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Assessment of Solid waste generation and composition in Bungoma County Urban Centres for appropriate waste management approaches

Assessment of Solid waste generation and composition in Bungoma County Urban Centres for appropriate waste management approaches

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Abstract
The quantity and characteristics of urban solid waste are a result of the interconnectedness of diverse factors at play including social, economic, and environmental factors. These directly influence the choice of management practice at the household or community level. Understanding these relationships can help policymakers and urban planners develop more effective waste management strategies. This study aimed at assessing solid waste generation and composition in Bungoma county urban centers to inform on strategies for effective management of urban waste. The study was carried out in Bungoma County urban centers, specifically Bungoma town, Webuye, Kimilili, Kapsokwony, Chwele, and Sirisia townships. The study applied a stratified sampling technique to select the urban and peri-urban centers while random sampling was used to select respondents in residential dwellings, business people, urban residents, and officers from government institutions including public health and environment, water, and natural resources were interviewed. Ancillary data was collected using questionnaires and interview schedules while historical data was obtained from the Bungoma County Department of Environment and used to validate observed data. Data was analysed using descriptive and inferential statistics and summarized using tables, charts, and graphs. Our findings show that the highest waste was generated from residential homes, commercial, and municipal services. In terms of composition, biodegradable waste had the highest proportion, followed by plastics and glass waste. Population growth could be a key factor in the increased generation of the waste.

Introduction

Solid waste generation is inevitable due to increasing population, changing consumption patterns, economic development, income, urbanisation and industrialisation. The world generates 0.77 kilograms of waste per capita per day, yet national waste generation rates range from 0.12 to 4.39 kilograms per capita per day, correlating with income levels and urbanisation rates. In 2012, the world generated 1.3 billion tons of waste annually (Kumari & Raghubanshi, 2023). Kaza and Yao (2018) estimated that 2.10 billion tonnes of municipal solid waste generated in 2016 would grow to 3.76 billion by 2050. However, the total quantity of waste generated in low-income countries is on the increase due to the increasing urban population. Globally, the World Bank estimates that the amount of municipal solid waste generated by urban areas is growing even faster than the rate of urbanisation (Kaza and Yao, 2018).

Solid waste management in sub-Saharan Africa faces significant challenges due to rapid urbanisation, lifestyle changes, and regional governance. Africa's total municipal solid waste generation is expected to triple by 2050, necessitating urgent improvements in waste management practices. Waste composition is equally diverse. Though it reflects changing lifestyles, it can also be influenced by climate variables such as temperature and rainfall. It has been observed that biodegradable waste comprising food waste forms the largest fraction of waste in Africa (Orhorhoro & Oghoghorie, 2019). Inefficient waste management is attributed to poor infrastructure, inadequate sector funding, lack of information, and poor policy implementation. Driving forces for urban solid waste generation include population, household size or institution size, economic status, season and legislation (Adeleke et al., 2021).

Solid waste collection

Waste management comprises formal and informal systems, whereas the formal systems include collection by County trucks, which make weekly visits to the collection centres and deliver the waste to designated dump sites. Informal waste management systems are found in rural and peri-urban areas where waste often remains uncollected or is deposited on roadsides, abandoned yards, or burnt in open fields. Alemu (2017), reported that informal solid waste collection is a livelihood sustenance primarily for the urban poor, who collect, sort, and sell recyclable materials. Further, informal collectors contribute positively to the environment by reducing reliance on disposal and increasing recycling (Egbu & Okoroigwe, 2014). Formal solid waste collection is complex and expensive, requiring efficient logistics to reduce costs, time, fuel consumption, and carbon emissions (Hannan et al., 2020). The system is well established in developed countries and large urban and metropolises in developing countries where regional or national governments manage residential, commercial, and industrial waste (Singh et al., 2014).

Urban solid waste composition

The composition of urban solid waste results from various players, especially population, education level and revenue (Ying, 2018). Understanding this composition is crucial for designing effective waste management strategies, recycling programs, and disposal methods. Common components of urban solid waste are organic waste (food, yard, and compostable materials), paper products, plastics, metals, glass, textiles, and hazardous waste. Waste composition depends on variation by region, trends and changes, and impact on waste management, collection and reduction strategies.

