy plant [36]

Rys. 9. Zakład przetwarzania odpadów na energię Reppie [36]

3.6. Solid waste management plans

During the revision of Addis Ababa's 1986 Development Plan, urban issues like pollution and sanitation made solid waste management (SWM) a priority. The 2003-2010 Development Plan aimed for a "Safe and Clean Environment" by focusing on SWM standards to protect public health and the environment, including proposals for landfill sites across the city. However, many of these sites, such as Bole-Arabsa, Yeka Abbado, Fili Doro, and Dertu Mojo, were never developed, leaving the Reppi (Koshe) dumpsite as the main waste disposal location. This open dump created serious environmental risks, including leachate contamination, and posed health dangers due to its proximity to residential areas [8]. To address these issues, the updated Development Plan emphasized improving sanitation services and reducing pollution, with objectives like better waste collection and new landfills. The latest master plan incorporates detailed strategies for waste disposal to enhance quality of life, decrease waste in residential areas, and ensure proper waste transport. The city's current structural plan for 2025 and 2040 outlines specific SWM goals, focusing on providing adequate waste management services and promoting environmental sustainability across all residential and commercial zones [8].

Table 2. Addis Ababa Waste management plan

Tabela 2. Plan gospodarki odpadami w Addis Abebie

Plan Component	Implementation Details	Target Years
Sanitary Landfill	Develop at Legetafo (Chembe) outside Addis Ababa	Ongoing
Transfer Stations	Construct three stations in the southern, eastern, and western areas of the city with materials recovery facilities	Ongoing
Waste Separation	Initiate three-way waste separation (recyclable, biodegradable, hazardous) at source	By 2025
Waste Separation Expansion	Expand to five-way waste separation (paper, plastic, other recyclables, biodegradable, hazardous) at source	By 2040
Recycling Targets	Increase recycling rates to 10% and 20%	2025 and 2040, respectively
Organic Waste Transformation	Increase composting and animal feed conversion to 25% and 40%	2025 and 2040, respectively
Reppi Dumpsite Conversion	Close and transform Reppi dumpsite into a green space	By 2040

4. Municipal solid waste management practice in Warsaw.

4.1. Overview of Warsaw City

Warsaw, officially known as the Capital City of Warsaw (Warszawa in Polish), is Poland's largest and most populous city, located along the Vistula River in east-central Poland. It is not only the political and cultural heart of the country but also a major economic hub in the European Union, ranking seventh in EU urban population with about 1.86 million residents within the city and 3.27 million in the metropolitan area [10][37]. Covering 517 square kilometres and divided into 18 districts, Warsaw is central to the Masovian Voivodeship and houses both national and local government institutions. Since Poland joined the European Union in 2004, Warsaw has experienced remarkable economic growth, becoming a centre for foreign investments and international business. The city generated a GDP of approximately €100 billion in 2021—around 20% of the country's total—and recorded an unemployment rate of just 1.4% in 2024 [10][37]. The average monthly salary stands at about €2,228.26. Warsaw's infrastructure has kept pace with its economic expansion, supported by EU funding. Its transportation system is among the most extensive in Central Europe, including a growing metro system—launched in 1995 and expanded in 2015—133 km of tram lines, and an expansive bus network. The city experiences a continental climate, characterized by cold winters averaging – 1.5 °C in January and warm summers reaching 19.7 °C in July, with an annual average of 9 °C and about 482 mm of precipitation [10].

4.2. Municipal Solid waste management history in Warsaw

The Municipal Cleaning Company (MPO) has been responsible for managing Warsaw's municipal waste since 1927, playing a vital role in the city's environmental upkeep. Initially founded as the City Cleaning Plant by the Warsaw City Council, the company quickly grew; by 1929, it employed 2,000 workers to clean all paved streets, and by 1939, it operated with 1,500 staff and a fleet of specialized vehicles, including garbage and sewage trucks. During World War II, MPO maintained sanitation and contributed to wartime recovery efforts by clearing rubble, handling unexploded ordnance, and assisting the wounded [43].

In 1951, it became Miejskie Przedsiębiorstwo Oczyszczania (MPO) and expanded during the 1970s with district-level cleaning facilities. It transitioned into a sole-shareholder company owned by the city in 2003 and merged in 2011 with Przedsiębiorstwo Robót Inżynieryjne Budownictwa Warszawa. That year, MPO also took over the ZUSOK incineration plant, Poland's first [43]. Today, MPO oversees waste collection in eight Warsaw districts, managing over 23,000 collection points and 62,000 containers, while implementing circular economy strategies and modern technologies to meet EU environmental standards [43].

