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Establishing Spatial Characteristics of High-Density Residential Neighbourhood That Can Influence a Sustainable Solid Waste Management System in Kasarani, Nairobi

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Abstract

Kasarani, a densely populated residential neighbourhood in Nairobi City County, has experienced increased demand for solid waste management services due to its rapid population growth. This study focused on establishing spatial attributes that can influence a sustainable solid waste management system in Kasarani. The study was conducted through random sampling where 105 housing units, 30 blocks, and 30 clusters were selected. It was established that the average amounts of solid waste generated per week in the study area were 8.64 kg, 198.72 kg, and 4968 kg per housing unit, per block, and per cluster, respectively. The per capita waste generation rate was 0.31 kg/capita/day, with an average household size of 4.90% of the residential blocks in the study area devoid of waste storage containers. This was attributed to high ground coverage, leaving minimal space for such facilities. This factor had a negative effect on waste segregation at the housing unit level. The illegal dumping in the study area was exacerbated by the lack of solid waste collection facilities and long distances covered by waste collectors to pull their carts to reach designated disposal sites. Housing units' spatial characteristics, such as household size and number of rooms, had a positive correlation with solid waste generated by a housing unit at 0.709 and 0.534, respectively. Similarly, blocks' spatial attributes, such as block population density and number of housing units, had a positive correlation with waste generation at 0.832 and 1, respectively. This means that as household size, number of rooms, population density and number of housing units increase, so does the amount of waste generated. This finding can be used by policymakers and developers to compute the capacity of block solid waste storage container, capacity and number of collection facilities, and the capacity of waste transportation vehicles.

Keywords

High-Density Residential Neighbourhood, Spatial Characteristics, Sustainable Solid Waste Management System, Kasarani, Nairobi, Kenya

1. Introduction

From 2002 to 2012, global municipal solid waste (MSW) generation increased by 91%, from 0.68 to 1.3 billion metric tons, and is anticipated to reach 2.2 billion metric tons annually by 2025 (Cogut, 2016; World Bank, 2022). Similarly, Africa is projected to generate 250 million tons of municipal solid waste in the same period, surpassing any reduction in waste generation in other parts of the world. This is due to significant social and economic changes in Africa, driven by a rapidly growing population, urbanization of cities, and evolving consumer purchasing patterns (Jayasinghe, 2013; UNEP et al., 2018).

A solid waste management system comprises six functional elements: generation, on-site handling and storage, collection, transfer and transport, processing and resource, and disposal (Jamal, 2020). The management of solid waste remains a significant societal and governance issue, particularly in urban areas issue (World Bank, 2022), (Sawaya et al., 2024), where 33% of global solid waste is improperly managed (World Bank, 2022). In many developing nations, solid waste management is mainly marked by ineffective collection methods, inadequate coverage of the collection system, and overflowing dumping sites (Ogutu et al., 2018). For example, an average of 55% of the waste generated is collected in these cities (Abubakar et al., 2022; UN-HABITAT, 2018).

More than 90% of the waste generated in the global south is disposed of at uncontrolled dumpsites and landfills (UNEP et al., 2018). This method has limited capacity, is costly, and environmentally harmful (Debrah et al., 2022). The open dumping is commonly coupled with waste open-burning practices (Muchangos & Tokai, 2020). These practices are major sources of greenhouse gases (GHG), such as carbon (IV) oxide (CO_2), nitrous oxide (NO_2), and methane (CH_4), plus particulate matter in the air. Williams et al. (2018) records that open burning contributes about 5% of GHG emissions. Approximately 3.1 million people globally die prematurely due to fine particulates ($PM_{2.5}$) emitted during the open burning of solid waste (Cogut, 2016). Regrettably, open dumping is expected to contribute an average of 9% of the global anthropogenic GHG emission by 2025 if nothing changes (Williams et al., 2018). Additionally, this practice can lead to the contamination of surface and groundwater through leaching, soil pollution from direct contact with waste, and the spread of diseases through various vectors like rodents and insects (Naibbi & Umar, 2017), (Mirmotalebi et al., 2023).

Several studies, including those by Godfrey et al. (2019), Šedová (2016), Nagpure (2019), Rodney (2018), and Kathambi & Ogutu (2021), have identified numerous factors contributing to Africa's poor solid waste management. These factors include weak organizational structures, high dumping costs, lapses in institutional frameworks, low-income levels, limited public awareness, insufficient skills, and varying education levels. Additionally, weak legislation, inadequate budgets, poor coordination across the waste management chain, a lack of political will, weak enforcement, corruption, insufficient waste management infrastructure (such as waste collection centers and transportation), governance failures, rigid centralized administrative systems, and inefficiencies in waste collection are also cited as contributing factors. Poor solid waste management leads to several significant issues, including environmental pollution, global warming, the spread of diseases, such as malaria and dengue, and the blocking of drains, which can result in flooding (Abubakar et al., 2022; Alajmi, 2016).

Like many other urban areas in the global south, Kasarani study area has experienced increased demand for solid waste management services due to its rapid population growth. However, the county government of Nairobi provides minimal solid waste management services (less than 10%) to the residents of Kasarani (KNBS, 2019). With the minimal SWM services and facilities from the county government in Kasarani, waste collection and disposal services are provided through private and community-based organisations. Disadvantageously, these collectors experience innumerable challenges in their service delivery, such as a lack of solid waste collection facilities, and suitable garbage transportation vehicles. The inadequacy of these facilities leads to a proliferation of unplanned dumpsites. Open dumping leads to environmental pollution and amplifies the susceptibility of urban residents to health risks and insecurities.

Despite the growing number of studies on solid waste management, not much attention has been devoted to understanding the connection between spatial characteristics of densely populated neighbourhood areas and a solid waste management system in Kasarani. For instance, a study by W. Muthoni (2014), addressed the deficiencies in solid waste management within public, private, and community-based organizations. The study recommended research into sustainable facilities suitable for waste management in urban centers in developing countries. Additionally, a study conducted by E. Muthoni (2018), focused on the utilization of the Internet of Things (IoT) to enhance efficient solid waste disposal systems. Under the business-as-usual scenario, the adverse effects of ineffective solid waste management on human health and the environment will be augmented. Thus, the main purpose of this study was to establish the spatial attributes of a densely populated neighbourhood that can influence a sustainable solid waste management system in Kasarani. The specific objectives of the study were:

1) To establish the solid waste management system in Kasarani.

