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Household Solid Waste Management Practices and Perceptions of Residents in Mekelle City

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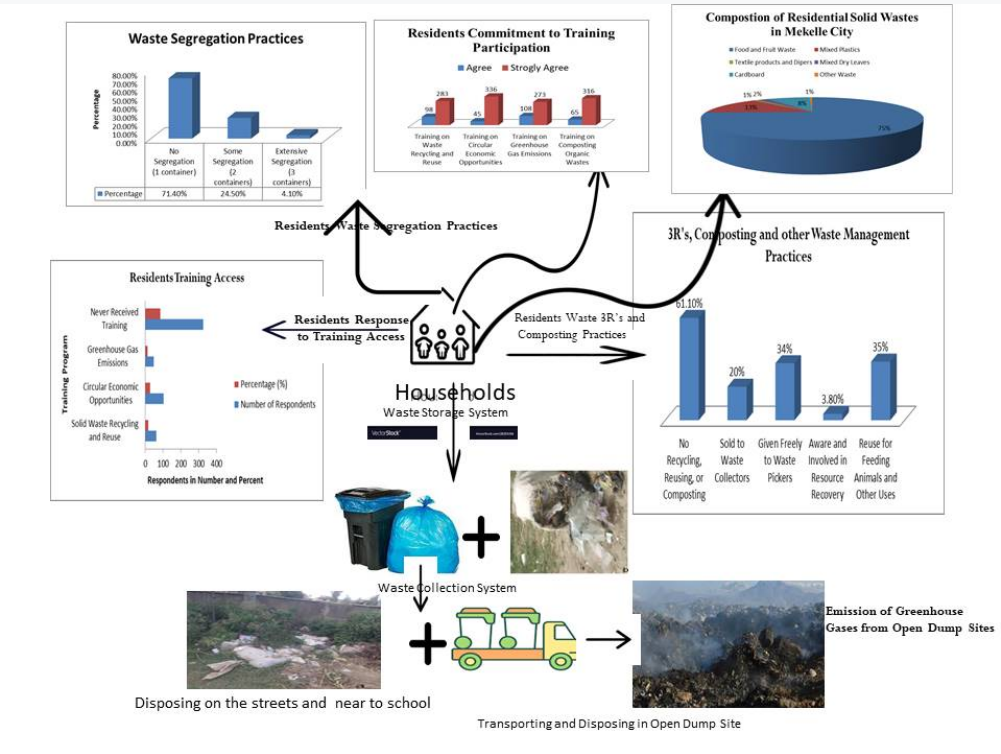
Abstract

Mekelle City, Ethiopia, faces growing challenges due to the increasing volume of municipal solid waste (MSW). Inadequate management systems pose significant threats to public health and the environment. This research investigates the practices and perceptions of residents regarding household solid waste management in Mekelle City, Ethiopia. Utilizing a mixed-methods approach, data were collected through interviews, observations, and surveys involving 400 households to assess waste management practices such as segregation, recycling, reusing, composting, selling, and disposal. Our findings reveal that households in Mekelle contribute significantly to the city's overall solid waste burden, generating an average of 0.44 kg of solid waste per capita per day. A significant majority of respondents (71.4%) reported not segregating their waste before collection and disposal, using only a single container for all types of waste. Only a small portion (4.1%) engaged in extensive segregation using three distinct containers. While 133 respondents (35%) reused food waste for animal feed or other purposes, 130 (34%) gave it to waste pickers, and only 76 (20%) sold it to traditional waste collectors. Our observations revealed a network of waste collectors operating in all sub-cities, primarily engaged in collecting sorted recyclables from households.

The survey also indicated that only 3.8% of respondents were aware of and involved in resource recovery practices like composting. A significant majority (71%) had never received any training on household solid waste management, highlighting a critical knowledge gap. To understand the factors influencing residents' practices and perceptions, we conducted a chi-square test. Statistical analysis shows significant differences in perceptions based on demographic factors such as sex, education, and age ($p < 0.001$).

Our causal loop analysis using Vensim PLE identified low awareness, lack of training, and population growth as key factors contributing to weak practices and perceptions regarding solid waste management in Mekelle City. The absence of awareness and promotion regarding waste segregation, reuse, composting, and proper disposal was the primary reason cited by household residents for not segregating their waste. These findings underscore the need for enhanced awareness campaigns, educational programs, and infrastructure development to promote sustainable waste management practices in Mekelle City.



Graphical Abstract

Keywords: Solid Waste Management; Recycling; Reusing; Mekelle city; Households; Residents

Introduction

Human activities generate waste materials that are often discarded because they are considered useless. These wastes usually are solid and the word waste suggests that the material is useless and unwanted [1]. Solid waste is defined as any material that is thrown away by a person because it is no longer needed and is no longer usable by that person at that time, despite the possibility of benefiting from those materials thrown away in another place and at another time [2]. Municipal solid waste management (MSWM) problems have become more pronounced in recent years coupled with inadequate financial resources, has led to indiscriminate dumping of solid waste into roadsides, open spaces, football fields, river banks, drainage channels and even grave yards as dumping sites and causing flooding, environment pollution and public health issues because as long as humans have been living in settled communities, solid waste generation has been an unavoidable and critical issue [3-6].

Solid waste management (SWM) refers to collection, storage, transportation, processing, treatment, recycling and final disposal of waste. Systems need to be simple, affordable, and sustainable (financially, environmentally and socially) and should be equitable, providing collection services for poor as well as wealthy household [7-8]. In most developing countries, wastes are either scattered in urban centers or disposed-off and dumped in unplanned way in slopes and gorges. The infrastructure, facilities and skills for collection, transportation, treatment and disposal of solid waste is not up-to-date. The public attitude is low in terms of proper collection and sorting frameworks; these situations are exacerbating environmental and health related problems in urban areas of developing countries [9]. In many fast growing cities of developing countries, dealing with household waste has become a vital policy problem. Policies and regulations aimed at good management of wastes, ranging from specifically controlling wastes at the household level to integrated municipal and economy- wide waste reduction efforts have been implemented with mixed outcomes [10]. Solid waste generation, particularly in developing countries, is experiencing a significant increase that exceeds the capacities of cities and municipalities in terms of removal and recycling. In these countries, the

waste collection rates are 70% lower than the generation rates, and over 50% of the collected waste is disposed of in uncontrolled landfills or open dumpsites, often without adequate recycling measures [11].

Among the waste management strategies being exercised around the world are recycling, re-using and composting of waste in different forms for organic fertilizer production and biogas generation [12-14]. Implementation of circular economy approach is being also an important and critical path for waste utilization for economic development [15-17].

Food waste especially, is contributing to GHG emissions because its degradation creates methane, a very potent greenhouse gas. When looking at the whole supply chain of food, from farm to table, food waste contributes to around 6 per cent of global GHG emissions [18]. This means that if it was a country, it would be the third largest GHG emitter in the world. A large percentage of food waste happens before it reaches the consumer, representing both wasted resources and emissions [18]. In developing countries dumping of solid waste in the non-engineered landfill is very common. Among the different disadvantages of this kind of landfilling, leachate is the major concern to public health, which is a toxic byproduct generated from the landfill; and can percolate to the ground water and consequently migrate in surface water [19].