4.3. Main Source and Composition of Waste

To understand Warsaw's waste management practices more comprehensively, data from the Mazowieckie Voivodeship—which includes the capital—provides valuable insights. As Warsaw is the largest city in the region, this data effectively reflects its municipal waste trends. In 2022, the voivodeship generated 1,973.8 thousand tonnes of municipal waste, accounting for 14.7% of Poland's total. On a per capita basis, this amounted to 358.1 kg per inhabitant. The main source of this waste was households, contributing 1,729.4 thousand tonnes (an increase of 3.3% from 2021), with the remaining 244.4 thousand tonnes coming from municipal services, small businesses, offices, and institutions [41].

Within separately collected waste, there were increases in paper, cardboard, glass, and biodegradable materials, while plastics, metals, electronics, and bulky waste saw slight declines. Biodegradable waste remained the largest fraction, demonstrating continued efforts to improve organic waste separation [41].

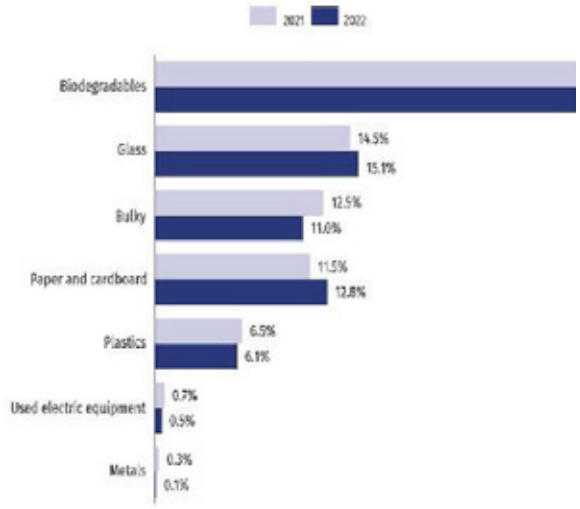

Fig. 10. Share of selected fractions in the total amount of municipal waste collected separately [41]

Rys. 10. Udział wybranych frakcji w całkowitej ilości odpadów komunalnych zebranych selektywnie [41]

4.4. Collection and Transport of Waste

In 2022, 87.6% of total municipal waste came from households. However, mixed waste still dominated, comprising 61.9% of total collected waste. Households alone produced 1,020.9 thousand tonnes of mixed waste (83.6%), averaging 237.4 kg per resident. Other sources generated 200.5 thousand tonnes (16.4%). In contrast, 752.5 thousand tonnes of waste (38.1%) were separately collected—94.2% of which came from households [41].

To assist residents, Warsaw provides updated information via the website warszawa19115.pl, offering guidance on segregation rules, schedules, fees, and regulations. Since 2012, the city has managed collection services, set standardized fees and awarding contracts to private companies handling residential and commercial waste streams including segregated dry waste, glass, bulky items, bio-waste, and mixed waste [40].

The city maintains two Civic Amenity Sites (PSZOK) and operates five mobile collection vehicles (MPSZOK) that service 40 locations citywide. CAS and PSZOK centers accept hazardous waste and bulky items (up to 39 waste types), while MPSZOK vehicles collect 15 types of selectively collected waste [39][40].

From January to June 2023, residents in eight districts generated nearly 255 thousand tonnes of waste. Of this, 167 thousand tonnes (65.5%) were mixed waste. Recyclables included 20 thousand tonnes of paper, 19 thousand tonnes of metals/plastics, and 14 thousand tonnes each of packaging glass and bio-waste. Green and bulky waste were lower at 10.5 and 10 thousand tonnes, respectively [43].

Color-coded bins support waste separation: blue (paper), green (glass), yellow (metal/plastics), brown (bio-waste), and black (mixed waste). The selective collection system, updated in 2014, aligns with EU standards and consists of three methods:

- Drop-off points (MPSZOK/PSZOK) in suburban areas
- Public recycling bins for multifamily buildings
- Kerbside collection for single-family homes [38][40].

Waste collection companies, contracted by the municipality, prioritize recycling. Still, landfilling remains prevalent—47.8% of waste was landfilled in 2022, while 26.8% was recycled [38][41].

Fees vary single-family homes pay PLN 107/month, multi-family households pay PLN 85, with PLN 9 discounts for composting. Non-compliance with segregation rules can double the fee. Mixed waste

is sent to MPO for sorting, while selectively collected fractions go directly to treatment plants [39].