2) To establish spatial characteristics that can influence a solid waste management system in Kasarani.

3) To recommend spatial strategies that will influence a sustainable solid waste management system in Kasarani.

Study Area

Kasarani is located in the northeast of Nairobi and is about 15 km from the central business district (CBD). It is along Thika Road (A2). It is traversed by Kasarani Mwiki Road, which joins Thika and Kangundo roads. The study area has a population of 50,112 with an annual population growth rate of 4.1% (KIPPRA, 2022). The study area covers 5.91 km^2, with a population density of 8480 persons per km^2. It is estimated that with an annual population growth rate of 4.1%, the population will increase to approximately 167,288 by the year 2049. **Figure 1** illustrates Kasarani study area in the context of Nairobi City County.

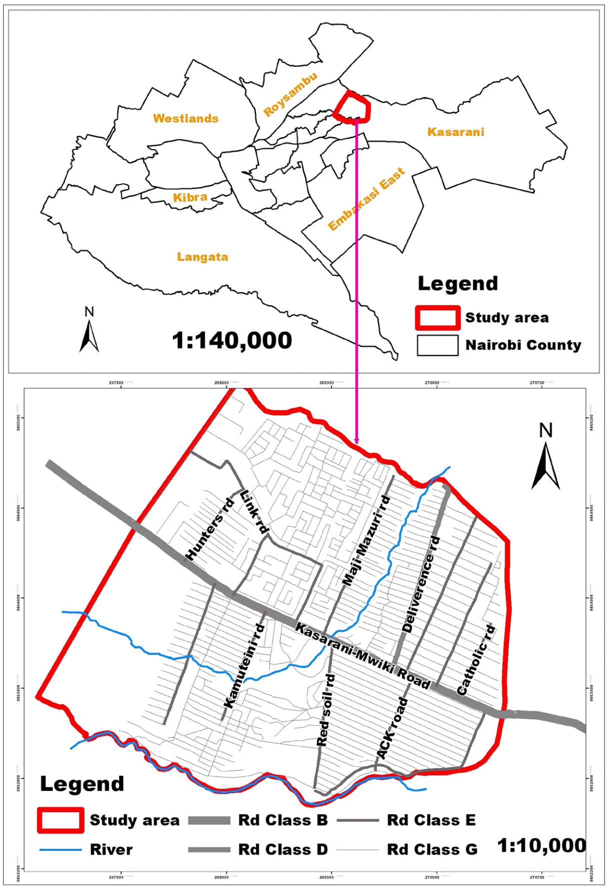

Figure 1. Kasarani Study Area in Relation to Nairobi City.

2. Methodology

The study employed a mixed approach, incorporating both quantitative and qualitative research approaches, allowing for a multi-dimensional exploration of the research variables in Kasarani study area. Quantitative data collected included the quantity of solid waste generated, household size, number of bedrooms, area of the housing units, number of units per floor, number of units per block, number of people per floor, floor area, occupancy density, plot size, ground coverage, number of people in the cluster, cluster area, cluster population density, and frequency of solid waste collection. Qualitative data, gathered through observations and interviews, provided insights into waste separation, waste dumping, and open waste burning, helping the researcher understand residents' solid waste management practices. Additionally, both quantitative and qualitative methods were used to evaluate the types of waste storage containers, waste transportation methods, road conditions, and locations of disposal sites. 105 housing units, 30 blocks, and 30 clusters obtained through simple random sampling were the subject of the study. The KoBoCollect application, which was used as the study's data recording tool, incorporated skip-logic and validation criteria to enhance efficiency and accuracy when administering the interview guide. A simple analysis of the collected data was performed in KoBoToolbox before downloading in .CSV format for further analysis in Excel, SPSS, and ArcGIS. Data presentation was done in the form of tables, figures, and texts. As well, the study employed a multiple regression model to analyse the effect of spatial attributes and the solid waste management system, specifically focusing on waste generation. The independent variables considered at the housing unit level were: household size, number of rooms, housing unit size, household income, and occupancy density. The independent variables considered at block level were: block area (m^2), number of people in the block, number of housing units, ground coverage, block occupancy density. The dependent variable at each level was the amount of waste generated. The study's indicator system's formation involved a thorough analysis of existing literature on waste generation and supervisory consultations to ensure that the chosen variables are relevant and capable of providing meaningful correlations with solid waste generation.

Expression of the model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_n X_n + \varepsilon \tag{1}$$

where:

Y is the amount of waste generated;

β_0 is a constant equivalent to the dependent variable if no independent variable is influencing the dependent variable;

X_1 is the first independent variable;

X_n is the n^{th} independent variable;

β_1 is the coefficient of X_1;

β_n is the coefficient of X_n;

ε is the error.

3. Results and Discussion

3.1. Solid Waste Management System in Kasarani Study Area

3.1.1. Waste Generation

The primary contributors to solid waste within the study area included food waste, food soiled paper, plastic, textile (e.g., clothing, linens, and towels), metal, glass, rubber, leather, cardboard, special waste (e.g., sanitary towel, diaper, cleaning products, sharp objects such as needles and beauty-related waste products), and electronic waste (e-waste), such as bulbs, batteries, phones, and sockets among others. Organic waste contributed more than 50% of the solid waste generated in the study area. The approximate volume of waste generated per week per housing unit was 8.64 kg, with the least recorded output of 1 kg and the highest amount of solid waste generated of 20 kg. The per capita waste generation rate was calculated by dividing total average amount of solid waste generated per household by the average household size per the number of days the waste was generated, see Equation (2). The formula was also employed to calculate the per capita waste generation in studies conducted by Dangi et al. (2011) and Dikole & Letshwenyo (2020).

$$g = \frac{G}{d \cdot h} \tag{2}$$

where:

g is the amount of waste generated per person per day;

G is the average amount generated by a housing unit per week;

d is the number of days the housing unit waste volume was averaged;

h is the average household size;

$G = 8.64$ kg;

$d = 7$ days (1 week);

$h = 4$.