Management of solid waste

Solid waste management (SWM) involves storage, collection, transportation, treatment, and disposal (Filiberto, 2011). Its goal is to minimise environmental (land, air, and water) pollution, conserve resources, and promote public health through waste reduction, recycling, and composting (Meenakshi Suhag, 2021). In many developing countries, SWM faces challenges such as changes in climate, which affect disposal infrastructure, inadequate collection infrastructure, inefficient institutional arrangements, and weak legislation (Kumar, 2021). Managing urban solid waste involves various methods, including burning (incineration), open dumping and other disposal techniques. Kumar et al. (2017) account for how open burning of municipal solid waste contributes to the emission of harmful carcinogenic substances and poses significant challenges to effective waste management. Rochin et al. (2011) accounts for incinerating urban solid waste that orphan sources or radioactive materials have unintentionally contaminated, which poses significant environmental and public health risks. Additionally, releasing radioactive fumes during incineration can severely contaminate the facility, resulting in substantial economic losses. Kiran et al. (2020) affirm that there is a considerable impact on the environment and humans due to heavy metals in crops, soil and water due to open dumping of waste.

Challenges of urban solid waste management

Urban solid waste management (SWM) faces numerous challenges depending on the urban area's size, location, and development level. They range from segregation, transportation, and recycling

to disposal (Joshi et al. 2016). Addressing these challenges requires a multifaceted approach involving improved infrastructure, better public awareness, effective policy enforcement, and investment in technology and innovation. Collaboration between governments, the private sector, and communities is essential for developing and implementing effective solutions to enhance urban solid waste management.

The socio-economic aspects of solid waste management

The socio-economic aspects of solid waste management (SWM) are deeply interconnected with various facets of waste management systems. Jagun et al. (2022) account that key socioeconomic factors, including financial resources, population density, per capita income, education levels, policies, and technology, influence waste management practices. These factors affect various aspects of waste management, such as waste generation, collection, composition, and disposal or treatment. Despite the challenges, effective waste management brings several economic advantages, including financial stability, job creation, and enhanced community cohesion. Addressing these aspects effectively can improve waste management's efficiency while promoting social equity and economic development. Socio-economic factors relating to different areas of SWM include waste minimisation, efficient collection systems, advanced recycling programs, community involvement and waste-to-energy technologies.

Theoretical framework

This study was anchored on Urbanization Theory by Louis Wirth (1897–1952) through his work "Urbanism as a Way of Life" (1938), which posits that the urban environment impacts social relationships, behaviours, and lifestyles. Wirth argued that urban environments create distinctive social patterns and ways of life. As such, urbanisation significantly impacts solid waste generation and management in cities due to unprecedented population growth, industrialisation, and changing lifestyles, which contribute to increased waste production. Studies by Chen (2018) have shown that household population and economic indicators are closely related to the volume and composition of solid waste. The theory best fits this study because it provides a basis for determining waste generation patterns and determinants of management in Bungoma County urban centres, which could inform waste management plans.

Research Design

The study adopted a cross-section survey coupled with stratification of the urban centres and random sampling of respondents. A multi-stage sampling procedure, which included stratifying the sampling area into urban and peri-urban areas followed by random sampling of residents, was applied to select residential areas to study. In contrast, snowball sampling was used to select individual homeowners and residents. In each, respondents were put in various strata. Thus, it includes business or business enterprises, residential/households, institutions such as schools and colleges, and government and private institutions. Structured questionnaires were administered to residents, focus group discussions (FGDs) were conducted, and in-depth interviews were conducted with key informants in the county government offices. Secondary data was collected from the county government Ministry of Environment. The researcher applied visual observations of solid waste management and composition to validate the primary data. According to KNBS (2019), the population of Bungoma County was reported as 1,670,570, of which 812,146 were males and 858,389 females.

The Krejcie and Morgan (1960) was adopted to determine the sample size based on:
$S = X^2NP(1 - P) \div d^2(N - 1) + X^2P(1 - P)$
S = required sample size
X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level where
N = the population size
P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size)
D = the degree of accuracy expressed as a proportion (0.05)

The sample size for this study was 382 from the target population of 190,112 urban dwellers distributed by probability, as shown in Table 1.

