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Solid waste management service chain and sanitation safety: a case study of existing practice in Addis Ababa, Ethiopia

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Background: Poor sanitation safety in municipal solid waste management can cause environmental and public health problems. This is the case in Ethiopia, where the sanitation safety standards are low in the municipal solid waste management operations. Therefore, the sanitation safety practices along the solid waste management service chains in Addis Ababa, Ethiopia are poorly understood, and this research will contribute new insights for the scientific community and can also inform policies and the current solid waste management operations in Addis Ababa.

Materials and Methods: This study evaluated the safety of sanitation practices in the solid waste management service chain using a community-based approach in Addis Ababa city from January to August 2023. We have interviewed 384 participants using a cluster-random sampling technique and collected data through direct observations and face-to-face interviews. The study employed descriptive statistics, factor analysis and multiple linear logistic regression to analyze the data.

Results: The findings of the study revealed significant variations in sanitation safety practices and risks among households during solid waste management. While 60% of households practiced solid waste segregation, only 15% of them followed safe segregation practices. The majority of households (85%) used unsafe segregation practices, such as mixing different types of waste and storing wet and dry waste together. Additionally, 85% of households used storage and transport containers that had leaks, potentially leading to contamination and infection. Furthermore, the study identified sanitation safety risks and practices at waste collection and transport sites. The risks included solid waste droppings during transport, inadequate vehicle cleaning and disinfection, lack of personal protective equipment (PPE) for workers, and uncovered waste collection vehicles, leading to environmental contamination. At transfer stations, the study found several risk factors, such as the lack of protection from animals and human activities, absence of shower facilities for workers, and inadequate storage facilities for PPE and tools. The transfer stations also lacked odor-neutralizing systems, proper waste handling practices, and physical fly barriers. Workers did not have the opportunity to shower after work, further increasing the risk. The sanitation safety practices and risks at solid waste treatment/disposal sites were also assessed. The study revealed medium risks associated with waste treatment/disposal operations, including working without PPE, handling contaminated containers and raw waste, and releasing airborne particulates that could be inhaled by workers or the nearby

community. Factor analysis was conducted to categorize the variables related to sanitation safety practices. Six factors were identified, explaining approximately 60.6% of the overall variance. These factors represented different aspects of sanitation safety, including onsite waste handling practices, failure to maintain proper standards, risks related to unsafe waste storage, failure to properly store wastes at the household level, having safe storage practices, and unsafe waste segregation and storage. The study also examined the association between sanitation safety practices and sociodemographic factors using multiple linear regression analysis. Marital status, education, occupation, and income were found to be significant factors influencing sanitation safety practices during onsite waste handling. Income and marital status had the highest contribution, while occupation had the lowest contribution.

Conclusion and Recommendation: the research findings highlight the wide variation in sanitation safety practices and risks associated with solid waste management. The study emphasizes the need for improved waste management practices at the household level, waste collection and transport sites, transfer stations, and waste treatment/disposal sites. The identified risk factors should be addressed through targeted interventions, including public awareness campaigns, proper training of waste management workers, and the implementation of safety protocols and infrastructure improvements. Additionally, sociodemographic factors play a role in determining sanitation safety practices, emphasizing the importance of considering these factors when developing waste management strategies and interventions.

KEYWORDS

municipal waste, sanitation chain, sanitation safety, solid waste, waste collection, waste disposal

1 Introduction

The United Nations Environment Programme (Wilson et al., 2015) global waste management outlook warns that the growing volume and complexity of garbage produced by the modern economy puts ecosystems and human health at risk. An estimated 11.2 billion tonnes of solid trash are collected annually worldwide, and around 5% of the global greenhouse gas emissions are caused by organic waste decomposition (Ram et al., 2021). Solid waste management (SWM) is the process of collecting, treating, and disposing of solid materials that are discarded because they have served their purpose or are no longer useful. SWM can pose various environmental, health, and safety risks, such as pollution, disease transmission, fire, explosion, injury, and accidents (Naidu et al., 2021).

How much people are exposed depends on many factors. It is important to consider how different solid waste management methods, ways of moving contaminants, and health effects are connected. People can get exposed by touching waste, breathing polluted air, or eating polluted food or water (Alam et al., 2022).

Solid waste management has different activities along the service chain, which include generation, collection, transportation, treatment, reuse, recycling, and disposal. Risks are present at every step of the service chain, from the point of generation at homes to solid waste recycling and disposal (Ike et al., 2018; Beka and Meng, 2021). Solid waste management workers can be affected by various health and sanitation safety risks, especially injuries, allergies, respiratory, gastrointestinal, and infectious diseases (Cruvinel et al., 2019; Melaku and Tiruneh, 2020). For instance, according to a study among municipal solid waste workers in Egypt, poor personal hygiene, inadequate use of personal protective equipment, and failure to apply safety measures were associated with accidents and needle stick injuries in 46.5% and 32.7% of the study participants respectively (Madian and Abd El-Wahed, 2018). A similar study also reported that 73.8% of the study participants had unsafe solid waste management practices which caused a high prevalence of gastrointestinal, respiratory, skin, and other infectious diseases (Kasemy et al., 2021). Another similar assessment on occupational health and safety among scavengers in the Gaza Strip, Palestine, revealed that the occupational health and safety conditions of waste pickers are in a state of constant deterioration, primarily due to the informal nature of their work. These waste pickers are reportedly facing severe hardships, with the majority lacking access to potable water, adequate sanitation, and hygienic places to sleep and eat. Furthermore, none of the waste pickers have ever received occupational health and safety training, exacerbating their vulnerability and health risks (Al-Khatib et al., 2020).

Improper disposal of household solid waste can cause environmental degradation and deterioration. When organic solids decompose, they produce odors, leachate, and other acids that can destroy plants, dissolve important soil minerals, and contaminate groundwater. This can lead to ecosystem disturbances by some organisms such as water hyacinth, which kills aquatic life and causes water-borne diseases such as cholera, diarrhea, dysentery, and typhoid (Mandevere and Jerie, 2018; Rautela et al., 2021).