Solid waste management poses a big challenge for many urban households, especially in developing countries. Overcrowding and informal settlements have emerged with illegal and indiscriminate waste disposal. Guidelines for proper management of solid waste are least observed at household level in such setting [20]. While rapid Urbanization is integral to societal progression and economic development, it has been significantly affected the environmental sustainability including increased greenhouse gas emissions; urban heat island effect amplification, loss of green spaces, and disturbances in local biodiversity [21].

Cities generate about 1.3 billion tons of solid waste per year, a volume expected to rise to 2.2 billion tones by 2025, more than double increase for developing countries[22]. The annual volume of waste generated in sub-Saharan Africa (SSA) increased from 81 million tons to 174 million tons per year between 2012 and 2016 and is projected to reach 269 million tons in 2030 [23], [24]. In Ethiopia, MSWM is a major issue owing to its fast-growing economy, expansion of urbanization, and industrial development in its major cities[25]. In Ethiopia over 67.4% of generated solid waste is dominated by organic biodegradable materials which can be recycled, however, only 5% is recycled in non-standard ways [26]. The solid waste generated in Ethiopia in the year 2012 has been estimated to be an average of 110 kg/capita, leading to 1,615,000 tons/year on average of waste generation [27] ; very little of this is properly collected. The main principles of circular economy are: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature [28]. Emissions of CH_4 result from the decomposition of biodegradable components in the waste stream such as paper, food scraps, and yard trimmings[29-30].

Major cities of Ethiopia like Addis Ababa, Mekelle, and Bahir Dar generates significant amounts of waste, much of which ends up in open dumps or landfills without being harnessed for economic value. More than 86.5% households in Mekelle city indicated that they didn't have access to waste disposal containers according the study by [27]. Since the turn of the new millennium, solid waste generation in the city of Mekelle has been increasing. However, on average only one-third has been collected and disposed and the Per capita waste generation in Mekelle is estimated to vary between 0.30 kg/day and 0.43kg/day [10-27]. The 2020 conflict in Tigray significantly damaged waste management infrastructure, disrupting the entire system. As a result, waste accumulates on streets and in green spaces near residences. In the war time service provider could be collapsed, waste would be left unmanaged, and a large quantity of waste like debris, housing furnishings, and hazardous substances could be produced [31].

While numerous studies have explored waste management practices in major Ethiopian cities like Addis Ababa and Bahir Dar, there is a significant lack of data specifically addressing household-level practices and perceptions in Mekelle City. This gap highlights the need for a deeper understanding of how socio-economic factors influence individual behaviors regarding waste

management. Most existing research has focused on broader systemic issues without adequately examining the nuances of household behaviors. For instances the researches by [10, 27] has been concentrated on broader municipal waste management systems and quantification measures of waste generation, composition and disposal options.

Despite increasing concerns about waste management in developing countries, research focusing on household-level data in Ethiopian cities remains scarce. This study aims to bridge that gap by providing empirical analysis of household practices related to solid waste management in Mekelle. By offering detailed insights into the challenges and opportunities associated with waste management, this research contributes to a better understanding of the dynamics at play not only in Mekelle but also in other Ethiopian cities.

Our findings shed light on the household-level factors influencing solid waste management practices in Mekelle City. Specifically, insights into the prevalence of informal waste collection services can inform policy development aimed at supporting and regulating these services to ensure their sustainability and effectiveness. Additionally, understanding the factors that influence waste segregation, recycling, recovery, composting, and selling can help design targeted awareness campaigns and incentives to promote sustainable practices at the household level.

The data collected through this study would assist policymakers in crafting strategies that enhance waste management practices grounded in the realities faced by residents. By providing critical insights that guide resource allocation and service improvements; our research serves as a benchmark for other Ethiopian cities facing similar challenges. Ultimately, this study contributes to a broader understanding of urban waste management issues across the country, offering valuable information for policymakers and practitioners seeking to improve solid waste management systems.

Therefore, this systematic assessment tries to provide useful information which would help to develop the Household solid waste recycling and reusing strategies, to develop good awareness and perceptions in household level in Mekelle city.

Methods

Description of the Study Area

Mekelle, the vibrant capital of the Tigray region, sits nestled in the northern Ethiopian highlands, 777 kilometers by road north of the national capital, Addis Ababa. Its geographical coordinates are 13° 24'30" to 13° 36'52" latitude and 39° 25'30" to 39° 38'33" longitude. At an average altitude of 2,200 meters above sea level, Mekelle experiences a semi-arid climate with a mean monthly temperature range of 8.7°C (minimum) to 26.8°C (maximum), averaging 17.6°C . Rainfall fluctuates throughout the year, with an average of 600mm, with over 70% falling during the July-August rainy season, followed by a prolonged dry season.

Data Source

This study utilized a multifaceted approach to gather data for analyzing solid waste management practices and community awareness in Mekelle City. Both primary and secondary sources were employed, ensuring a comprehensive and diverse information pool. During data collection households (400 samples) focus on waste management practices such as residents' segregation, recycling/repurposing, reusing and composting attitudes and practices through primary and secondary surveying.

Data Collection Methodology

The study was employed a comprehensive data collection method. Thorough review of relevant literature provided a strong theoretical foundation for the study. Based on the literature review, questionnaires and interview protocols were carefully crafted

to gather specific data from different stakeholder groups. To ensure consistent and reliable data collection, groups of data collectors were trained in administering the questionnaires and conducting interviews. Samples of household solid waste collection and segregation images were collected and analyzed to determine the awareness of the community's practice on recycle and reuse of solid wastes. Survey data was meticulously processed, cleaned, and analyzed using appropriate statistical methods to extract meaningful insights. Finally, findings from the data analysis were carefully evaluated to identify potential sustainable management options (recycle and reuse) for Mekelle's households' solid waste.

Questionnaire Development

To effectively engage local communities in the study, simple and relevant questionnaires were designed. The English version, attached in the appendix, was translated orally into Tigrigna to ensure clear understanding for participants. Households selected for the study completed the translated questionnaires prior to initiating sample collection, facilitating informed participation and maximizing data quality.

Sample Size Determination

To determine suitable sample size as indicated below in Table 1 a sample size formula provided by Slovin's formula was utilized.. The sample size of 400 households was determined based on a power analysis with a desired margin of error of ±5% at 95% confidence level. The population of Mekelle city is estimated to be 612,000 and the number of households was estimated to be 159,452 based on the projection of Ethiopian Statistical Agency, 2007 data. Stratified sampling was employed to ensure that the sample was representative of the diverse population of the city, with households selected from different neighborhoods based on their socio-economic characteristics. While a larger sample size would have increased the statistical power of the study, resources constraints and time limitations necessitated the choices of 400 households as a practical and feasible option. The sample size is consistent with those used in similar studies on households' solid waste management practices in urban setting.