Table 1: Distribution of respondents and sample population

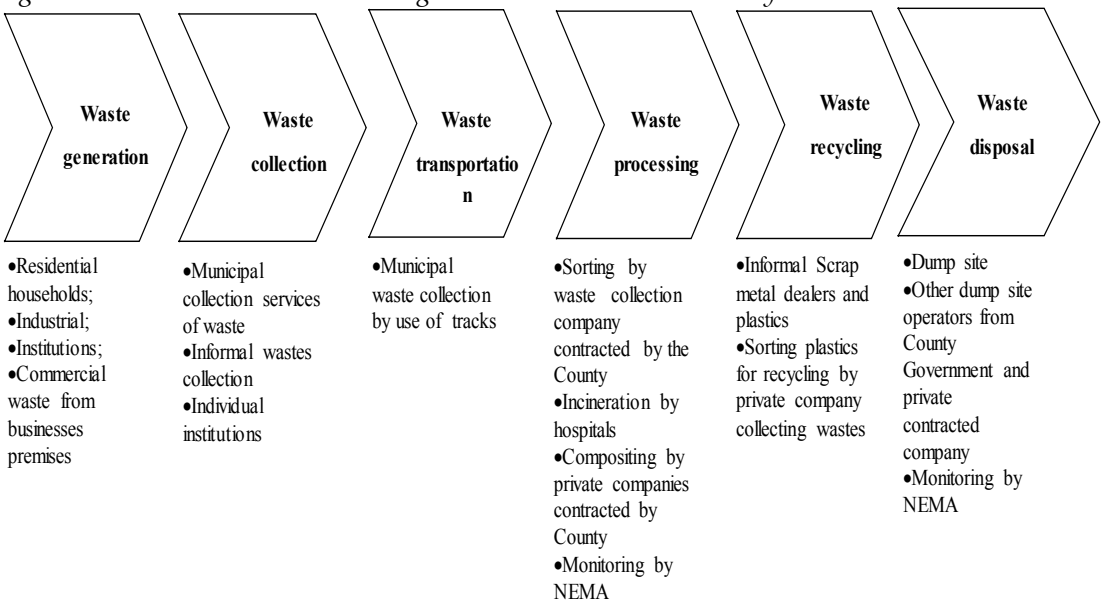
Respondents	Frequency	Percentage (%)
Business community	174	45.55
Residential homes	174	45.55
Institutions (NEMA, County government)	34	9.0
Total	**382**	**100**

A total of 310 questionnaires were filled and returned after the study, representing 82.4%. The data collected was analysed quantitatively using descriptive and inferential approaches. Data from the questionnaire was cleaned, edited, coded and analysed using Statistical Package for Social Science (SPSS) (version 28.0) descriptively using percentages, frequency and measures of central tendency, including mean and standard deviation, and presented using tables, graphs and pie charts.

Results and Discussions

The processes of the solid waste management value chain, as shown in Figure 1, were a consolidation of the researcher's observation, respondents' perspectives and document analysis.

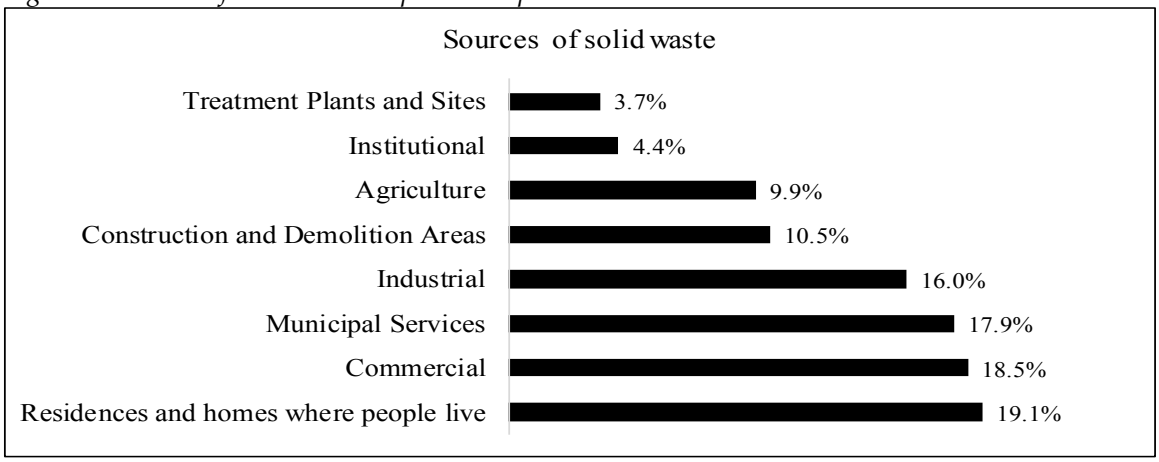
Figure 1: Observed Solid waste management value chain in the study area