Waste generation in Addis Ababa is driven by rapid urbanization, population growth, and economic activities. The

waste includes household, commercial, industrial, and healthcare waste, with a significant portion being organic waste (Mekonnen et al., 2024). Waste collection in Addis Ababa faces several challenges, including inadequate coverage, irregular service, and insufficient infrastructure. Many areas, especially informal settlements, do not receive regular waste collection services. Collection is often done using outdated and insufficient equipment, leading to inefficiencies and environmental pollution. In recent years, efforts have been made to improve collection services through the involvement of private sector players and community-based organizations. These initiatives aim to enhance the reach and efficiency of waste collection services across the city (Teshager Alemu, 2017). Transporting waste to disposal sites is another critical stage. The city's waste transportation system is often hindered by traffic congestion, inadequate vehicles, and poor road conditions. This results in delays and increases the risk of waste being dumped illegally or improperly managed. The city has initiated waste-to-energy projects, such as the Reppie waste-to-energy facility, which aims to convert waste into electricity. However, these projects face challenges related to technology, maintenance, and operational sustainability (Teshager Alemu, 2017). A significant portion of the waste generated in Addis Ababa is organic, making composting a viable treatment option. However, the city's composting infrastructure is underdeveloped, and much of the organic waste ends up in landfills due to insufficient sorting at the source. Plastic and metal recycling facilities exist but are limited, affecting the overall efficiency of the waste management system (Cheru, 2016).

The primary disposal site for Addis Ababa is the Repi landfill, also known as Koshe, which has been operational for several decades. Despite efforts to improve its management, the landfill remains a significant environmental and health concern. The city has explored waste-to-energy projects to reduce landfill dependency, but these initiatives are still in early stages (Furgasa et al., 2023).

Municipal solid waste poses a risk to the environment and public health in Addis Ababa, as only a fraction of it is properly managed. Out of the daily waste generation, 65% is collected and disposed of, 5% is recycled, 5% is composted, and the rest 25% is left uncollected and dumped in unauthorized areas (Gelan, 2021). In the city, inadequate household solid waste collection and disposal has led to significant waste piles in open temporary collection sites, building corridors and sewers. Until it is taken to the city's disposal site, the collected garbage is kept at roadside and between community neighborhoods. Furthermore, the collected waste is entirely left outside for days, exposed to sun and rain, and different animals including street dogs, cattle and horse scatter the solid waste in the surrounding. The piles and scattered wastes produce an offensive odor, ruin the surrounding urban landscape, attract pests, and interfere with local people's daily activities (Mohammed and Elias, 2017). Meanwhile, uncollected waste is disposed informally, with a small percentage being burned and dumped in open areas, drainage canals, rivers and gorges, and on the street (Gelan, 2021). The open-air burning and spontaneous combustion in dumping sites produce air pollution and unpleasant odors, which can travel several kilometers. These problems are exacerbated in areas where there is no solid waste collection at all such as in slum areas (Mazhindu et al., 2010).

The improper management of the solid waste in the city has become a threat to the surface and groundwater sources. The solid waste management system has several problems, despite the gravity of the issue. For instance, a study conducted on occupational injuries and illness symptoms among Addis Ababa city solid waste collectors reported that only 43.6% of municipal solid waste collectors were using some form of personal protective equipment (PPE) while performing their duties. However, 22.5% of these PPE users stated that they did not use their PPE constantly while performing their duties, indicating their awareness gap. Another study on the occupational health conditions and contributing factors among municipal solid waste collectors reported that 71.1% of the study participants did not receive occupational safety training (Melaku and Tiruneh, 2020). Approximately 74% of this study participants did not immediately manage their personal hygiene; 73.1% of municipal solid waste collectors have no access to PPE from their company and are forced to buy PPE for themselves (Melaku et al., 2020).

The study conducted on groundwater pollution and public health risk analysis in the vicinity of Reppi solid waste dumping site also concluded that the solid waste disposal site significantly impacts groundwater pollution and public health (Zedwie, 2007). A study carried out on the health risk assessment of heavy metals in exposed workers of municipal waste recycling facility in Iran showed that, waste recyclers, dismantlers and waste sorters have the highest exposure and public health risks to hazardous metals due to their occupational exposure who are working in the Municipal solid waste recycling sites (Ghobakhloo et al., 2024).

Studies on sanitation safety measures, standards, and approaches to implementation practice along the whole solid waste management service chain are scarce. There is no community-based study on assessing the existing practice of sanitation safety along the solid waste management service chain in Addis Ababa, Ethiopia. The current safety practices, risks, and their impact on public health and the environment are not well understood. Studies that can help to propose corrective measures that can help to appropriately maintain the sanitation safety practices across the municipal solid waste management service chains are rare. Therefore, this study was designed to look how the sanitation safety standards are practiced/implemented along the solid waste management service chains in Addis Ababa and generate scientific evidence that can inform policies and the current solid waste management operations.

2 Materials and methods

2.1 Description of study area and sampling sites

The study area was Addis Ababa, the capital city of Ethiopia and the seat of both federal and regional governments. The city covers an area of 54 km^2 and has an altitude ranging from 2,000 m to 2,800 m. It is surrounded by the Oromia National Regional State and divided into 11 sub-cities and 116 Districts. The city has a population of approximately 6 million people and is experiencing rapid urbanization and infrastructure development. Addis Ababa hosts over 2,000 industries, such as potable water, cement, textile, beverage