Table 1: Distribution of respondents from each sub-city

City	Sampled Sub-city	Sampled No of HHs	Sampled No of Wereda leaders	Sampled No of waste collectors	Total sample size
Mekelle	Semen	55	2	1	57
	Hawelti	55	2		57
	Ayder	55	1	1	57
	Adi-Haki	56		1	57
	Hadenet	55			
	Kedamay Weyane	52	3	3	58
	Kuha	53	2	2	57
Total	7 sub-cities	381	11	8	400

A sample of 400 provides a robust representation, ensuring that various socio-economic and demographic such as different income levels, household sizes, and waste management practices. The sample sizes formula used to determine the sample size was described as follows:

Where,

N: is the total population; n: is the required sample size; e: is the margin error

Study Variables

In this study, we investigated the factors influencing household solid waste management practices in Mekelle City. We focused on dependent variables such as segregation, recycling, reusing, composting, selling, and disposal. Independent variables included knowledge and awareness, availability of waste segregation collection services, perceptions and attitudes, access to training, and commitment to training.

Data Analysis

Data collected through interviews, observations, and questionnaires were meticulously reviewed for accuracy and completeness. Subsequently, the data was coded and analyzed using SPSS version 21. Frequency and percentage calculations were employed. Binary logistic regression analysis was conducted to examine the relationship between independent and dependent variables.

A multivariate analysis was performed to assess the independent effect of these selected variables on recycling and reusing practices while controlling for the influence of other factors. The results were evaluated using 95% confidence intervals, with a significance level set at $p < 0.05$.

Result and Discussion

Study Area and Sampling Strategy

This research was conducted across seven sub-cities of Mekelle City: Kdamay Weyane, Semen, Adihaki, Hawelti, Hadnet, Ayder, and Kuha as illustrated in Figure 1. To ensure a representative sample and capture the variations in solid waste management practices throughout Mekelle, households were selected from each sub-city based on diverse socio-economic characteristics, population densities, land use patterns, and geographical locations.

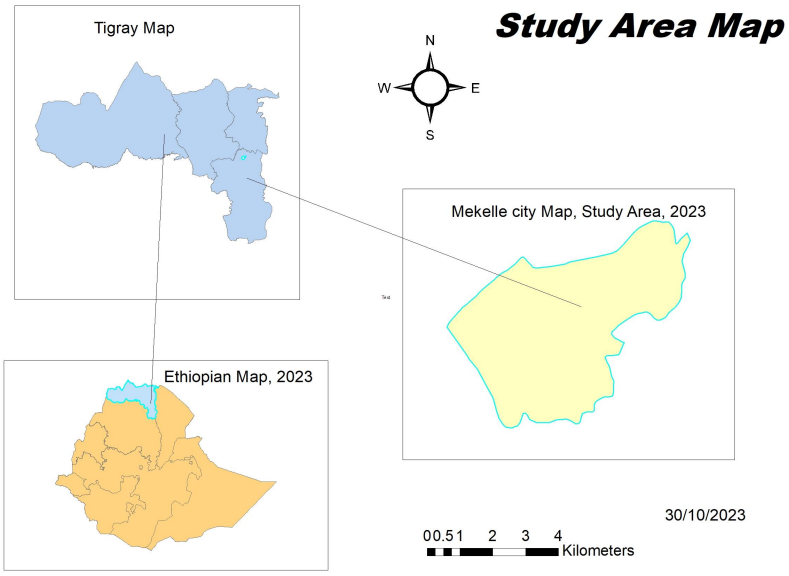


Figure 1: Map of the study area

The sub-cities of Ayder, Semen, and Kuha are primarily residential and industrialized areas. In contrast, Kdamay Weyane is characterized by a higher concentration of commercial activities. The sub-cities of Hawelti, Adihaki, and Hadnet feature a mix of commercial and residential zones with relatively high-income levels.

Data collection involved collaboration with the Mekelle Urban Development Office and the Mekelle City Municipality. This comprehensive approach resulted in 381 respondents being selected for interviews from households across all seven sub-cities. Additionally, 11 representatives from the Urban Development Office and the City Municipality were interviewed, along with 8 local waste collectors. This brought the total number of participants to 400.

Current Status of Solid Waste Management in Mekelle Municipality

Mekelle City grapples with a significant solid waste management crisis, mirroring challenges faced by many urban centers in Ethiopia [10]. Rapid population growth, IDP and war have outpaced the city's infrastructure, leading to inefficient waste collection, characterized by irregular schedules and limited coverage.

As we observed substantial portion of the generated waste finds its way into open dumps or is carelessly discarded, posing severe threats to public health and the environment. In addition to our observation the study by T. Alemayehu et al., (2021) also approves that the city's capacity for recycling and reuse remains underdeveloped; with the majority of waste ending up in open disposal sites and landfills without proper treatment. From the interview and physical observation of the research team, the main reasons are due to lack of awareness among residents about the importance of proper waste disposal and its environmental consequences, and absence of sufficient waste processing and disposal facilities. Figure 2 shows the current status of household solid waste (HSW) management practices in sub-cities of Mekelle City.

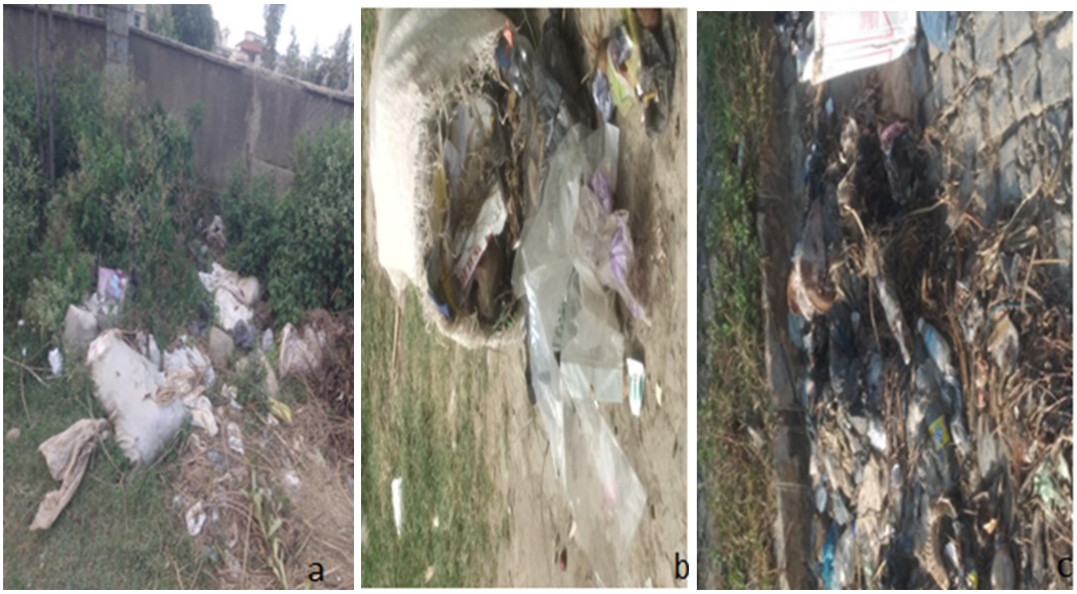


Figure 2: Current Status of Solid Waste Management in Mekelle Sub-cities; Source: Fieldwork, 2024