Thus,

$$g = \frac{8.64}{7 \times 4} = 0.31 \text{ kg}$$

Equation (3) illustrates how the approximate volume of waste generated per block per week was obtained:

$$G_B = G \times H_B \tag{3}$$

where:

G_B is the approximate average volume waste generated per block;

G is the average amount generated by a housing unit per week;

H_B is the average total number of housing units per block.

$$G = 8.64 \text{ kg}$$

$$H_B = 23$$

Thus,

$$G_B = 8.64 \text{ kg} \times 23$$

$$G_B = 198.72 \text{ kg}$$

Equation (4) illustrates how the approximate volume of waste generated per cluster per week was computed:

$$G_C = G_B \times B_C \tag{4}$$

where:

G_C is the approximate average volume waste generated per cluster;

G_B is the average amount generated per block per week;

B_C is the average total number of blocks per cluster.

$$G_B = 198.72 \text{ kg}$$

$$B_C = 25$$

Thus,

$$G_C = 198.72 \text{ Kg} \times 25$$

$$G_C = 4968 \text{ kg}$$

3.1.2. Waste Storage

Kasarani residents store their generated solid waste in single storage containers. 48% are stored in lidded plastic containers, 28% in plastic bags, and the remaining 14% in unlidded bins, see **Figure 2** and **Figure 3**. These types of households' storage containers discourage waste segregation at source since most residents lump together their generated waste. Regrettably, mixed solid waste presents challenges to waste recyclers in sorting and processing, impeding recycling efforts (Sheau-Ting et al., 2016). Additionally, this practice fosters waste contamination, indirectly impacting human health. For instance, some of the waste pickers retrieve organic waste from the disposal sites and sell it to pig farmers in the neighbourhood, who in turn sell the pigs to the nearby slaughterhouses. From the slaughterhouse, the meat is supplied to butcher shops in the neighbourhood. Ultimately, the consumers who purchase the pork meat are indirectly affected by the contaminated food waste. Furthermore, the unlidded solid waste storage containers have several adverse effects on the neighbourhood. They encourage intrusion by rodents and houseflies, which can spread diseases and create unsanitary conditions.

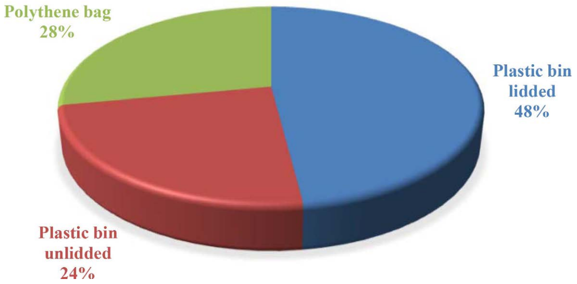

Figure 2. Household storage containers in Kasarani study area (%).

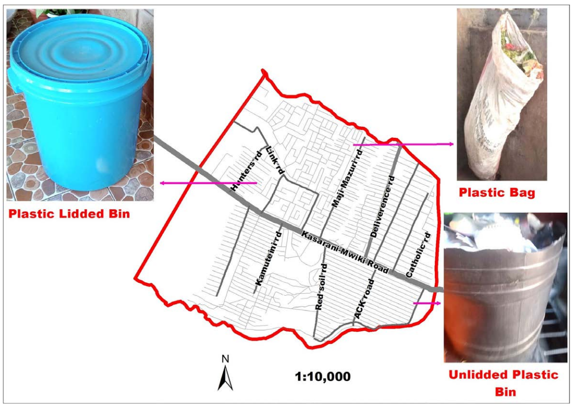

Figure 3. Types of household storage containers in Kasarani.

82% of the study area blocks were devoid of waste storage containers. Similar to the inadequate space for other essential facilities, like parking facilities, in a block due to high ground coverage, residential blocks lack space for storage containers. Most developers prioritize the optimum number of housing units over them. Unfortunately, this has a ripple effect on waste segregation at the housing unit level. The residents were demotivated to segregate their solid waste at the household level since it would be lamped together at the gate on waste collection day.

3.1.3. Solid Waste Collection

Commendably, 98% of the Kasarani study area receives waste collection services; this stands out compared to the 54.6% of Kenya's urban population that receives the same services and the 80% of the whole Nairobi City County population (KNBS, 2019). 60% of them receive services from community-based organizations. The remaining 31% receive the services from private companies. The county government doesn't offer waste collection service to this neighbourhood. The solid waste is majorly collected once a week for an average fee of Ksh. 150 per month. Generally, the blocks are devoid of space for solid waste storage or collection, as mentioned earlier. Thus, on the block's scheduled day for waste collection, the residents carry their garbage from their housing units to the plot's entrance, awaiting collection by the contracted waste collector, see **Figure 4**. However, in cases of delays in waste collection by the contracted waste collectors, the residents experience bad odors and flies in the surrounding area.

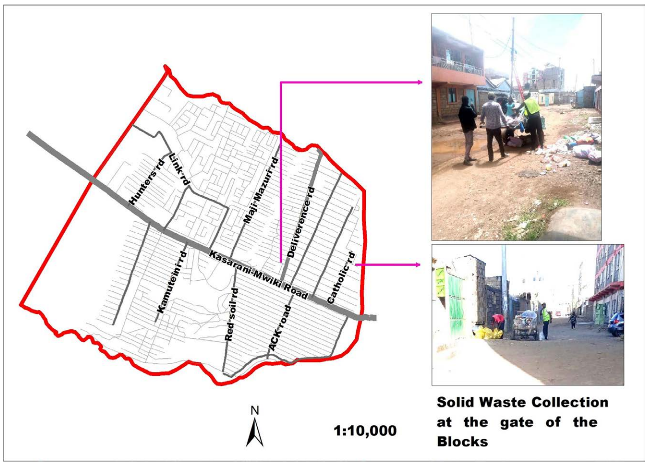

Figure 4. Solid waste collection at the entrance of the block in Kasarani study area.