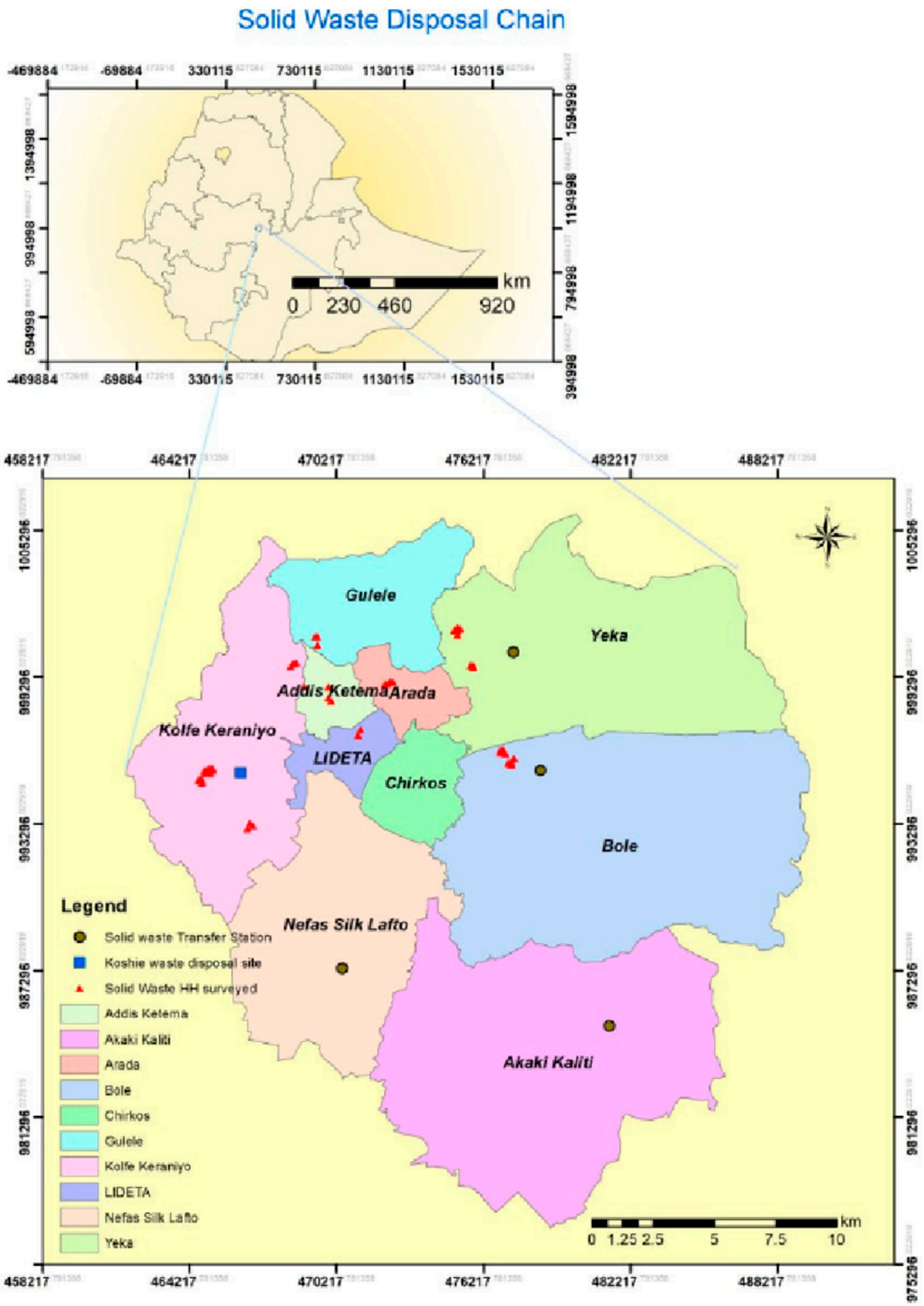

FIGURE 1
Maps of study sites showing the solid waste management service chain.

and alcohol, tobacco, leather, tannery, plastic, and food factories. The city is the country's industrial, cultural, administrative, commercial, and modern hub, as well as one of the central hubs in Africa with many international organizations and institutions (Spaliviero and Cheru, 2017). The African Union, United Nations Economic Commission for Africa, and more than a hundred

embassies are in Addis Ababa. The city is regarded as Africa's diplomatic capital and a symbol of humanitarian progress on the continent.

The study assessed the sanitation safety practices in 384 households (HHs) located in 23 districts of the ten sub-cities, which are represented by highlighted marks (Figure 1), and field observations were conducted on the operations of four solid waste collection and transport operations, at four solid waste transfer stations and in one final disposal, and recycling center.

2.2 Study design, and population selection

This study aimed to assess the sanitation safety of the solid waste management service chain in Addis Ababa city, Ethiopia, from January to August 2023. The study used a community-based cross-sectional design and collected both qualitative and quantitative data from various sources. The study population included community members who generated solid waste and solid waste management service providers who were involved in waste collection, transportation, treatment, and disposal. The study adapted tools from the World Health Organization (WHO) Water and Sanitation Safety planning manual (Bartram, 2009; World Health Organization, 2015) and to measure the sanitation safety indicators along the service chain.

2.3 Sample size, sampling technique, and sampling procedure

2.3.1 Sample size

The sample size for the quantitative data was determined using the single population proportion formula. Given the parameters, the calculation was based on a 95% confidence level, represented by a Z value of 1.96, and a precision or margin of error set at 5%. In the absence of prior studies on sanitation safety along the solid waste management service chain in Addis Ababa, and lacking the time to conduct a pilot study, we assumed the proportion (P) to be 0.5. This assumption provides the most conservative estimate, ensuring the largest necessary sample size.

The formula (Degu, 2005) used is as follows:

$$n = \frac{Z^2 P(1-P)}{d^2}$$

$$n = \frac{(1.96)^2 * 0.5\,(0.5)}{0.05^2}$$

$$n = 384$$

Where, n = the required sample size

p = the average proportion of in different settings.

Z = the critical value at 95% confidence level = 1.96.

d = precision (margin of error) = 5%.

To account for a potential non-response rate of 5%, the initial sample size of 384 was increased, resulting in a final sample size of 403 participants. This adjustment aims to mitigate the impact of non-participation and ensure sufficient data collection. Ultimately, data was collected from 385 participants, representing a 5% non-response rate.