Collection frequency varies:

- Single-family homes: paper, plastic, glass – every 4 weeks; bio – weekly; bulky – every 3 months
- Multi-family buildings: paper, plastic – every 2 weeks; glass – every 4 weeks; bulky – monthly; green (Mar–Nov) and bio – weekly; mixed – twice weekly
- Non-residential properties: most fractions every 4 weeks; bio for gastronomy/markets – twice weekly; mixed – biweekly [39].

Warsaw operates around 100,000 collection points, managing 170,000 containers monthly, emphasizing ease of access and compliance to boost recycling rates [39].

Fig. 11. Waste collection truck
Rys. 11. Samochód do odbioru odpadów

4.5. Waste Processing and Disposal

Waste generated in Warsaw is diverse, posing challenges for processing. Efficient source separation is critical to support treatment systems such as Mechanical-Biological Treatment (MBT). These facilities aim to recover reusable fractions and store the remaining residues [38].

The city's main waste manager, MPO, uses sorting, composting, shredding, and incineration to treat waste. Non-recyclables are incinerated at 900°C, producing energy and slag used in road construction. Mixed waste may also be converted into Refuse-Derived Fuel (RDF), mainly used by cement plants. Only stabilized organic material is sent to landfills [39].

Selectively collected waste is processed as follows:

- Paper, metal, plastic, and glass sent to recyclers
- Bio-waste: composted
- Mixed waste: directed to MBT plants for separation and incineration Only 6–7% of secondary materials can be recovered from unsorted waste, underscoring the importance of proper separation at home [39].

Both municipal and private plants handle Warsaw's waste under Polish regulations. MPO is currently expanding its facilities, including a Recycling and Ecological Education Centre, new bio-waste and bulky waste installations, and a planned biogas plant for organic waste [39].

A major development is the new ZUSOK plant in Targówek, which will process 265,000 tonnes/year of mixed waste, making it Poland's largest energy recovery plant from waste.

In 2022, the Mazowieckie Voivodeship recovered 1,022.8 thousand tonnes (51.8%) of waste:

- Recycling: 528.5 thousand tonnes (26.8%)
- Biological treatment: 256.2 thousand tonnes (13%)
- Incineration with energy recovery: 238 thousand tonnes (12.1%)
- Landfilled waste reached 943.8 thousand tonnes (47.8%), with 7.2 thousand tonnes incinerated without energy recovery [41].

There are 19 landfills across the voivodeship covering 141 hectares. Most are rural, equipped with degassing systems, five of which vent directly to the atmosphere. Landfill gas generated 23,342.8 thousand MJ of heat and 9,581.5 thousand kWh of electricity [41].

Despite advancements, illegal dumping persists. In 2022, 1,088 sites were cleared, collecting 3.4 thousand tonnes of waste, though 157 illegal dumps remain, spanning 86.5 thousand m² [41].

Table 3. Waste Generation, Collection, and Treatment Statistics for Mazowieckie Voivodship (2022)
Tabela 3. Statystyki dotyczące wytwarzania, zbierania i przetwarzania odpadów w województwie mazowieckim (2022).

Description	Amount (thousand tonnes)	Percentage of Total municipal waste (%)
Total municipal waste	1,973.80	100
Waste Collection		
Separately Collected	752.5	38.12
Mixed waste	1,221.30	61.88
Collected from other sources	200.5	10.16
Collected from households	1,020.90	51.72
Waste Procesing and Disposal		
Landfilling	943.8	47.82
Incineration with energy recovery	238	12.06
Incineration without energy recovery	7.2	0.36
Recycling	528.5	26.78
Biological processing (Composting and Fermentation)	256.2	12.98
Controlled landfill sites in operation		-
Number	19	
Area in ha	141	
Illegal dumps		-
Existing	157	
Liquidated	1088	

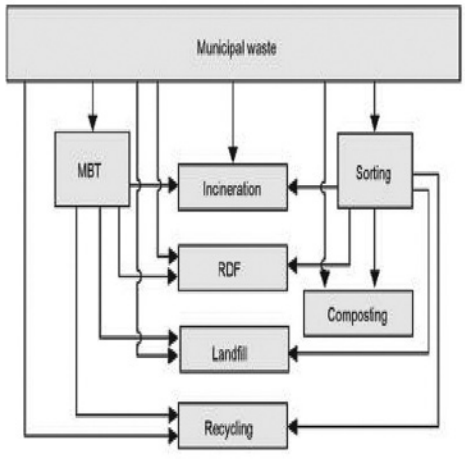

Fig. 12. The municipal solid waste management system in Poland [38]
Rys. 12: System gospodarki odpadami komunalnymi w Polsce [38]