The region's solid waste value chain is dynamic due to internal factors (relationships between actors) and external factors (population attributes). According to our findings from the respondents and key informants, the solid waste management value chain commences from the household, institutional or commercial waste generators, which are the main producers or generators of waste, as shown in (Figure 1). The main actors in waste generation include the commercial sector or businesses, residential homes, and institutions. All these actors play a vital role in ensuring waste is managed as much as possible before it is released to the collection stage. The collection stage is when the generator waste is put forth in collection centres or points before transportation. Again, some management aspects occur, including conventional burning, separation and sorting. The transportation stage follows the dumping site. Here, management aspects like complete waste coverage to avoid littering on collection routes and quick

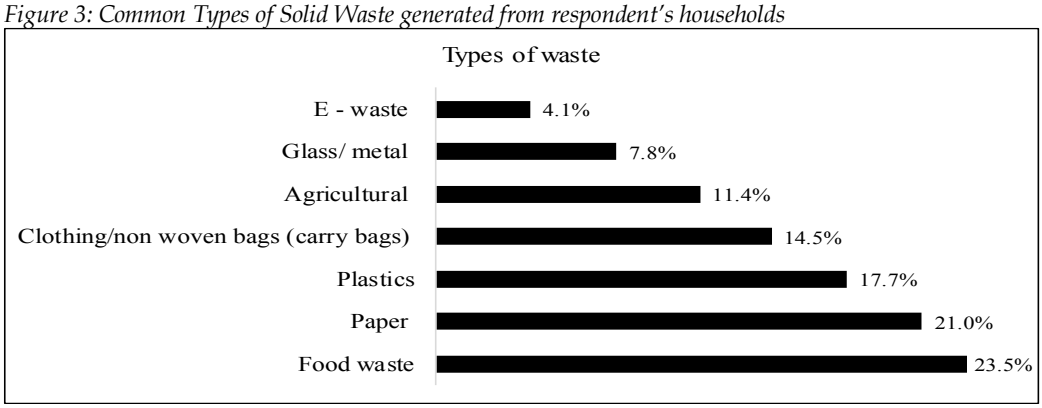
transportation to avoid its effects like a foul smell. Contracted companies and the private sector do it. Then, we have processing, which involves incineration for hazardous waste and sorting and separation for recycling. Other processes here include gasification and pyrolysis. Recycling is done by actors such as private companies, while composting can occur even at the generation stage. Respondents were asked about sources of solid waste. The findings are shown in Figure 2.

Figure 2: Sources of Solid waste as per the respondents



Findings showed that residences and homes were the main sources of solid waste, with the highest percentage of sources of waste being 19.1%. The garbage from residences and homes mainly includes food leftovers, pilings, and household items wraps. Commercial waste followed at 18.5%. This waste business premises in the urban centres, including hotels, markets, restaurants, and stores. Municipal services were 17.9% of the sources of waste. This is the waste collected and treated by the county government, including street cleaning, waste from parks, wastewater, landscaping, and recreational areas and markets. Industrial waste constituted 16% of the total waste in the study area. This was waste from major light industries in the towns (urban centres) such as the *Jua Kali* sector. Construction and demolition waste accounted for 10.5% of the waste, as well as buildings and roads, road repairs, building renovation, and building sites. The waste from construction and demolition includes steel materials, concrete, wood, plastics and debris. Agriculture waste constituted 9.9% due to land preparation, plant management and harvesting for crop production. Institutional waste was 4.4%, and treatment plants at 3.7%.

Figure 3: Common Types of Solid Waste generated from respondent's households



Respondents were asked about the types of solid waste generated. The results are shown in Figure 3. The findings revealed that food waste comprised the highest amount of waste generated at 23.5%, followed by paper (21%), plastic (17.7%), clothing (14.5%), agricultural waste (11.4%), glass/metal (7.8%), and E-waste (4.1%).