Evidence from households, municipal officers, and waste collectors indicates that the city of Mekelle relies solely on its municipality for the management of household waste collection and disposal. A few private contractors and a number of informal collectors play a minor role in the management of household waste collection and disposal. The city is presently experiencing a significant population explosion that comes with increased rates of waste generation, but the city's system of waste management remains highly antiquated and limited by the overall shortage of resources and personnel. Municipalities are responsible for collecting and transferring household, commercial, and institutional waste to open dumpsites.

We then conducted in-depth interviews with governmental officials, experts, and private waste collectors to get insight into the limited engagement of private collectors. Our findings showed that complex licensing procedures, coupled with high setup costs, act as a significant deterrent to new entrants in the waste management of Mekelle City. Second, low profit margins due to the many informal collectors discourage the sustainability of a private company in the business. Other factors include cultural ones where most the residents prefer the traditional ways of waste disposal, and there is also a lack of interest of the community in waste management activities. All these put together constitute the very minimal participation of private waste collectors in Mekelle.

Currently, two main methods are applied for the collection of municipal waste in Mekelle: door-to-door collection with trucks and fixed communal bins. Door-to-door collection is the most prevalent method of municipal waste collection in Mekelle. The waste collectors give a special traditional sound called 'Turumba', which notifies the resident that they will collect the waste. Such a sound serves like an alarm to take sorted waste in sacks to the truck once a week or once every two weeks.

The problems facing the municipal solid waste management system in Mekelle make a comprehensive strategy that addresses modernization of the waste collection system, improvement of regulatory frameworks, community participation, and involvement with private sector entities-very important.

Sources of Solid Wastes in Mekelle City

Mekelle City Municipal Authorities reports that residents are the primary source of solid waste, contributing 62% of the total. This residential waste includes food scraps, packaging materials, yard waste, and other household discards. Following households, Manufacturing Industries, hotels and cafeterias are significant contributors, generating 20-30% of the city's solid waste. These categories encompass leftover food, disposable tableware, and packaging waste. The remaining 10-20% of the waste originates from various sources, including manufacturing facilities, hospitals, schools, commercial areas, and others.

The results in Figure 3 indicated that residential areas in Mekelle City are the biggest contributor of solid waste, followed by commercial areas. This might be due to factors like organic waste from food scraps and yard trimmings in households, and packaging waste from commercial activities. Manufacturing industries, hospitals, and hotels appear to contribute a smaller share, likely due to a lower number of such establishments compared to residences and commercial spaces.

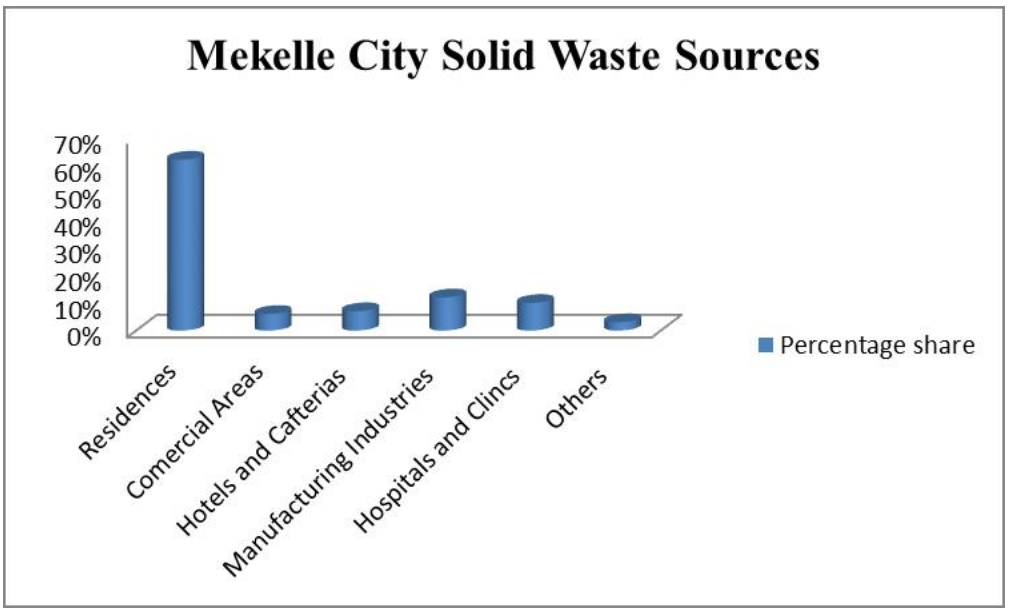


Figure 3: Major Sources of Solid in Mekelle City

Generation and Composition of Residential/households Solid waste in Mekelle City

The collected data from the interview shows that Households in Mekelle City are a major contributor to the city's overall solid waste burden and generates averagely 0.44 kg of solid waste per capita per day. Therefore, the annual waste production in the city of Mekelle is estimated to be at around 98,287.2 ton. Studies by Tadesse et al., (2008) indicate that residents generate an average of 0.33 kg of waste per person per day and of 73,715 ton annual waste generation. Increment of the waste generation of per capita could be due to increment in daily consumption in households. According to Mekelle City municipal authorities as shown in Figure 4; food and fruit waste make up the largest portion of the city's solid waste, accounting for 75.3%. Up to 21.4% of Mekelle City's waste stream is composed of recyclable materials like plastics and cardboard, highlighting the potential for improved recycling initiatives. The remaining 3.99% consists of textiles, mixed paper, diapers, and other miscellaneous items. Almost similar results was also studied by Gebreslassie et al. (2019) shows that the main composition of the generated waste was 71.43 % food wastes, 13.59 % mixed plastics, 8.80 % cardboards, and 1.99 % mixed dry leaves. Textile products, mixed paper, diaper and others (shoe, bones and mobile card) constitutes for 1.77 %, 1.61 %, 0.61 % and 0.19 % respectively.