3.1.4. Solid Waste Transportation

90% of the solid waste generated in the study is transported via cart to the disposal areas, see **Figure 5**. The remaining 10% of the garbage is transported via private trucks. The cart pullers resort to dumping their waste in their preferred accessible space within the study area due to the extensive distance to the county-designated space (Dandora dumpsite), which is 15 km from the study area. The study area lacks a designated space for waste disposal, collection, or transfer. The human-pulled carts are open and prone to leaks, resulting in waste dropping and leachate dripping during transportation, contaminating the environment, e.g., soil and water sources, and posing risks to human health.

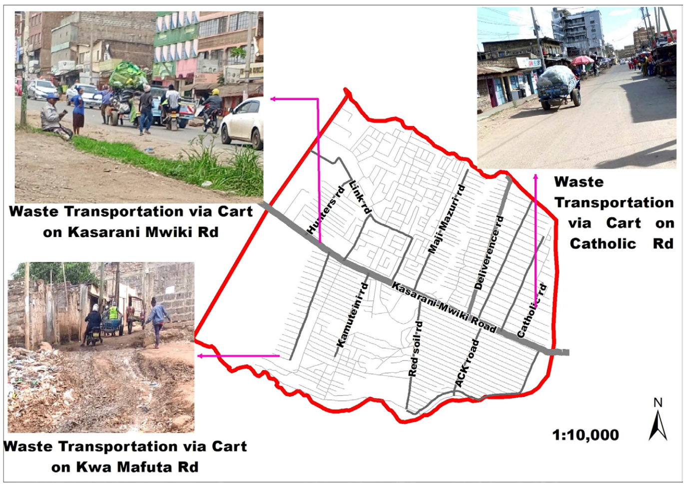

Figure 5. Solid waste transportation vehicles.

3.1.5. Solid Waste Disposal

The study area is characterized by open-space waste dumping, including on vacant plots, riparian reserves, railway reserves, and street dumping, see **Figure 6**. The open dumping of solid waste is attributed to the extensive distance the cart pullers have to cover to reach the designated disposal site, 15 km from the study area. It is also ascribed to the lack of solid waste collection facilities, which act as a linkage between residential blocks, waste recyclers, and the designated disposal site. Open dumping poses significant environmental and public health hazards. The compounded waste contaminates the soil, water sources, and air. As well, the disposal of waste in the rivers and drainage channels causes blockage, affecting storm water flow and leading to flooding during rainy seasons. To reduce the volume of solid waste accumulated in the dumping areas, residents burn the accumulated waste, see **Figure 7**. This mode has health and environmental adverse effects, such as the emission of greenhouse gases (GHG), such as ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S), methane (CH_4), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), plus particulate matter in the air (Jakhar et al., 2023; Ramadan et al., 2022).

3.2. Spatial Characteristics That Influence Solid Waste Management System in Kasarani

3.2.1. Housing Unit Level

Spatial attribute at housing unit level. The spatial attributes at the housing unit level included household size, number of rooms in the housing unit, housing unit area size (m^2), household income (Ksh.), and housing unit occupancy density (persons/m^2).

Figure 6. Solid waste disposal in Kasarani study area's open-space.

Figure 7. Burning of accumulated solid waste in Kasarani study area.

Correlation analysis. To explore the relationships between spatial attributes and the amount of solid waste generated at housing unit level, a correlation analysis was conducted. The variables included in this analysis were: household size, number of rooms, housing unit area size (m^2), household income (Ksh.), housing unit occupancy density, and amount of solid waste generated by the housing unit. Pearson's correlation coefficient was used to measure the strength and direction of the linear relationships between these variables. The results are summarized in Table 1.

From Table 1, household size, number of rooms, housing unit size (m^2), and household income (Ksh.) had a positive correlation with the amount of solid waste generated by a housing unit at 0.709, 0.534, 0.547, and 0.474, respectively. This means that as they increase, the amount of solid waste also increases, and vice versa. The increase in household size with the amount of waste generated by the housing unit is in line by another study by Trang et al. (2017). In the study area, housing units with smaller household sizes often depend on nearby motels

Table 1. Correlation matrix table showing correlations between the spatial attributes and solid waste generation at housing unit level.

Correlations							
		Household size	No. of rooms	Housing unit area	Amount of waste	Household income	Occupancy density
Household size	Pearson Correlation	1	0.616**	0.547**	0.709**	0.488**	0.033
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.737
	N	105	105	105	105	105	105
No. of rooms	Pearson Correlation	0.616**	1	0.863**	0.534**	0.540**	−0.574**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
	N	105	105	105	105	105	105
Housing unit area	Pearson Correlation	0.547**	0.863**	1	0.547**	0.540**	−0.543**
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.000
	N	105	105	105	105	105	105
Amount of waste	Pearson Correlation	0.709**	0.534**	0.547**	1	0.474**	−0.135
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.170
	N	105	105	105	105	105	105
Household income	Pearson Correlation	0.488**	0.540**	0.540**	0.474**	1	−0.298**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.002
	N	105	105	105	105	105	105
Occupancy density	Pearson Correlation	0.033	−0.574**	−0.543**	−0.135	−0.298**	1
	Sig. (2-tailed)	0.737	0.000	0.000	0.170	0.002	
	N	105	105	105	105	105	105

**. Correlation is significant at the 0.01 level (2-tailed).

or informal food vendors for cooked meals and pre-prepared vegetables, thereby minimizing the amount of solid waste they generate. The increase in solid waste generated by household income levels is supported by other studies (Visvanathan & Trankler, 2003). Housing unit occupancy density had a weak negative correlation with the amount of solid waste generated at −0.135. This means that when the housing unit occupancy density increases, the amount of solid waste decreases insignificantly.

Regression analysis. A stepwise regression analysis was conducted to model the relationship between housing unit spatial attributes and the solid waste management system, specifically focusing on waste generation. The independent variables considered in this analysis were: household size, number of rooms, housing unit size, household income, and occupancy density. These variables were entered into SPSS for the analysis. The dependent variable was the amount of solid waste generated by the housing units. The stepwise regression approach was chosen for its ability to identify the most significant predictors by systematically adding or removing variables based on their p-values. This approach helps in refining the model to include only those variables that have a statistically significant impact on the dependent variable. The results of the regression analysis are summarized in Table 2, Table 3 and Table 4.

Table 2. Model summary regression of solid waste generation and spatial elements at housing unit level.