The achieved sample size of 385 participants was designed to be representative of the broader population, based on several key factors. To enhance representativeness, a random sampling method was employed, ensuring that each member of the target population had an equal chance of being selected. This minimized selection bias and helped to achieve a sample that mirrors the population's diversity. The sample covered various geographical areas within Addis Ababa and included diverse demographic segments such as different age groups, genders, socio-economic statuses, and educational backgrounds. This diversity helps in capturing a wide range of perspectives and behaviors related to sanitation safety.

While the calculated sample size included a 5% buffer for non-response, the final sample size of 385 falls slightly short of the intended 403. This slight shortfall is within acceptable limits and still allows for a reliable representation of the population. Efforts were made to follow up with non-respondents and encourage their participation to reduce non-response bias.

In the absence of previous studies specifically on sanitation safety along the solid waste management service chain in Addis Ababa, the use of a conservative proportion estimate ($p = 0.5$) provided a robust and safe estimate for the required sample size. Careful design and implementation of the survey further enhanced representativeness. This included clear and unbiased questions, trained data collectors, and ensuring accessibility of the survey to all potential participants, including those with limited literacy or digital access.

The sample size of 385, despite falling slightly short of the intended 403, was calculated using rigorous statistical principles to ensure representativeness. Random sampling, demographic and geographical coverage, and efforts to minimize non-response bias were critical in achieving a representative sample. While the methodology provided a solid foundation, the actual representativeness also depended on the practical execution of the sampling and survey processes. By following these guidelines, the sample is designed to be a reliable representation of the population for the study on sanitation safety along the solid waste management service chain in Addis Ababa.

2.3.2 Sampling technique and sampling procedure

The sampling techniques used for the quantitative data included simple random sampling and cluster sampling. Figure 2 illustrates the household sampling procedures followed. For the qualitative data, purposive sampling was employed. The steps of the sampling procedure was as follows:

First, we identified the key actors involved in the solid waste management service chain in Addis Ababa, such as waste collectors, transporters, treatment plant operators, landfill workers, and municipal officials.

Second, we selected a representative sample of each actor group purposively based on their availability, willingness, and experience in the solid waste management service chain.

Third, we conducted in-depth interviews with the selected participants using a semi-structured interview guide.

2.4 Data collection methods and tools

The study utilized a cross-sectional research design to evaluate sanitation safety practices in solid waste management. The data

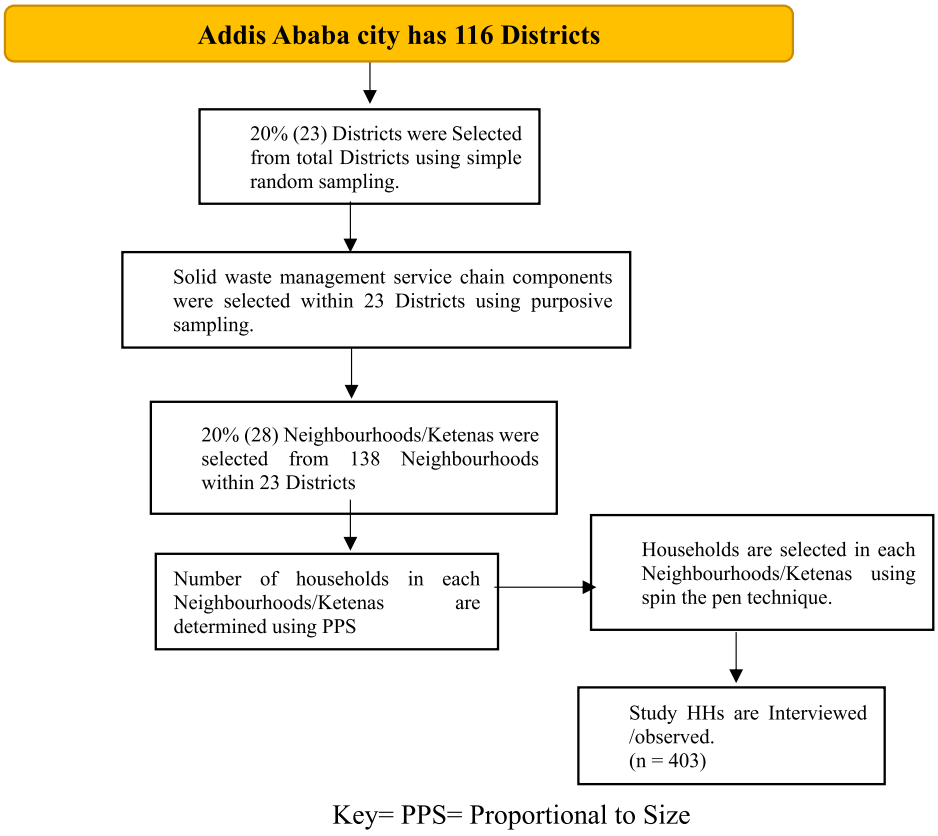

FIGURE 2
Sampling technique and sampling procedure.

collection process adhered to the methodology outlined in the WHO Sanitation Safety Planning Manual, Second Edition (World Health Organization, 2015). A structured semi-quantitative risk assessment questionnaire was developed, taking into account the manual's guidelines and tailored to the specific study context. The questionnaire encompassed multiple sections that addressed various facets of solid waste management, including household waste handling practices, waste collection and transport, transfer stations, and solid waste treatment/disposal sites.

To ensure the credibility and accuracy of the data, a pilot study was conducted with a small sample of participants. Study subjects and areas under the solid waste management service chain were selected from the total number of Addis Ababa city administration Districts using simple random and cluster sampling methods. The primary sampling units, Districts, were selected using simple random sampling techniques. Accordingly, 20% (23 out of 116) of the total Districts were selected for the household survey.

Following the selection of the primary sampling unit (Districts), secondary sampling unit (neighborhoods) were considered as clusters, assuming homogeneity among them concerning sanitation safety practices. Neighborhoods within the randomly selected Districts were included based on the Probability Proportion to Sampling from each sampled District. The sampling frame was constructed by obtaining a list of neighborhoods with their household size from the sampled Districts. Subsequently, neighborhoods were randomly selected from the 23 Districts, resulting in a total of 28 neighborhoods (20% of the 138 neighborhoods).