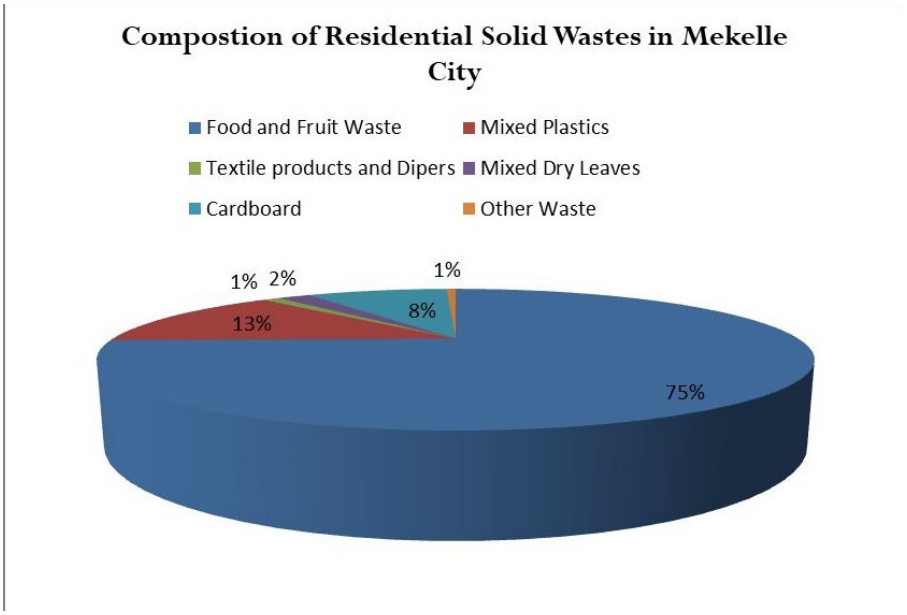


Figure 4: Compositions of Households solid waste in Mekelle City

The results of both studies showed us the most significant contributor is food and fruit waste. Decomposition of this organic waste generates methane, a potent greenhouse gas. According the study by [33] the total GHG emitted in Ethiopia in the year 2013 was estimated to be 146,160.43 Gg of carbon equivalent. In this case Waste sector has a contribution of 5% emission in this inventory. Municipal solid waste landfills are the third-largest source of methane emissions from human activities in the United States, contributing methane emissions equivalent to 94 million metric tons of carbon dioxide (CO_2) in 2020 [34]. Globally, solid municipal waste management (MSW) is responsible for over 10 % of all methane emissions[35].

Respondent Age

As it is presented in Table 2, our analysis showed that our study was significantly represented by younger people; 23.8% of our respondents were between the ages of 18 and 25 years old. The largest proportion was the age group of 26-35-year-olds, 26.3% of the total number of valid responses, showing active participation in issues related to household waste management. Importantly, our sample included the whole array of ages from the youngest to the oldest, which is crucial for taking a wider view on the subject.

Table 2: Age distribution of respondents in a survey

Age of Respondents					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-25	95	23.8	23.8	23.8
	26-35	105	26.3	26.3	50.0
	36-45	120	30	30.0	80.0
	>46	80	20	20.0	100.0
	Total	400	100	100.0	
Missing	System	0	0		
Total		400	100.0		

Respondent Education Levels

Results in Figure 5 showed us analysis of the educational levels of the 400 respondents in the study. Based on the data gained from the questioner, interview and observations the Frequency Distribution eight respondents Unable to read and write, 114 respondents Primary school, 122 respondents were Secondary school and 163 respondents were at the level Diploma or higher. Therefore, the majority of respondents (38.8%) possess a diploma or higher degree, approximately one-third of respondents (30.6%) have completed secondary school and A smaller proportion of respondents have completed primary school (28.6%) or are unable to read and write (2.0%). Accordingly, the data suggests a relatively high educational attainment among respondents, with nearly 70% having completed secondary school or higher education.

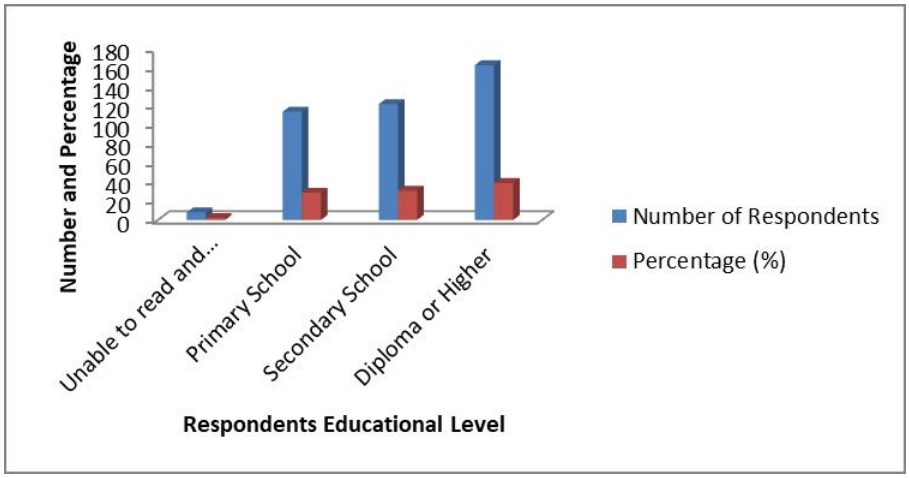


Figure 5: Respondents Education LevelRespondent Occupations

Based on the data we gained from the questioner, interview and observations from the total of 400 respondents; the majority of respondents (42.9%) are employed in the private sector as indicated in Figure 6, a significant portion (30.6%) is housewives, indicating a focus on domestic responsibilities and Students (14.3%) and government employees (12.2%) represent smaller segments of the respondents.

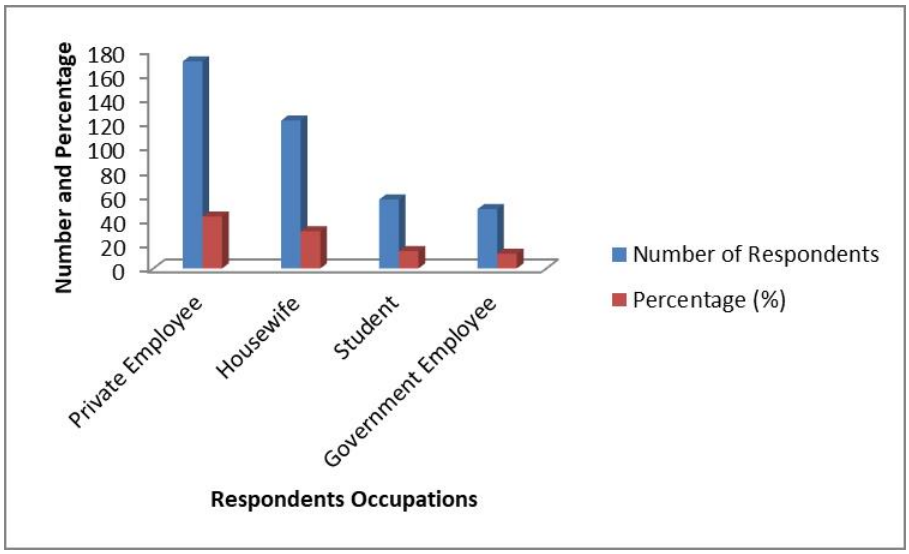


Figure 6: Respondents Occupations

Residents Practices and Perceptions

Waste Segregation Practices

As indicated in Figure 7 we observed that a significant majority of respondents (71.4%) reported not segregating their waste before collection and disposal, utilizing only a single container for all types of waste. A smaller portion (24.5%) utilized two containers, indicating some effort toward segregation. Only 4.1% of surveyed households engaged in extensive waste segregation, using three distinct containers. This is comparable with findings from similar studies conducted in Addis Ababa (Abebe, 2017), Gondar (Shiferaw et al., 2023), and Jigjiga (Birhanu, 2015), which reported respective segregation rates of 4.9%, 6%, and 8% at the household level.