Model Summary									
					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	0.709[a]	0.503	0.498	1.488	0.503	104.177	1	103	0.000
2	0.734[b]	0.539	0.530	1.439	0.036	8.010	1	102	0.006

a. Predictors: (Constant), Household size; b. Predictors: (Constant), Household size, Housing unit area.

Table 3. Sample ANOVA for regression of solid waste generation and spatial elements at housing unit level.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	230.560	1	230.560	104.177	0.000[b]
	Residual	227.954	103	2.213		
	Total	458.514	104			
2	Regression	247.158	2	123.579	59.639	0.000[c]
	Residual	211.356	102	2.072		
	Total	458.514	104			

a. Dependent Variable: Amount of waste; b. Predictors: (Constant), Household size; c. Predictors: (Constant), Household size, Housing unit area.

Table 4. Regression coefficients for solid waste generation and spatial elements at housing unit level.

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.907	0.369		2.457	0.016
	Household size	0.952	0.093	0.709	10.207	0.000
2	(Constant)	0.774	0.360		2.149	0.034
	Household size	0.785	0.108	0.585	7.280	0.000
	Housing unit area	0.017	0.006	0.227	2.830	0.006

a. Dependent Variable: Amount of waste.

From the stepwise regression, two models were generated, illustrated by Equations (5) and (6). In the first model, the household size was identified as the most significant predictors by systematically excluding the number of rooms, housing unit size, household income, and occupancy density basing on their p-values. In the second model, household size and housing unit area size were identified as the most significant predictors whereas number of rooms, household income, and occupancy density were excluded. The F and T tests were used to determine the significance of the models and parameters. Cumulatively, the spatial elements predictors explain 49.8% and 53% of the variance waste generation in the two models respectively, Table 2. The regression model was significant as F < 0.10, Table 3. In the model, household size and housing unit area size (m^2) elements were significant at t < 0.10, Table 4.

Model 1

$$ASWG = 0.907 + 0.709HS + 1.49 \tag{5}$$

Model 2

$$ASWG = 0.774 + 0.585HS + 0.227HUA + 1.44 \tag{6}$$

where:

$ASWG$ is the amount of solid waste generated at the household level;

HS is the household size;

HUA is the housing unit area (m^2).

3.2.2. Block Level

Spatial attribute at block level. The spatial attribute at block level entailed block area (m^2), number of people in the block, number of housing units, ground coverage, block occupancy density (persons/m^2).

Correlation analysis. To explore the relationships between neighbourhood spatial attributes and the amount of solid waste generated at block level, a correlation analysis was conducted. The variables included in this analysis were: block area (m^2), number of people in the block, number of housing units, ground coverage (%), block occupancy density (people/m^2), and amount of solid waste generated (kg) in the block. The results are summarized in Table 5.

Table 5. Correlation matrix table showing correlations between the spatial attributes and solid waste generation at block level.

Correlations							
		Number of housing units	Block area	Ground coverage	Number of people	Occupancy density	Amount of waste
Number of housing units	Pearson Correlation	1	0.178	0.261	10.000**	0.832**	10.000**
	Sig. (2-tailed)		0.347	0.164	0.000	0.000	0.000
	N	30	30	30	30	30	30

Continued

Block area	Pearson Correlation	0.178	1	−0.291	0.178	−0.334	0.178
	Sig. (2-tailed)	0.347		0.119	0.347	0.071	0.347
	N	30	30	30	30	30	30
Ground coverage	Pearson Correlation	0.261	−0.291	1	0.261	0.359	0.261
	Sig. (2-tailed)	0.164	0.119		0.164	0.051	0.164
	N	30	30	30	30	30	30
Number of people	Pearson Correlation	10.000**	0.178	0.261	1	0.832**	10.000**
	Sig. (2-tailed)	0.000	0.347	0.164		0.000	0.000
	N	30	30	30	30	30	30
Occupancy density	Pearson Correlation	0.832**	−0.334	0.359	0.832**	1	0.832**
	Sig. (2-tailed)	0.000	0.071	0.051	0.000		0.000
	N	30	30	30	30	30	30
Amount of waste	Pearson Correlation	10.000**	0.178	0.261	10.000**	0.832**	1
	Sig. (2-tailed)	0.000	0.347	0.164	0.000	0.000	
	N	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

The Pearson Correlation (r) explained the strength of the correlation. From Table 5, block area (m^2), ground coverage, block occupancy density, number of housing units, and the number of people in the block, have a positive correlation with waste generation element of 0.178, 0.261, 0.832, 1, and 1 respectively. This means that when they increase, the amount of solid waste also increases, and vice versa. For instance, a residential block with a higher number of housing units generates more volume of waste compared to a block with a lower number of housing units.

Regression analysis. A regression analysis was also conducted at block level to develop the waste generation model. The F and T tests were used to determine the significance of the model and parameters, respectively. Cumulatively, the spatial elements predictors explain 92.9% of the variance waste generation, see Table 6. The regression model was significant as $F < 0.10$, see Table 7. In the model, the block area and occupancy density were significant at $t < 0.10$, see Table 8.

Model:

$$AG = -179.268 + 0.525BA + 0.059GC + 0.986OD + 27.96 \tag{7}$$

where:

AG is amount of waste generated;

BA is block area;

GC is the ground coverage;

OD is occupancy density.

Table 6. Model summary regression of waste generation and spatial elements at block level.

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.964[a]	0.929	0.921	27.960	0.929	113.753	3	26	0.000

a. Predictors: (Constant), Occupancy density, Block area, Ground coverage.

Table 7. ANOVA for regression of waste generation and spatial elements at block level.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	266791.542	3	88930.514	113.753	0.000[b]
	Residual	20326.458	26	781.787		
	Total	287118.000	29			

a. Dependent Variable: Amount of waste; b. Predictors: (Constant), Occupancy density, Block area, Ground coverage.

Table 8. Regression coefficients for waste generation and spatial attributes at block level.

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	−179.268	47.526		−3.772	0.001
	Block area	0.745	0.080	0.525	9.296	0.000
	Ground coverage	0.477	0.462	0.059	1.032	0.312
	Occupancy density	422.744	24.806	0.986	17.042	0.000

a. Dependent Variable: Amount of waste.