Quantity of solid waste generated and composition

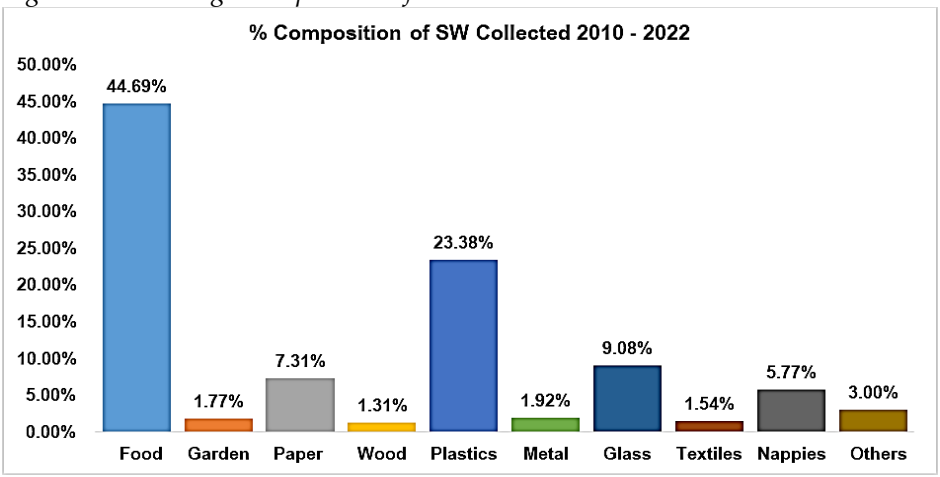
Respondents were asked about the quantity of waste produced per week in the study area, and their responses are shown in Table 2.

Table 2: Average Amount of Solid Waste Generated per week in the study area as per the respondents

Average amount of solid waste generated	Frequency	Percentage
Less than 5 kg	12	3.9
5-10 kg	152	49.0
10-20kg	93	30.0
20-50kg	34	11.0
Above 50kg	19	6.1
Total	**310**	**100**

Most respondents (49%) produced 5-10 kg of waste per week, 30.0% produced more than 10-20 kg per week, 11% produced 20-50kg of waste,6.1% above 50%, and 3.9 less than 5kg. This implies that households produce the highest quantity of waste. Solid waste composition from the study area is presented in Figure 4.

Figure 4: Percentage Composition of Solid Waste Collected



Findings show that food waste (44.69%) and plastics (23.38%) are the main sources of solid waste in Bungoma town. Plastics are mainly used to pack food and soft drinks, adding to the composition of solid waste in the area. Paper waste had a significant percentage (7.31%) owing to Kenya's ban on polythene bags in 2017. The ban gave way to using paper for packaging household items like sugar, rice, and many others. There was a significant number of nappies (5.77%) in the waste collected, a common occurrence in urban centres, especially in estates with high concentrations of young children. Wood waste, garden waste, metal and textiles had a remarkably lower percentage (1.31, 1.77, 1.92, and 1.54% respectively. Wood is easily compostable and combustible, and its reuse is inevitable in terms of fuel as firewood and the other remaining end up in the compost. Hence, little is found in the municipal waste. Garden waste, too, is easily compostable; hence, a lower percentage ends up in the waste channel at disposal. The scrap metal industry has taken most waste for reuse and recycling, hence, minimal traces of metal end up at the dump site. On the other hand, textiles can easily burn in open burning, both at collection centres on sunny days. As a result, a lower percentage ends up at the disposal site.

Waste disposal and management in the study area

Most of the solid waste in the study area is dumped in the open fields at designated collection centres and left unmanaged for some time before collection and eventual transportation, as shown in Figure 5.

Figure 5: Open waste collection site (a) (Kimilili) and (b) the Muanda dumpsite in Bungoma

(a) Solid waste Collection centre in Kimilili Urban centre (b) Open Muanda dump site in Bungoma County

Observations revealed that solid waste in the study area is dumped in open fields at designated collection centres, as in Figure 5a. It is then collected by a transportation company contracted by the county government. The collected waste is then taken to the dump site at Muanda dumpsite (Figure 5b), the only dumpsite in the County. In the study area, waste is mainly managed by open burning, leaving it in open fields (unmanaged), and incineration. Results are shown in Table 3.