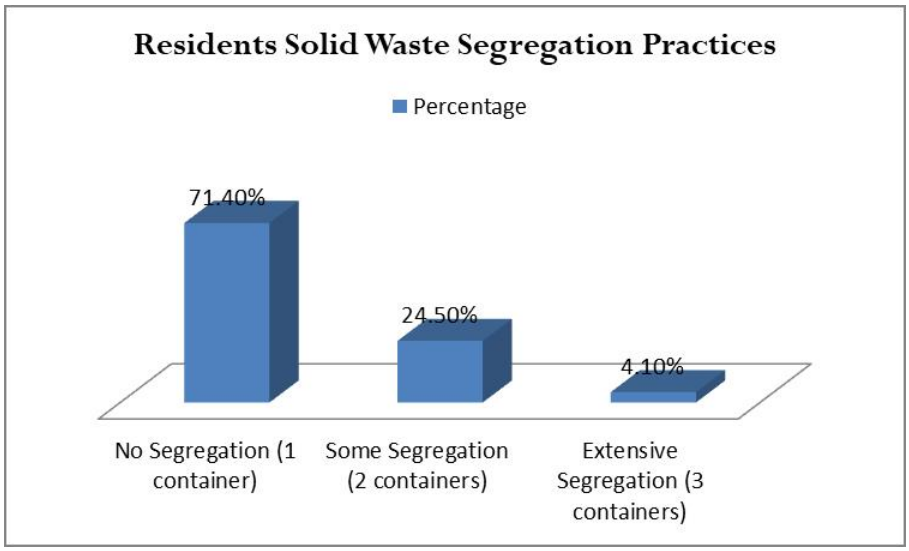


Figure 7: Segregation Practices among Mekelle Residents

The primary reason raised by non-segregating households was the absence of awareness and promotion regarding waste segregation, reuse, and proper disposal. This shows a lack of knowledge and understanding about the benefits of waste segregation and the need for behavioral change. During our observations sacks were the most preferred method of waste storage among all respondents. This indicates limitations in access to alternative storage options or a lack of awareness about their potential bene-

fits. Study by [36] reasons out that this could contribute to higher waste volumes, reduced collection and disposal efficiency, and hindered recovery and recycling efforts. Other study by Adefris et al., (2023) proves that waste processing and treatment technologies, resulting in a higher quantity of segregated materials that can be recycled and reused, thus reducing the need for virgin materials.

Waste Recycling, Recovering and Composting Practices

Results from Table 3 showed that about 133 (35%) of the respondents indicated to reuse the recoverable waste (food waste) for feeding animals and other reuse purposes, 130 (34%) would give freely to waste pickers and only 76 (20%) would sold to waste collectors traditionally called Quraleos or exchanged for liwach. Our observations and interviews reveal a network of waste collectors operating in all sub-cities. These individuals typically collect sorted dry recyclables directly from households, often exchanging them for goods or money. This activity is almost common and practiced worldwide[37], [38]. There are also waste pickers/scavengers who picks wastes such as Cardboard boxes, Paper packaging, Plastics, Metals, Glass from streets, open dump sites and landfill. This all are informal waste recycling practices.

Table 3: Awareness and Practices of residents on Waste Segregation (N = 381)

Questions	Frequency (%)	
	Yes	No
Do you separate your household waste into different bins or containers for recycling?	109	272
Do you compost any organic waste (food scraps, garden waste) from your household?	15	366
Do you use more than one container for segregating your household waste?	106	275
Do you reuse any items (e.g., plastic containers, glass jars) for other purposes instead of discarding them?	133	247
Are you aware of the different types of recyclable materials (e.g., paper, plastic, glass, and metals)?	183	198

While organic wastes (food scraps, garden waste) presents a significant opportunity for nutrient recovery[39], [40]; . A study conducted by [9] in Addis Ababa found that approximately 5% of household organic waste is recovered and utilized as compost. This figure is comparable to the rate of organic waste recovery practices among residents in Mekelle City. We gained Results as in Figure 8 and showed that the full potential of proper waste recycling, recovering, reusing, selling and composting practices remains untapped across all sub-cities, due to lack of adherence to segregation methods by waste collection services, insufficient financial incentives or penalties for segregation, inadequate awareness campaigns by the city government, lack of enforcement against illegal waste disposal, limited backyard space for composting, and absence of interested parties to purchase compost.

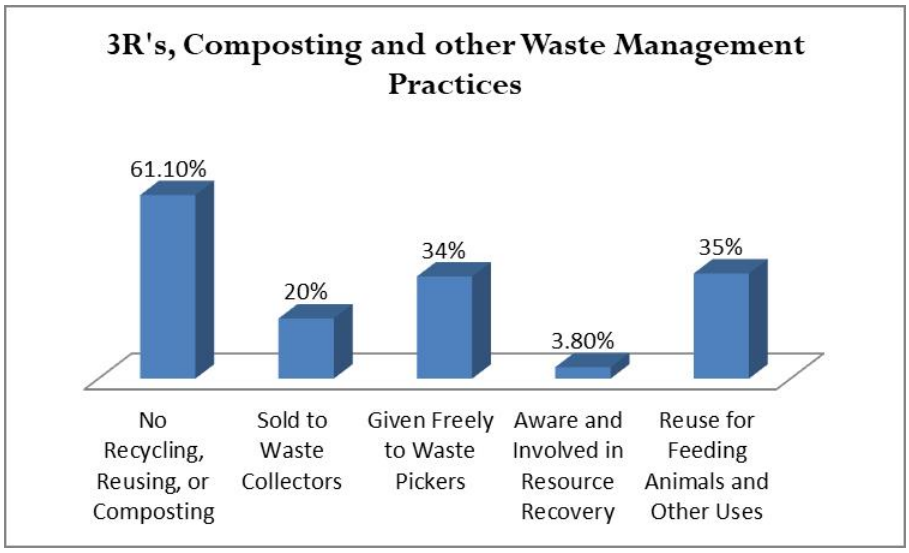


Figure 8: Residents' Solid Waste Management Practices

Residents Training Access

The data in Table 4 reveals a significant lack of training opportunities across all four areas of waste management, with the majority of respondents having never received any formal training. Only 63 respondents (16.3%) reported having received training on solid waste recycling and reuse. A significant majority 325 respondents (83.7%) reported never having received such training, highlighting a significant gap in knowledge and skill development. Around 103 respondents (26.5%) reported having participated in training on circular economic opportunities, indicating some awareness and understanding of this concept. However, 286 respondents (73.5%) still lack exposure to this training, suggesting a need for broader dissemination of knowledge and skills related to circular economy principles. Respondents were also asked to response about their experience on greenhouse gas emission. Accordingly, the lowest participation rate 12.2% (47 respondents) was observed for training focusing on greenhouse gas emissions, indicating a critical lack of awareness and understanding of this crucial environmental issue. In general, according the results in Figure 9, a large majority (71%) have never received any training on this topic, suggesting an urgent need for interventions to address this knowledge gap.