The occupancy density and block area emerged as the significant predictors of variations in waste generation element at 98.6% and 52.5% respectively, see Table 8.

3.2.3 Cluster Level

Spatial attribute at block level. The spatial attribute at cluster level entailed cluster area (m^2), cluster population, and cluster population density.

Correlation analysis. To explore the relationships between neighbourhood spatial attributes and the amount of solid waste generated at cluster level, a correlation analysis was conducted. The variables included in this analysis were: cluster area (m^2), cluster population, cluster population density (persons/m^2), and amount of solid waste generated by the cluster. The results are summarized in Table 9.

Table 9. Correlation matrix table showing correlations between the spatial attributes and solid waste generation at cluster level.

Correlations					
		Cluster area size	Population density	Amount of waste generated	Population
Cluster area size	Pearson Correlation	1	−0.355*	0.642**	0.642**
	Sig. (2-tailed)		0.046	0.000	0.000
	N	32	32	32	32
Population density	Pearson Correlation	−0.355*	1	0.310	0.310
	Sig. (2-tailed)	0.046		0.084	0.084
	N	32	32	32	32
Amount of waste generated	Pearson Correlation	0.642**	0.310	1	10.000**
	Sig. (2-tailed)	0.000	0.084		0.000
	N	32	32	32	32
Population	Pearson Correlation	0.642**	0.310	10.000**	1
	Sig. (2-tailed)	0.000	0.084	0.000	
	N	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

The Pearson Correlation (r) explained the strength of the correlation. From Table 9, cluster area (m^2), population of the cluster, cluster population density, have a positive correlation with waste generation element of 0.642, 1, and 0.310, respectively. This means that when they increase, the amount of solid waste generated also increases, and vice versa. For instance, a cluster that is highly populated generates more solid waste compared to a cluster that is less populated.

3.3. Strategies That Can Influence Sustainable Solid Waste Management System in Kasarani

3.3.1. Provision of 9n kg Capacity Waste Container at Block Level

All residential blocks to have a 9n kg capacity solid waste storage container (*where n is the number of housing units and* 9 *is the average amount of waste generated by a housing unit*). As well, the block's storage container should have six compartments to accommodate the segregated solid waste from the *nth* housing units. These include: organic waste, plastic waste, metal and glass waste, electronic waste, sanitary waste (diapers and sanitary towels) and hazardous waste, and other inorganic waste. This will motivate the residents to continually segregate their waste at source. This practice is key for solid waste material recycling due to the minimal contamination that arises from solid waste compounding. Figure 8 illustrates partitioned housing units' storage container that will feed to the compartmentalized block's solid waste storage container:

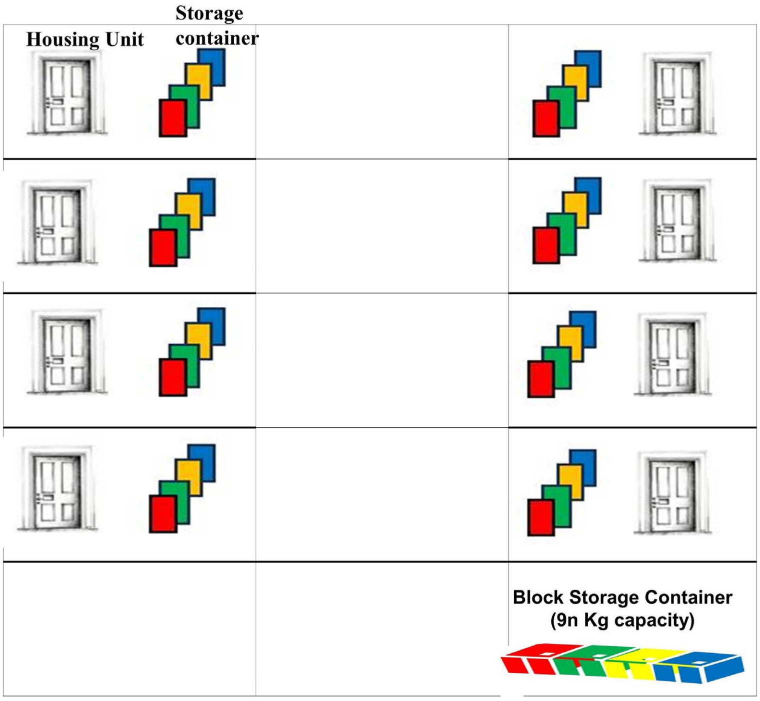

Figure 8. Housing units' and blocks compartmentalized solid waste storage containers.

3.3.2. Provision of 200 kg Capacity Partitioned Rickshaw to Transport Solid Waste Collected from Residential Blocks to the Collection Centers

Averagely, a residential block generates about 198.72 kg. A rickshaw with a 200-kg capacity can accommodate the amount of solid waste generated by the block. The rickshaw will transport the solid waste to a collection center within a radius of 1 km. The rickshaw should also be partitioned to encourage further solid waste segregation. Figure 9 illustrates a rickshaw of 200 kg capacity collecting waste from the block storage container.

Figure 9. 200 Kg capacity partitioned rickshaw.

3.3.3. Provision of Solid Waste Collection Facilities

Solid waste collection facilities should be installed in the high-density residential neighbourhood. Six residential clusters should be served by one collection facility of 30-ton capacity. The capacity of the solid waste collection facility was computed with the formula below:

$$C = AN \tag{8}$$

where:

C is the capacity of the collection facility;

A is the average amount of waste generated by a cluster;

N is the number of clusters to be served by the collection facility;

$A = 5$ tonnes;

$N = 6$.

$$C = 5 \text{ tonnes} \times 6 = 30 \text{ tonnes}$$

The collection facilities should be partitioned to allow further waste segregation. The section for organic solid waste should be substantial since it takes a significant share of the solid waste generated (more than 50%). These segregated organic solids can be sold to the pig farmers within the study area since they are not contaminated. The remaining less fibrous organic solid waste can be used for biogas production, and the more fibrous waste can be used for making compost to be used as organic fertilizer. Similarly, the segregated inorganic solid waste can be recovered by waste recyclers. The remaining segregated waste is to be taken to the material recovery facility, where the other waste recyclers can get their recoverable. Figure 10 illustrates the proposed solid waste collection facilities.