The number of households in each selected neighborhood was determined using the Probability Proportional to Size (PPS) method, where size is defined as the total number of households derived from the population size in the sampled neighborhoods. Finally, tertiary sampling units (households) were selected using the "spin the pen" technique to identify the starting point within a sampled neighborhood. Spinning a ballpoint pen at the center of the neighborhood helped the study team randomly choose a direction to follow. Once the starting household was identified, households who were beneficiaries of the solid waste service chain and residing in the sampled neighborhoods were interviewed/observed using a standardized questionnaire until the desired sample size per neighborhood was achieved.

Other components of the solid waste management service chain, including waste collection, transportation, treatment, and disposal sites and service providers, were purposively selected. Field observations were conducted on the operations of four solid waste collection and transport operations, four solid waste transfer stations, and one final disposal and recycling center. Key informant interviews were also conducted with responsible personnel at the solid waste collection and transport operations, solid waste transfer stations, and the final disposal and recycling center to obtain additional primary information on the practice of safe solid waste management operations. These personnel provided insights into the facilities and processes involved.

TABLE 1 Semi-quantitative risk assessment matrix for sanitation safety practices in solid waste management.

Risk level	Risk score range	Description
Low risk	<6	Sanitation safety practices are well-implemented, with minimal risk factors identified
Medium risk	16–12	Some sanitation safety practices have moderate risk factors that may require attention and improvement
High risk	13–32	Significant sanitation safety risks are present, indicating a need for immediate action and remediation measures
Very high risk	>32	Severe sanitation safety risks exist, posing a serious threat to public health and requiring urgent intervention to prevent potential outbreaks or hazards

Data collectors, each holding a Bachelor of Science degree in Environmental Health, were carefully selected based on their expertise and experience. They underwent a comprehensive 2-day training program that included 1 day of theoretical training and 1 day of practical pretesting. The training covered the study's objectives, ethical considerations, detailed instructions on administering the questionnaire, and techniques for accurate data recording.

The proficient data collectors conducted household surveys under the supportive supervision of field supervisors who possessed a Master of Science degree in Environmental Health. The field supervisors provided continuous guidance and quality control to ensure the reliability of the data collected. Additionally, four data collectors with a Master of Science degree in Environmental Health were assigned to collect qualitative data across the solid waste management service chain, conducting in-depth interviews and focus group discussions.

The questionnaires, initially designed in English, were translated into the local language, Amharic, to facilitate effective communication and ensure comprehension by the respondents. The translation process included back-translation to verify accuracy and cultural relevance. Based on feedback from the pilot study, the questionnaire was further refined to improve clarity and relevance.

Trained surveyors administered the finalized questionnaire to the selected households in face-to-face interviews, ensuring that all sections were thoroughly covered. The administration process included obtaining informed consent, explaining the purpose of the study, and ensuring the confidentiality of the responses. In addition to the survey, direct observations were conducted at waste collection and transport sites, transfer stations, and solid waste treatment/disposal sites. These observations aimed to evaluate sanitation safety practices and identify potential risks, providing a comprehensive understanding of the solid waste management system.

2.5 Data processing and analysis

The collected data underwent a series of steps, including data entry, cleaning, editing, and analysis, conducted by the principal investigators using SPSS version 26 (Statistical Package for the Social Sciences). These processes aimed to ensure the accuracy, consistency, and completeness of the data, enhancing the reliability of the analyzed results.

To categorize sanitation safety risk practices, the study followed the risk scoring system outlined in the WHO Sanitation Safety Planning Manual, Second Edition. Risk levels were classified as low risk, medium risk, high risk, and very high risk. Table 1 shows semi-quantitative risk assessment matrix we have used to analyse the sanitation safety practices along the solid waste management service chain:

Diagnostic sanitary inspection questions were utilized to assign standard scores to each component of the safe solid waste management system, enabling the evaluation of risk levels associated with sanitation safety practices.

Descriptive statistics, such as frequency tables, percentages, means, and standard deviations, were employed to analyze most variables. These statistics provided a comprehensive overview of the data, allowing for a better understanding of the distribution and characteristics of the variables.

Additionally, factor analysis was conducted to assess the variability and identify common themes among observed, correlated variables related to sanitation safety practices. This analysis aimed to determine the relative importance of variables contributing to sanitation safety risks at the household level. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy value of 0.680 indicated that the manifest variables had enough in common to justify the use of factor analysis on the empirical data, supporting the validity of this technique. To enable linear regression analysis, transformations were applied to the originally categorical data, creating continuous data. Multiple linear regression was then conducted to estimate the relationship between sanitation safety practices and socio-demographic variables.

The data cleaning process ensured accuracy, consistency, and completeness of the data and variables, enhancing the reliability of the analyzed results.

3 Results

3.1 Socio-demographic characteristics

A total of 384 individuals (95% participation rate) provided information on their gender, religion, education level, marital status, and income for the research. Table 2 presents the frequency (percentage) of these major socio-demographic characteristics of the study population.

3.2 Sanitation safety and risk assessment in solid waste management operations

3.2.1 Sanitation safety and risk in household solid waste management

The study aimed to assess sanitation safety practices and associated risks in household solid waste management within the

TABLE 2 Socio-demographic characteristics of study participants.