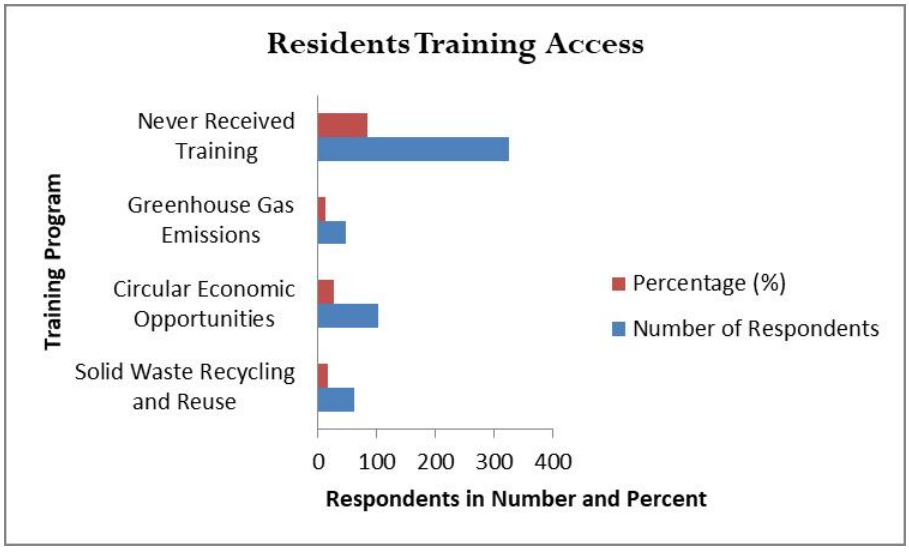


Figure 9: Residents' Knowledge of and Involvement in Waste Management Training

Table 4: Residents' Knowledge of and Involvement in Waste Management Training (N=381)

Questions	Frequency (%)	
	Yes	No
Have you ever participated in any training program related to household solid waste management?	56	325
Have you attended any workshops or seminars on recycling and reusing household waste materials?	63	317
Have you been informed about the impacts of improper waste disposal on climate change and greenhouse gas emissions?	47	334
Have you received training on composting organic waste for home use or community-level initiatives?	103	278

Residents' Interest in Training Programs

As shown from our survey in Figure 10, the absolute majority of respondents expressed a great interest in being trained regarding household solid waste management. All the respondents wanted to be trained on material recycling and material reuse; 88.19% strongly agreed and 11.81% agreed. It seems that they are fairly enthusiastic about the skills of learning. While the interest in training dealing with opportunities of circular economics was relatively low, the level of engagement turned out to be promising: 71.68% strongly agreed and 28.32% agreed. These points to an increased awareness of the circular economy and its potential applications to effective waste management.

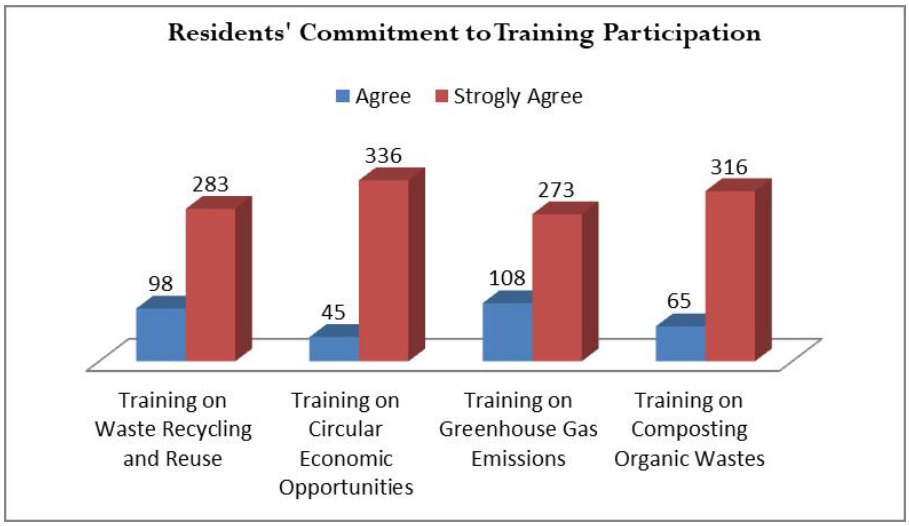


Figure 10: Residents' Attitudes towards Training on Waste Management Practices

In addition to that, all the respondents expressed interest in training on greenhouse gas emissions. Responses ranged from 71.68% strongly agreeing to 28.32% agreeing. This shows concern for environmental impacts and interest in contributing to climate mitigation. Finally, 82.94% of the respondents were interested in composting training, as 82.94% strongly agreed and 17.06% agreed. This shows the strong commitment of residents to adopt sustainable waste management practices and reduce reliance on landfills.

In general, the findings from the interview as shown in Table 5 showed that an optimistic keen view of the residents in their bid to improve waste management practices at the household level. This could mean that any form of effort put in place for improving the sustainable management of waste is bound to be embraced and supported by the community.

Table 5: Residents' Interest in Waste Management Training (N=381)

Questions	Frequency (%)			
	Strongly disagree	Disagree	Agree	Strongly agree
I am interested in participating in a training program on how to properly manage household solid waste.	0	0	63	318
I believe that learning about the environmental impacts of improper waste disposal, including climate change and greenhouse gas emissions, is important.	0	0	108	273
I am interested in learning how to recycle and reuse household waste to reduce waste volume and conserve resources.	0	0	98	283
I would like to learn about composting organic waste to produce valuable soil amendments.	0	0	65	316
I am interested in understanding the concept of a circular economy and how it relates to waste management	0	0	45	336

Analysis of Factors Association in with Solid Waste Management Practices and Perceptions

The results in Table 6 showed associations between the age of respondents and their waste management practices using Chi-square test. The results indicated a significant relationship between age and waste management practices (χ^2) = 8.500, p = 0.037). Furthermore, significant associations were observed for questions related to waste management practices: Q2 (χ^2) = 176.890, p < 0.001), Q1 (χ^2) = 82.810, p < 0. 001), and Q3 (χ^2) = 176.890, p < 0.001). During our Analysis using SPSS, Q1 was the sum of Q11, Q12, Q13, Q14 and Q15 questions. Q2 was the sum of Q21, Q22, Q23 and Q24 questions; and Q3 was the sum of Q31, Q32, Q33, Q34 and Q35 questions.