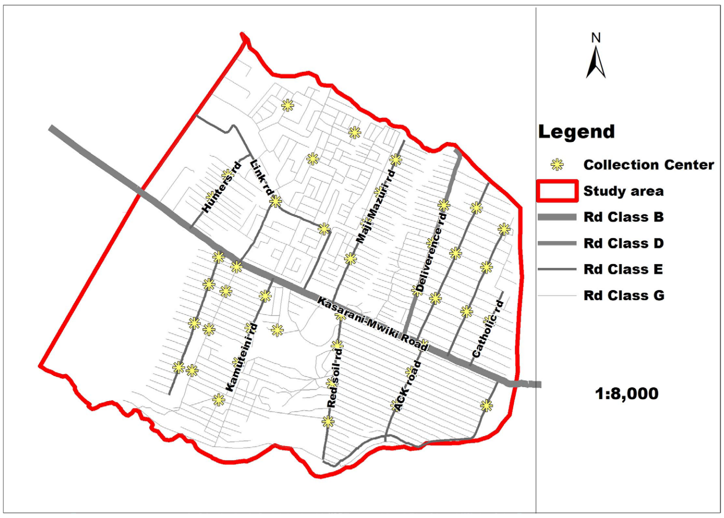

Figure 10. Proposed solid waste collection facilities.

Figure 11 illustrates how six clusters can be served by a solid waste collection facility that is also compartmentalized to allow material recovery and reduce the amount of solid waste heading to the designated disposal site, where further material recovery should happen.

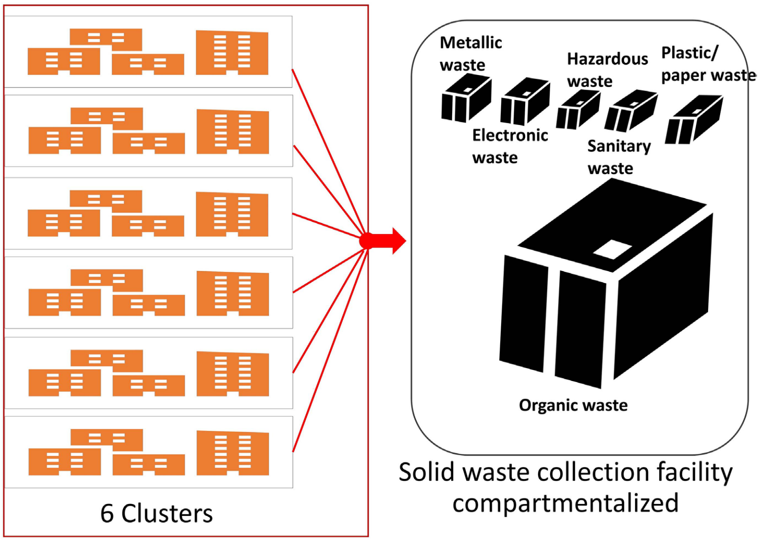

Figure 11. Six clusters served by a solid waste collection facility.

3.3.4. Provision of 30-Ton Trucks Capacity to Transport Solid Waste from the Collection Facility to Material Recovery Facility in Dandora

A 30-ton truck should be involved in transporting solid waste material from the collection facility to the material recovery facility, located in Dandora, which enhances further waste material recovery, see Figure 12. Only materials that have reached their lifespan should be sustainably disposed of through a sanitary landfill.

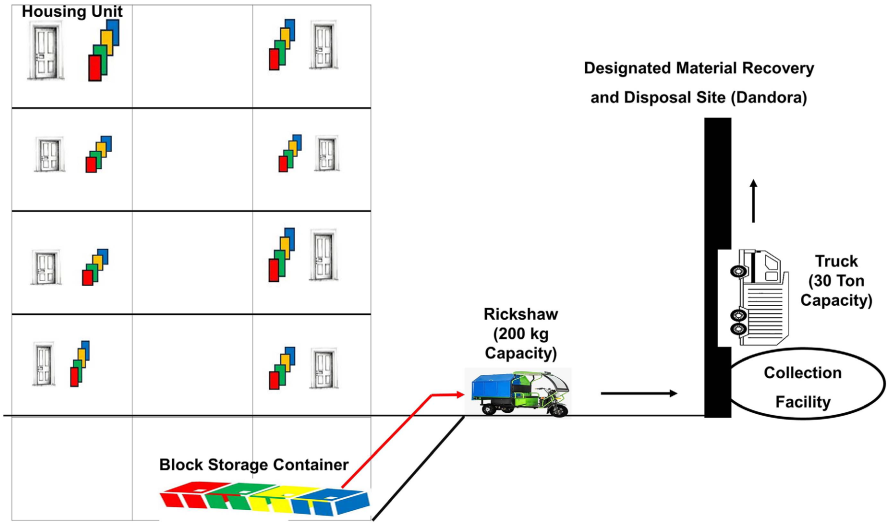

Figure 12. 30-Ton truck capacity to transport solid waste from the collection facility to material recovery facility.

3.3.5. Expanding and Improving the Condition of the Access Roads

All roads linking the residential blocks to solid waste collection facilities should be at least 6 meters wide and be upgraded to cabro standard so as to ease waste transportation in all-weather conditions.

4. Conclusion

90% of the residential blocks in the study area were devoid of waste storage containers. This was attributed to the high ground coverage, leaving minimal space for such facilities. This factor had a negative effect on waste segregation at the housing unit level. The illegal dumping in the study area was attributed to the lack of solid waste collection facilities, which act as a linkage between residential blocks, waste recyclers, and the designated disposal site. It was also explained by the distance the waste collectors have to cover with their human-pulled cart to reach the designated disposal site. The study noted that spatial characteristics such as block number of housing units had a positive correlation with the amount of waste generated at block level. This means that as the number of housing units goes up, so does the amount of waste they generate. This finding can be used for sustainable solid waste management by policymakers and developers to compute the capacity of the proposed block solid waste storage container, the capacity of the waste transportation vehicle from the block storage container to the collection facility, and the capacity of the transportation vehicle from the collection facility to the designated disposal site, which is also designed for further waste recovery.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S. et al. (2022). Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. *International Journal of Environmental Research and Public Health, 19,* Article 12717. https://doi.org/10.3390/ijerph191912717

Alajmi, R. G. (2016). The Relationship between Economic Growth and Municipal Solid Waste & Testing the EKC Hypothesis: Analysis for Saudi Arabia. *Journal of International Business Research and Marketing, 1,* 20-25.