Variables	Characteristics	Frequency (%)
Gender	Female	146 (38)
	Male	238 (62)
Family	Daughter/son	98 (26)
	Father	51 (13)
	House maid	37 (10)
	Mother	148 (39)
	Others	50 (13)
Education	Can not read and write	36 (9.4)
	Primary education (1–8)	88 (22.9)
	Higher diploma (diploma to Masters)	92 (24)
	Read and write only	57 (14.8)
	Secondary (9–12)	111 (28.9)
Marital status	Married	223 (58.1)
	Separated	20 (5.2)
	Single	119 (31)
	Widow	22 (5.7)
Income	High (>25,000 ETB)	20 (5.2)
	Intermediate (8,000–25,000 ETB)	198 (51.6)
	Low (<8,000 ETB)	166 (43.2)
Occupation	Government employee	52 (13.5)
	Private employee	94 (24.5)
	Business	41 (10.7)
	Housewife	105 (27.3)
	Daily laborer	20 (5.2)
	Retired	8 (2.1)
	Other (Driver, student, maids, jobseeker, have no job)	64 (16.7)

study area. Sixteen indicators were used, categorized according to the WHO Sanitation Safety Planning Manual (World Health Organization, 2015). These indicators were classified into four levels of sanitation safety risk: low (<6), intermediate (6–12), high (13–32), and very high (>32), with higher scores indicating higher risks.

Results revealed significant variations in sanitation safety practices and risks among households. Hazardous practices were observed, indicating significant risks to human health and the environment. For example, while 60% of households practiced solid waste segregation, only 15% implemented safe segregation practices, such as using separate bins, washing, and drying waste before storage, and using protective gloves and masks. The remaining 85% of households engaged in unsafe segregation practices, including mixing different waste types and storing wet and dry waste together without any protection. Additionally, 85% of households used leaky storage and transport containers, leading to potential contamination and infection.

Nevertheless, according to the risk level categorization by the World Health Organization (WHO), the findings indicated that a significant majority of households (88%) were classified as low risk. Conversely, 12% of households were categorized as having an intermediate risk level. Notably, no households were identified as having high or very high-risk scores.

Factor analysis was conducted to further examine sanitation safety practices and risks related to household solid waste management which helped to reduce the number of variables, categorize them into groups, and ascertain the significance of each variable in relation to the risks of sanitation safety at the household level (Table 3). To determine the number of factors to retain, the eigenvalue-greater-than-one (1) retention criterion was utilized. Accordingly, six factors were retained, explaining approximately 60.6% of the overall variance. Conversely, the remaining ten factors were excluded as they collectively accounted for only about 39.9% of the total variance.

TABLE 3 Factor analysis—total variance explained.

Component	Initial eigenvalues			[a]ESSL			[b]RSSL		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.18	19.893	19.893	3.183	19.893	19.893	1.884	11.777	11.777
2	1.88	11.748	31.641	1.88	11.748	31.641	1.817	11.354	23.132
3	1.35	8.451	40.092	1.352	8.451	40.092	1.711	10.696	33.828
4	1.21	7.556	47.648	1.209	7.556	47.648	1.609	10.054	43.882
5	1.07	6.657	54.305	1.065	6.657	54.305	1.49	9.313	53.195
6	1.01	6.295	60.6	1.007	6.295	60.6	1.185	7.405	60.6
Extraction Method: Principal Component Analysis									

[a]ESSL: extraction sums of squared loadings.
[b]Rotation Sums of Squared Loadings.

The varimax rotation with Kaiser normalization identified six factors from the indicator variables. The four variables that loaded high on Factor 1 were related to "sanitation safety practices during onsite waste handling." These variables were access to a solid waste collection service, proper onsite solid waste storage, waste segregation at home, and handwashing after waste handling. Factor 2 represented "failure to maintain proper sanitation safety standards in waste storage and safe waste handling." The three variables that loaded high on this factor were mixing hazardous wastes with other wastes, unclean waste container, and hand contamination due to lack of handwashing. Factor 3 depicted "risks related to unsafe management of waste storage at household level". The three variables that loaded high on this factor were emission of airborne particulates from poor sealing of waste storage containers, exposure to sanitation safety risks during primary collection, and poor waste storage at household level. Factor 4 indicated "failure to properly store wastes at household level." The four variables that loaded high on this factor were lack of access to handwashing facilities, presence of scavenging animals and rodents at waste storage container, presence of flies/bad smell in the storage container, and presence of accumulated refuse near to the houses (20 m). Factor 5 described "having safe storage at house". The four variables that loaded high on this factor were airborne particulates from poor sealing of waste storage containers, presence of flies/bad smell in the storage container, accumulated refuse near household, and leak-free closed container for onsite storage. Factor 6 reflected "Unsafe waste segregation and storage." The two variables that loaded high on this factor were safe waste segregation practice and waste scattering/splashing from waste storage container (especially solid waste, urine, faeces, tissue) and contaminates surfaces.

3.2.2 Sanitation safety practices and risk at the waste collection and transport sites

The study employed a health risk assessment matrix to evaluate sanitation safety practices and risks in solid waste collection and transport across four operation areas (Akaki kality, Bole, Yeka, and Nifas Silk-Lafto sites). Fourteen sanitation safety risks/practices were identified, including waste droppings during transport, inadequate vehicle cleaning and disinfection, lack of personal protective equipment (PPE) for workers, and uncovered waste collection vehicles, leading to environmental contamination. Observations at the collection and transport sites highlighted risks faced by workers, such as the inability to shower after work, handling different waste types, feeling stressed and disrespected, and wearing dirty and damaged PPE. These factors posed high threats to human health and the environment.

3.2.3 Sanitation safety and risk at transfer stations

The study assessed sanitation safety practices and risks at four transfer stations. Thirteen diagnostic indicators were collected, all of which (100%) were identified as risk factors for safe solid waste management at the transfer stations. Risk factors included lack of protection from animals, scavengers, and human activities, absence of shower facilities for workers, inadequate facilities for washing boots and tools, absence of separate storage facilities for workers' clothing and PPE, lack of odor-neutralizing systems, failure to practice "first-in, first-out" waste handling, absence of physical fly barriers, and workers not showering after work. All these factors were observed as the highest risk factors related to ineffective sanitation safety practices during solid waste management at the transfer stations.