5. Comparative Analysis of Municipal Solid Waste Management in Warsaw and Addis Ababa

Warsaw and Addis Ababa represent two contrasting municipal solid waste management (MSWM) systems shaped by differing socio-economic, infrastructural, and regulatory contexts. Warsaw benefits from an advanced and integrated waste management framework characterized by high recycling rates, structured collection systems, and public participation. With an annual per capita waste generation of approximately 358.1 kg, Warsaw has implemented efficient sorting mechanisms using color-coded bins and Mechanical Biological Treatment (MBT) facilities that recover recyclable materials before final disposal [41]. Nearly 100% of the city's waste is collected, and the use of incineration plants like ZUSOK supports energy recovery from non-recyclable waste [39].

Conversely, Addis Ababa generates less waste per capita—about 0.45 kg/day (164.25 kg/year)—but struggles with inefficient collection systems and minimal segregation. Roughly 25% of the city's waste remains uncollected, often dumped in unauthorized areas. Although some informal recycling occurs, particularly at the Koshe landfill, only about 10% of waste is recycled or composted [41]. The Reppie waste-to-energy plant operates below capacity due to technical limitations and low waste calorific value [41].

While Warsaw's model demonstrates the effectiveness of coordinated infrastructure, policy, and civic engagement, adapting such systems to Addis Ababa would require overcoming significant challenges in awareness, financing, and regulatory enforcement.

Table 4. Comparative Analysis of Municipal Waste Management Systems: Addis Ababa vs. Mazowieckie Voivodeship/Warsaw

Tabela 4. Analiza porównawcza systemów gospodarki odpadami komunalnymi: Addis Abeba i Warszawa/ województwo mazowieckie

Aspect	Addis Ababa	Mazowieckie Voivodeship /Warsaw
Waste Generation		
Waste Generation	0.45 kg/day per capita (164.25 kg/year)	358.1 kg/year per capita
Organic	63.1% of generated waste including food and leaves/grass	34% of total biodegradable waste
Recyclables	19.4% of generated waste including paper, textile, plastic, glass and metal	34.1 % of total waste including paper, plastic, glass and metal
Other	17.5 % of generated miscellaneus waste	11.5 % of total waste including bulky waste and used electronic equipments
Waste Collection		
Collection Coverage	75% of generated waste collected, 25% remains uncollected and dumped illegally.	Almost 100% coverage through a structured system
Type of collected waste	100% mixed waste	34.5 % is Separately collected which can be recycled and 65.5% is mixed waste including collected with black bin
Primary Collection Methods	Door-to-door collection by Micro and Small Enterprises (MSEs) using pushcarts and small trucks.	Curbside collection: Bins for paper, metals/plastics, glass, bio-waste, and mixed waste.
Secondary Collection Methods	Waste transferred to landfill by government and private trucks from communal bins and depots.	Mobile points (MPSZOK) and Civic Amenity Sites (CAS) for drop-off by residents.
Waste Processing and Disposal		
Waste Facilities	Koshe landfill and Reppi waste-to-energy plant	Regulated landfills, ZUSOK incineration plant, and recycling facilities.
Recycling Rate	5% of collected waste	26.78% of total waste
Composting Rate	5% of collected waste	12.98 % total waste
Waste-to-Energy	Reppie plant: Processes 22% collected waste	12.06 % of incineration with and 0.36% of without energy recovery
Landfill Use	73% of collected waste	47.8% of total waste
Public Engagement	Limited awareness programs; reliance on informal networks for recycling.	High participation due to awareness campaigns, guidelines, and clear penalties for non-compliance. Website: warszawa19115.pl provides updates and guidelines.