Table 6: Chi-square analysis Ages of respondents with solid waste management Practices and perceptions

Test Statistics				
	Age of Respondents	Q2	Q1	Q3
Chi-Square	8.500	176.890	82.810	176.890
df	3	1	1	1
Asymp. Sig.	.037	.000	.000	.000

In our research, we conducted a Chi-square test to examine whether there are significant differences in the responses based on the sex of respondents across the three quarters (Q1, Q2, and Q3). The results of our analysis are presented in the Table 7.

Table 7: Chi-square analysis Sex of Respondents with solid waste management Practices and perceptions

Test Statistics				
	Q2	Q1	Q3	Sex of Respondents
Chi-Square	176.890	82.810	176.890	25.000
df	1	1	1	1
Asymp. Sig.	.000	.000	.000	.000

We found that the Chi-square statistic was 176.890 for Q1, 82.810 for Q2, and 176.890 for Q3, with degrees of freedom (df) equal to 1 for all three quarters. Importantly, the asymptotic significance (p-value) for each quarter was 0.000. From our results,

it is clear that the p-value is statistically significant across all three quarters ($p < 0.05$). These show that gender plays a significant role in shaping the responses of participants in our survey across the different quarters. This indicates that men and women may have different perspectives and experiences related to household waste management.

The Chi-square test was conducted also to examine the association between respondents' educational levels and their responses to waste management practices and perceptions. Table 8 shows the analysis revealed significant relationships for all variables tested: Q2 (χ^2) = 176.890, $p < 0.001$), Q1 (χ^2) = 82.810, $p < 0.001$), Q3 (χ^2) = 176.890, $p < 0.001$), and educational level (χ^2) = 122.800, $p < 0.001$). Our findings highlight that a person's level of education significantly influences their understanding of and actions related to household solid waste management in Mekelle City.

Table 8: Chi-square analysis between Educational Level of Respondents and solid waste management Practices and perceptions

Test Statistics				
	Q2	Q1	Q3	Educational Level of Respondents
Chi-Square	176.890	82.810	176.890	122.800
df	1	1	1	3
Asymp. Sig.	.000	.000	.000	.000

Modeling of Current Status of Waste Management in Mekelle City

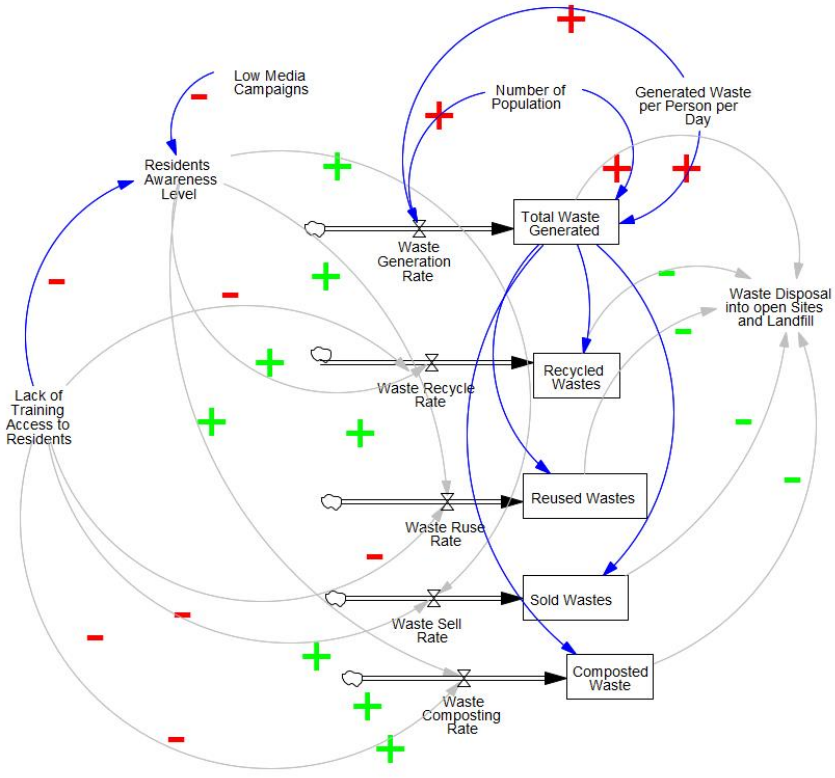


Figure 11: Causal Relationships between Household Waste Management Variables of Residents in Mekelle City

In the diagram, the red negative sign indicated factors such as lack of access to training and low media campaigns that could decrease residents' awareness levels and negatively impact their practices in waste segregation, sorting, recycling, reusing, selling, and composting. The green negative sign represented factors like waste recycling, reusing, recovering, selling, and composting that could positively minimize total waste disposal in streets, open landfills, and other sites. The red positive sign also showed

factors such as population size and waste generation per capita per day that negatively maximized the total waste generation rate and total waste disposal. Conversely, the green positive sign illustrated that residents' awareness levels positively maximized the rates of waste recycling, reusing, composting, selling, and overall waste disposal.

To summarize, public awareness campaigns, strengthening government policies, investing in training and education, and encouraging waste reuse and composting deserved priority. If these strategies were applied, household waste management practices in Mekelle would improve and minimize some of the environmental, economic and social impacts caused by improper household waste management.

Conclusion

The overall awareness and practice levels regarding household solid waste management in the community of Mekelle City were found to be weak. A statistically significant correlation was identified between training on household solid waste management and recycling, reusing and composting practices, indicating that educational initiatives can enhance community engagement in effective waste management. To improve these practices further, the development and implementation of comprehensive training programs focused on solid waste recycling, reusing, composting and circular economy principles are essential.

Recommendations

To improve solid waste management in the community, it is crucial to develop training programs on recycling, reuse, circular economy principles, and greenhouse gas emissions. Educational campaigns will enhance public awareness of the environmental impacts of waste management and promote responsible disposal practices. Encouraging community participation in initiatives like waste segregation and recycling will foster collective responsibility. Public awareness campaigns through various media channels should educate residents about proper waste disposal and recycling. Organizing workshops will provide hands-on training in waste segregation, composting, and recycling. Establishing designated collection and recycling centers will facilitate easy drop-off of sorted waste. Finally, collaborating with local businesses, schools, and community organizations will promote waste reduction and encourage recycling initiatives.

Statements & Declarations

Funding and/or Conflicts of interests/Competing interests

The authors declare that there are no conflicts of interest related to this research or the manuscript's preparation. All authors have no financial, professional, or personal relationships or affiliations that may have influenced the research or the manuscript.

Authors' Contribution

All authors were participated in the study of the whole concept such as study design, testing, data collection, questioners, data analysis and interpretation development of the theory and performed the computations, Verified the analytical methods, encouraged to investigate and supervised the findings of this work and all authors were discussed the results and contributed to the final manuscript.

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