3.2.4 Sanitation safety and risk at solid waste treatment/disposal site

The study assessed sanitation safety practices and risks at Reppi/Koshe solid waste disposal and recycling site. The study utilized a sanitary safety inspection checklist adapted from WHO and other sources to assess sanitation safety practices and risks associated with solid waste disposal and reuse. Out of the eleven sanitary safety assessment questions, nine (82%) were identified as risk factors for safe solid waste management at the Solid Waste Treatment/Disposal Site which is classified as "medium risk" to workers, the nearby community, and the environment as per the WHO semi quantitative risk score levels due to waste treatment/disposal operations. Risk factors at the disposal site included working without personal protective clothing, handling contaminated containers and raw waste, splashing contaminated waste on operators, and releasing airborne particulates that could be inhaled by operators or the nearby community. Table 4 shows the summary of risk levels of

TABLE 4 Summary of the risk levels of sanitation safety practices along the solid waste management service chain.

Solid waste management service chain	[a]Score	%	WHO risk level			
			Low risk<6	Medium risk 6–12	High risk 13–32	Very high risk >32
Solid Waste collection and transport sites	14/14	100%			14	
Solid Waste transfer stations	13/13	100%			14	
Solid waste treatment/disposal site	9/11	82%		9		
Household level sanitation safety practice	4/16	25%				

[a]The four levels of sanitation safety risk: low (<6), intermediate (6–12), high (13–32), and very high (>32).

TABLE 5 Multiple linear regression analysis of sanitation safety practices and sociodemographic characteristics of the households.

Sociodemographic variables	Unstandardized coefficients		Standardized coefficient	t-value	Sig (95% CI)
	B	Std. Error	Beta		
Constant	0.816	0.065		12.587	0.00
Marital status	−0.056	0.016	−0.176	−3.499	0.001
Education	0.002	0.01	0.011	0.215	0.83
Occupation	0.016	0.005	0.155	3.142	0.002
Religion of the respondent	−0.017	0.015	−0.057	−1.143	0.254
Income of the HH	−0.117	0.02	−0.284	−5.774	<0.001

sanitation safety practices along the solid waste management service chain evaluated by standard risk scores based sanitary inspection questions (SIQ).

3.3 The association between sanitation safety practices and sociodemographic factors

Multiple linear regression was conducted to determine if the dependent variable shows a linear relationship with the independent variables (Socio demographic variables) (Table 5). Correlation analysis was conducted to examine the strength of relationship between independent and outcome variables. It is observed that gender, marital status, education, occupation, and income are highly correlated. The multiple linear regression analysis shows that marital status, education, occupation, and income of the respondent are significant ($p < 0.05$). More specifically, income and marital status have the highest contribution to applying sanitation safety practices during onsite waste handling; whereas occupation had the lowest contribution as indicated in a standardized beta coefficient column (Table 5).

4 Discussion

The Our study's results reflect a scenario where the majority of households exhibit intermediate risk in their waste management practices. This intermediate risk category suggests that while some waste management measures are in place, they are insufficient to mitigate potential adverse effects. Such practices include sporadic waste collection, improper disposal methods, and a lack of waste segregation, all of which contribute to increased risks of health and environmental degradation. This finding aligns with previous research conducted in developing countries, which similarly reports suboptimal waste management practices and the associated risks (Srivastava et al., 2015; Mmereki et al., 2016; Serge Kubanza and Simatele, 2020).

For instance, studies in urban areas of developing countries frequently highlight challenges such as inadequate waste collection infrastructure, limited recycling facilities, and inefficient waste disposal practices (Wilson and Velis, 2014). These deficiencies often result in health risks such as the spread of infectious diseases, including cholera and respiratory infections, and environmental problems such as soil and water contamination, as noted by several researchers (Hoornweg and Bhada-Tata, 2012; Katiyar, 2016). The intermediate risk levels observed in our study reflect a similar pattern of inadequate waste management practices that have been documented globally.

The implications of these practices are profound. Poor waste management can lead to the accumulation of waste in public spaces, creating breeding grounds for vectors like mosquitoes and rodents, which can transmit diseases (Akmal and Jamil, 2021). Furthermore, improper waste disposal can lead to the leaching of contaminants into groundwater and the emission of greenhouse gases from decomposing organic waste, both of which have long-term environmental consequences (Kaza et al., 2018). The findings from this study are consistent with these observations,

reinforcing the understanding that intermediate levels of risk in household waste management can have serious repercussions for public health and environmental sustainability.

Comparative analysis with similar research in developing countries reveals that our findings are part of a broader trend (Wilson et al., 2012) which demonstrate that in many developing regions, the waste management systems are often inadequate due to infrastructural limitations, economic constraints, and insufficient regulatory frameworks. This study's results contribute to a growing body of evidence indicating that without significant improvements in waste management practices, communities will continue to face health and environmental risks.

Socio-demographic factors, such as marital status, education, occupation, and income, were found to significantly influence sanitation safety practices. Married individuals tended to handle household waste more safely than single or divorced individuals. Income emerged as the most important factor for safe waste segregation and storage, as higher and middle-income households had better sanitation facilities and equipment. Education played a role in the safety of waste storage, as more educated individuals had greater awareness, knowledge, and access to information and technology for reducing sanitation risks. Occupation had the least impact on maintaining sanitation safety standards, with housewives, maids, and students being more exposed to unsafe waste handling practices than other professionals.

The findings align with a study conducted in the East Coast of Malaysia (Fadhullah et al., 2022), which also identified income and marital status as significant influencers of sanitation safety practices. However, our study revealed a much lower percentage (15%) of households practicing safe waste segregation compared to the study in Malaysia. These differences may be attributed to socio-economic and cultural factors that influence waste management behaviors in different countries. Similarly, a study in Benin highlighted the influence of socio-demographic characteristics, including income, marital status, and education level, on adopting good hygiene and sanitation practices (Sintondji et al., 2017). Our study is consistent with a study conducted in Bogotá, Colombia, which pointed out that low income and education levels impact households' sanitation safety practices during solid waste management (J Padilla and Trujillo, 2018).