Table 3: Waste disposal and management in the study area

	Amount of waste disposed (Tonnes per day)		
Year	**Open burning**	**Unmanaged waste**	**Incineration**
2010	563.4	10253.0	450.7
2011	542.9	9880.8	434.3
2012	663.0	20553.0	884.0
2013	999.6	30989.1	1332.9
2014	721.1	33602.7	1730.6
2015	1058.4	48686.4	3175.2
2016	539.8	49554.4	3886.6
2017	811.2	73816.7	6489.4
2018	795.5	71758.4	7000.8
2019	459.8	82304.2	9196.0
2020	450.7	78869.0	10816.3

Data source (Bungoma County Ministry of Environment)

Results revealed that open burning increased from 2010 to 2015, with a slight drop in 2014. There was an observable decline up to the year 2020, which could be attributed to improved management by the County government since improved waste collection methods were initiated in 2016. Incineration increased steadily from 2013 to 2020, indicating the county government's enhanced waste management. The waste generated was incinerated daily, a better waste management strategy than open burning. Information from key informants is in support of these findings. The

waste generated was incinerated daily, a better waste management strategy than open burning. Information from key informants is in support of these findings. They indicated that:

> *Incineration is done by county government hospitals, which also incinerate for private facilities that do not have these facilities. Plans are underway to have an incinerator at the dumpsite in Siritanyi to reduce the incineration load at public hospitals. Further, the county government of Bungoma has acquired land in Kimilili sub-county to cater to urban centres and markets in its proximity' (Key informant 1).*

Separating or sorting waste generated and eventually using it for another form of production is common among the waste-pickers. Waste-pickers mine for valuable materials and items before garbage enters the waste stream or en route, especially in many municipalities' lower and middle-income areas. The county government of Bungoma has constructed incineration facilities in major health centres to manage clinical waste. Unmanaged waste is, however, considerably high, which shows a gap in waste management by the county government.

Strategies for Managing Solid Waste

Respondents were asked to indicate how much they agreed with approaches to managing solid waste in the town. The findings are presented in Table 4.

Table 4: Strategies of Managing Solid Waste (N=310)

	Frequency				
Approaches	SA	A	NS	D	SD
Public participation and awareness	73(23.5%)	109(35.2%)	6(1.9%)	110(35.5%)	12(3.9%)
Private sector and public partnerships	126(40.6%)	135(43.5%)	29(9.4%)	12(3.9%)	8(2.6%)
Proper sites for disposal facilities	180(58.1%)	75(24.2%)	15(4.8%)	24(7.7%)	16(5.2%)
Re-use, energy recovery and recycling	187(60.3%)	87(28.1%)	12(3.9%)	24(7.7%)	0(0%)
Waste to energy	174(56.1%)	84(27.1%)	48(15.5%)	4(1.3%)	0(0%)
Laws and Legislation	162(52.3%)	24(7.7%)	48(15.5%)	68(21.9%)	8(2.6%)
Waste avoidance and reduction	175(56.5)	95(30.6%)	12(3.9%)	28(9%)	0(0%)
Integrated planning considering climate changes	130(41.9)	100(32.2%)	22(7.1%)	22(7.1%)	36(11.6%)
Investment in resilient infrastructure	94(30.3%)	160(51.6%)	12(3.9%)	20(6.4%)	24(7.7%)

Key: SD= SA= Strongly agree, A=Agree, NS=Not Sure, D=Disagree, Strongly disagree. The numbers in parenthesis are percentages

Findings show that respondents strongly agreed on investment in resilient infrastructure for mitigating rainfall effects of waste management, reuse, energy recovery, and recycling. Other respondents agreed on public participation and awareness (23%), integrated planning considering climate changes (41.9%), laws and legislation (52.3%), private sector and public partnerships (40.6%), waste to energy (56.1%), as essential approaches of managing solid waste. Findings support Owiti (2019), who reported that the community had limited awareness of the laws and the County Government and National Governments' role in enforcing waste management regulations. The involvement of NEMA was also not sufficient. The regulator could not solve waste management disputes as expected, and public participation was poor towards supporting the law on waste management.