6. Gaps and Challenges in Addis Ababa's Waste Management System

- **Limited Waste Collection Coverage:**
  Addis Ababa collects only 75% of generated waste, leaving 25% uncollected and often dumped in unauthorized areas. This contributes to pollution and health risks, especially in informal settlements. Waste collection relies on Micro and Small Enterprises (MSEs) using outdated equipment, resulting in poor service coverage compared to Warsaw's near 100% collection rate [41].
- **Inefficient Collection and Segregation Practices:**
  All collected waste is mixed due to a lack of formal source segregation. Informal waste pickers ("koraleo") collect recyclables door-to-door, while MSEs perform basic manual sorting at temporary storage sites. These informal practices are unregulated, posing health risks and reducing waste quality for facilities like the Reppie WtE Plant [41].
- **Underutilized Waste-to-Energy Capacity:**
  The Reppie Waste-to-Energy Plant, designed to process 1,400 tons/day, operates at only 600 tons/day (43% capacity) due to technical issues and poor waste quality from lack of segregation. Despite this, it incinerates 22% of collected waste—higher than Warsaw's rate—and could significantly reduce landfill pressure if fully operational [41].
- **Overreliance on the Koshe Landfill:**
  Koshe landfill receives 73% of collected waste and lacks essential infrastructure like leachate systems and proper covering. It poses environmental risks, including groundwater contamination, and endangers informal workers exposed to hazardous conditions. Ongoing efforts to install gas venting systems are a step forward, but the site remains hazardous [41].
- **Minimal Recycling and Composting Rates:**
  Only 5% of collected waste is recycled and another 5% composted, mostly by informal workers. With organic waste comprising about 60% of total waste, the lack of formal recycling and industrial composting represents a major missed opportunity for resource recovery [41].
- **Low Public Awareness and Engagement:**
  Public understanding of sustainable waste practices is limited. Unlike Warsaw, which has structured awareness campaigns and enforcement, Addis Ababa relies on informal systems, and many residents remain unaware of recycling benefits. Greater public education and engagement are needed to promote source segregation and sustainable habits [41].

7. Recommendation

To tackle Addis Ababa's waste management issues, a multifaceted approach inspired by Warsaw's best practices is proposed:

- **Improving Waste Collection and Segregation**
  - » Install public mixed-waste bins along busy streets to minimize littering.
  - » Support MSEs with modern trucks, tools, and training for improved coverage.

- » Implement source segregation via a color-coded bin system, modeled after Warsaw's household scheme.
- » Enforce penalties for improper waste disposal to boost compliance and awareness [41].

- **Empowering Informal Sector (Koraleos & Wholesalers)**
  - » Formalize koraleos with equipment and training to improve recycling efficiency and expand coverage.
  - » Support wholesalers and Minalesh Tera workers through funding and capacity building to enhance material processing.
  - » Relocate landfill scavengers to safer temporary sorting facilities equipped with infrastructure [41].
- **Improving Processing via MBT and Biogas**
  - » Install MBT systems at storage sites to sort recyclables and organics from mixed waste.
  - » Expand sorting centres to manage increasing volumes and protect informal workers.
  - » Develop biogas plants to convert organic waste (60% of total waste) into renewable energy and fertilizer [41].
- **Enhancing Waste-to-Energy (WtE) Operations**
  - » Upgrade Reppie WtE Plant to achieve its 1,400 tons/day capacity (currently only 600 tons/day).
  - » Promote Reppie as a model to attract investment in WtE technology and expand capacity [41].
- **Landfill Management**
  - » Maintain gas venting systems at Koshe to reduce methane emissions.
  - » Plan for Koshe's closure and convert it into green space.
  - » Build a new controlled landfill with proper leachate management to meet growing demand [41].
- **Strengthening Recycling & Composting**
  - » Subsidize local recyclers and provide equipment to Minalesh Tera workers.
  - » Launch decentralized composting in communities, schools, and farms to manage organic waste [41].
- **Public Awareness & Digital Engagement**
  - » Create a centralized digital platform (like Warszawa19115.pl) to unify waste info and schedules across all weredas.
  - » Run awareness campaigns through schools, media, and community programs.
  - » Engage citizens in cleanup events and composting workshops.
  - » Introduce penalties for non-compliance to reinforce education with enforcement [41].

8. Conclusion

The stark contrast between Warsaw and Addis Ababa's waste systems underscores disparities in infrastructure, regulation, and public involvement. Despite lower waste generation, Addis Ababa struggles with limited collection, mixed handling, and landfill dependence. However, informal recyclers like koraleos play a critical yet undervalued role, while the Reppie WtE Plant offers untapped potential.

By adopting Warsaw-inspired practices—structured segregation, empowering informal workers, expanding processing facilities, and enhancing public engagement—Addis Ababa can build a more sustainable, inclusive waste system. Success will depend on coordinated efforts from government, communities, and the private sector. These strategies not only promise better waste outcomes but also create jobs, cut pollution, and drive sustainable urban growth.

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