Education emerged as a significant determinant contributing to household-level solid waste handling and transport. Better awareness of the risks associated with solid waste led to more careful and effective waste handling and transport practices. Households with higher education levels demonstrated greater awareness of the dangers of solid waste, as supported by evidence from various countries such as Malaysia (Afroz, 2011; Al-Dailami et al., 2022) and Islamabad (Anjum, 2013).

The findings from our study align with several other studies conducted globally. For instance, research in Benin highlighted the influence of socio-demographic characteristics, including income, marital status, and education level, on adopting good hygiene and sanitation practices (Sintondji et al., 2017). The consistency of our findings with those from various regions underscores the universal impact of socio-demographic factors on waste management practices.

However, the disparities observed, such as the lower percentage of households practicing safe waste segregation in our study compared to Malaysia, suggest that socio-economic and cultural factors play a significant role in shaping waste management behaviors. These differences highlight the need for tailored interventions that consider the unique socio-demographic contexts of different communities.

Education emerged as a particularly significant determinant in enhancing household-level solid waste handling and transport. Households with higher education levels demonstrated a greater awareness of the risks associated with solid waste, leading to more careful and effective waste handling and transport practices. This finding is supported by evidence from multiple studies, which indicate that better-educated individuals are more likely to adopt safer sanitation practices due to their increased awareness and access to relevant information and technologies. The consistency of our findings with those from various regions underscores the universal impact of socio-demographic factors on waste management practices.

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The study also revealed unsafe and risky conditions during waste collection and transport operations, exposing workers to various risks. Inadequate access to personal protective equipment, sanitation facilities, and safe waste collection and transport equipment, along with low worker awareness of the risks associated with handling solid waste, contributed to these unsafe conditions. This finding is consistent with a study conducted in Alexandria, Egypt (Abd El-Wahab et al., 2014) which identified municipal solid waste management as one of the most dangerous jobs, exposing households and workers to physical, biological, and chemical hazards and occupational-related morbidities.

At the transfer station, all thirteen diagnostic indicators were identified as risk factors, indicating that several factors negatively affect the service chain. The high risk scores for sanitation safety practices and risks at transfer stations reflect a poor solid waste management system. Inadequate facilities to prevent odors, waste scattering, waste scavengers, and protection for workers contribute to these risk factors. Studies have shown that inadequate and mismanaged waste transfer stations can have significant public health and environmental consequences (Sarkhosh et al., 2017; Dixit et al., 2022). Similar findings have been reported in studies conducted in Addis Ababa (Mohammed and Elias, 2017), North East of Tehran (Daryabeigi Zand et al., 2019) and (Nhubu et al., 2021) Harare, Zimbabwe which highlighted the associations between transfer stations near residential areas and adverse human health and environmental impacts, particularly regarding occupational health conditions.

Sanitation safety risk assessment during solid waste collection operations yielded a high-risk score of 14, indicating high risk levels (Vimercati et al., 2016). Common risk factors along the sanitation

service chain during collection and transport included waste dropping on the ground and scattering in the environment, leading to infections in humans and environmental contamination. The unhygienic condition of vehicles emerged as a major risk factor for worker and community contamination during solid waste collection and transport. Environmental impacts from collection and transport primarily arise from the operation of collection and transport vehicles (Gupta et al., 2015), further emphasizing the risks posed to workers and the surrounding community. A study conducted in Ghana highlighted psychological stress and job satisfaction as significant factors (Lissah et al., 2022; Tshivhase et al., 2022).

The study findings also revealed that 82% of sanitation safety standards were not followed during waste reuse/disposal operations, indicating significant risks associated with these practices. Workers and the nearby community are exposed to bad odors, direct contact with waste on the skin, handling contaminated containers and raw waste, and performing tasks without personal protective clothing. The reuse/disposal operations result in contaminated waste and leachate being splashed into the environment, posing serious risks to individuals. These findings are consistent with studies conducted in Darfur state, Sudan (Adam et al., 2015), Freetown, Sierra (Sankoh et al., 2013), Kolkata, India (De and Debnath, 2016) and Umuahia, Nigeria (Chibwe et al., 2021).

Overall, these findings emphasize the multifaceted nature of solid waste management issues, with socio-demographic factors, lack of adequate facilities, and unsafe practices contributing to significant health and environmental risks. Addressing these challenges requires a comprehensive approach, incorporating policy interventions, community education, and improved infrastructure to enhance sanitation safety practices and mitigate associated risks.

5 Conclusion

In conclusion, this study reveals significant deficiencies in sanitation safety practices throughout the entire solid waste management process, from households to waste collection and transport sites, transfer stations, and solid waste treatment/disposal sites. Hazardous practices were observed, posing risks to human health and the environment. Factors such as unsafe waste handling, inadequate storage, and improper waste segregation were identified as key contributors to these risks. To address these issues, it is recommended to implement targeted interventions. These include raising awareness among households about proper waste segregation and storage, enforcing regulations for regular cleaning and disinfection of waste collection vehicles, improving physical infrastructure at transfer stations, implementing proper waste handling practices at treatment/disposal sites, and establishing comprehensive policies and regulations alongside monitoring mechanisms. Tailoring interventions based on socio-demographic factors such as income, education, and marital status is essential to support vulnerable populations and improve waste management practices. Additionally, fostering international collaboration to exchange best practices adapted to local contexts is crucial. These proposed measures aim to enhance sanitation safety practices, mitigate health risks, and promote environmental sustainability. By addressing identified deficiencies through a coordinated approach, communities can establish safer and more effective solid waste management systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study received ethical approval from the Ministry of Education National Research Ethics Review committee, in accordance with the Ethiopia National Research Ethics Review Guideline (Fifth Edition). Written informed consent was obtained from all participants who took part in the study, after explaining the purpose and significance of the research. Data collection proceeded only after obtaining fully informed verbal consent from the participants, and confidentiality measures were implemented to protect their privacy by excluding their names and personal identification information.

Author contributions

SS: Writing–original draft. SG: Writing–review and editing. AA: Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenve.2024.1414669/full#supplementary-material

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