The scenarios of poor waste management were attributed to diverse challenges, including insufficient waste collection services such as garbage bins or bags, thus making residents who

cannot afford to pay for private garbage collection to improvise ways of disposing of waste. Further limited budget allocation to waste collection by the County government and lack of dedicated income streams for solid waste services hindered financing of solid waste operations. There were inadequacies in skilled personnel, inadequate facilities, and lack of commitment of municipal staff to effect waste management plans.

Mitigation approaches to poor waste disposal

Respondents were also asked about the mitigation approaches to poor waste disposal, and the results are shown in Table 5.

Table 5: Approaches to effective Urban Solid Waste management

Mitigation approaches to curb socio-economic effects of urban solid waste	Number of records	Percentage of total records
Effective waste management	270	11.6
Emergency preparedness and response	262	11.2
Recycling and resource recovery	254	10.9
Research and data monitoring	226	9.7
Financial incentives	211	9.0
Public awareness campaigns	184	7.9
Climate resilient waste management practices	176	7.5
Innovation and technology adoption	168	7.2
Government policies and regulation	114	4.9
Community engagement	112	4.8
Green jobs and entrepreneurship	102	4.4
Infrastructure development	98	4.2
Collaboration and partnerships	83	3.6
Circular economy initiatives	75	3.2
Total records	**2335**	**100%**

Findings show that the most outstanding mitigation approaches to poor urban solid waste management in the study area were effective waste management (11.6%), emergency preparedness and response (11.2%), and recycling and resource recovery (10.9%). Effective waste management could include increasing the level of awareness of the community and the public and private sectors. Adequate financing by the County government and partners could support infrastructure for proper solid waste management. If most of the waste could be recycled, then a substantial reduction in final volumes of waste could be achieved, and the recovered material and resources could be utilised to generate revenue to fund waste management (Brunner & Fellner, 2007). Recent studies have proven that the most effective methods to reach solid waste management objectives are improving disposal systems such as complete collection, upgrading to sanitary landfilling, modern waste infrastructure, and government funding (Brunner & Fellner, 2007).

Discussion

Urban solid waste collection is critical to city management and public health. It involves systematically collecting, transporting, and disposing of waste generated by households, businesses, and institutions. Effective waste collection systems help maintain sanitation, prevent pollution, and enhance the quality of urban life. Key aspects of urban solid waste collection include collection methods (curbside collection drop-off centres and bin systems), collection schedules, transportation, sorting and processing, recycling and reuse. Effective urban solid waste collection systems are vital for maintaining public health, protecting the environment, and ensuring the sustainability of urban areas. Jia-Wei et al. (2017) affirm that a smart and green waste collection system designed to create a more sustainable waste management system will give solid management a great mileage.

Municipal solid waste composition analysis is crucial for developing effective waste management strategies such as composting, recycling, and energy recovery (Nyankson et al., 2015). In many countries, biodegradable waste typically constitutes the largest fraction of waste (Bölükbaş & Akıncı, 2018), followed by plastic waste (Daura et al., 2014). Common waste components include nappies, paper, glass, metals, and textiles.

Teshome (2020) states that to improve the status of urban solid waste management, political will, institutional reform, finance, and, most importantly, behaviour change are necessary to ensure sustainable waste management. Improving solid waste management involves a multi-faceted approach that addresses various aspects of waste generation, collection, treatment, and disposal. They are waste minimisation **(**reducing waste generated at the source), efficient collection systems, recycling programs, and organic waste management**.** Waste-to-energy technologies**,** improved landfill management**,** regulatory and policy framework, public participation and engagement**, t**echnological innovation**,** and infrastructure development.

Municipalities can enhance their SWM systems and reduce their environmental footprint by integrating sustainable practices, advancing technologies, engaging communities, and enforcing effective policies. Regular assessment and adaptation of strategies are also crucial to meet evolving challenges and opportunities in waste management.

Conclusion

Findings showed that residences and homes were the main sources of solid waste since they take up the highest percentage of sources of waste. Thus, there should be adequate provision of household waste infrastructural facilities. Findings further revealed that food waste and plastics were the main components of solid waste in Bungoma County urban centres. Proper disposal should be embraced at the collection points and the dump site. Findings on waste management strategies showed that 60.3% of the respondents strongly agreed on re-use, energy recovery & recycling as a strategy for waste management. At the same time, laws and legislation would help to manage the waste. The 4R (reduce, reuse, recycle, and recover) concept can minimise the quantity of solid waste produced and dumped.

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