Cogut, A. (2016). *Open Burning of Waste: A Global Health Disaster.* https://api.semanticscholar.org/CorpusID:202548765

Dangi, M. B., Pretz, C. R., Urynowicz, M. A., Gerow, K. G., & Reddy, J. M. (2011). Municipal Solid Waste Generation in Kathmandu, Nepal. *Journal of Environmental Management, 92,* 240-249. https://doi.org/10.1016/j.jenvman.2010.09.005

Debrah, J. K., Teye, G. K., & Dinis, M. A. P. (2022). Barriers and Challenges to Waste Management Hindering the Circular Economy in Sub-Saharan Africa. *Urban Science, 6,* Article 57. https://doi.org/10.3390/urbansci6030057

Dikole, R., & Letshwenyo, M. W. (2020). Household Solid Waste Generation and Composition: A Case Study in Palapye, Botswana. *Journal of Environmental Protection, 11,* 110-123. https://doi.org/10.4236/jep.2020.112008

Godfrey, L., Tawfic Ahmed, M., Giday Gebremedhin, K., H.Y. Katima, J., Oelofse, S., Osibanjo, O. et al. (2019). Solid Waste Management in Africa: Governance Failure or Development Opportunity? In N. Edomah (Ed.), *Regional Development in Africa* (pp. 2-5). IntechOpen. https://doi.org/10.5772/intechopen.86974

Jakhar, R., Samek, L., & Styszko, K. (2023). A Comprehensive Study of the Impact of Waste

Fires on the Environment and Health. *Sustainability, 15,* Article 14241. https://doi.org/10.3390/su151914241

Jamal, H. (2020). *Functional Elements of Solid Waste Management System.* https://www.aboutcivil.org/functional-elements-solid-waste-management-system

Jayasinghe, R. (2013). Waste Management in the Global South: A Sri Lankan Case Study. In R. Jayasinghe, (Ed.), *Garbage Crisis* (pp. 87-108). Springer International Publishing. https://doi.org/10.1007/978-3-031-02111-4_5

Kathambi, B., & Ogutu, F. A. (2021). *Effects of Institutional Framework Lapses in Solid Waste Management; Case of Ngomongo, Nairobi, Kenya.* https://doi.org/10.21203/rs.3.rs-475257/v1

KIPPRA (2022, March). *Accelerating Green Urban Growth in Nairobi.* https://kippra.or.ke/accelerating-green-urban-growth-in-nairobi/

KNBS (2019). *Kenya Population and Housing Census (Vol II, p. 270).*

Mirmotalebi, S., Rahman, S., Tithi, M. R., & Apu, I. K. (2023). Assessment of Municipal Solid Waste Management in the Farmgate Area of Dhaka North City Corporation. *World Journal of Engineering and Technology, 12,* 1-23. https://doi.org/10.4236/wjet.2024.121001

Muchangos, L. S., & Tokai, A. (2020). Greenhouse Gas Emission Analysis of Upgrading from an Open Dump to a Semi-Aerobic Landfill in Mozambique—The Case of Hulene Dumpsite. *Scientific African, 10,* e00638. https://doi.org/10.1016/j.sciaf.2020.e00638

Muthoni, E. (2018). *IoT for African Smart Cities: A Model for a Smart Solid Waste Management System in Nairobi.* https://repository.kcau.ac.ke/handle/123456789/111

Muthoni, W. (2014). *Inadequacies of Solid Waste Management among Public, Private and Community-Based Organizations in Kasarani Constituency, Nairobi County.* https://ir-library.ku.ac.ke/server/api/core/bitstreams/fc40789b-2ae6-4767-90ae-1ebd63b6c4de/content

Nagpure, A. S. (2019). Assessment of Quantity and Composition of Illegal Dumped Municipal Solid Waste (MSW) in Delhi. *Resources, Conservation and Recycling, 141,* 54-60. https://doi.org/10.1016/j.resconrec.2018.10.012

Naibbi, A. I., & Umar, U. M. (2017). An Appraisal of Spatial Distribution of Solid Waste Disposal Sites in Kano Metropolis, Nigeria. *Journal of Geoscience and Environment Protection, 5,* 24-36. https://doi.org/10.4236/gep.2017.511003

Ogutu, F., Kimata, D., & Kweyu, R. (2018). Essence of Environmental Governance in Solid Waste Management. *African Research Journal of Education and Social Sciences, 5,* 112-123.

Ramadan, B. S., Rachman, I., Ikhlas, N., Kurniawan, S. B., Miftahadi, M. F., & Matsumoto, T. (2022). A Comprehensive Review of Domestic-Open Waste Burning: Recent Trends, Methodology Comparison, and Factors Assessment. *Journal of Material Cycles and Waste Management, 24,* 1633-1647. https://doi.org/10.1007/s10163-022-01430-9

Rodney (2018). *Integrated Solid Waste Management in Nairobi City County: The Social Enterprise Framework [Policy Brief].* https://tisa.co.ke/resources/policy-brief-integrated-solid-waste-management-in-nairobi-city-county-the-social-enterprise-framework/

Sawaya, R., Halwani, J., Nehme, N., Alawiye, H., & Diab, W. (2024). Assessment of the Characteristics of the Municipal Solid Waste Compost in Lebanon. *Journal of Geoscience and Environment Protection, 12,* 17-39. https://doi.org/10.4236/gep.2024.125002

Šedová, B. (2016). On Causes of Illegal Waste Dumping in Slovakia. *Journal of Environmental*

Planning and Management, 59, 1277-1303. https://doi.org/10.1080/09640568.2015.1072505

Sheau-Ting, L., Sin-Yee, T., & Weng-Wai, C. (2016). Preferred Attributes of Waste Separation Behaviour: An Empirical Study. *Procedia Engineering, 145,* 738-745. https://doi.org/10.1016/j.proeng.2016.04.094

Trang, P. T. T., Dong, H. Q., Toan, D. Q., Hanh, N. T. X., & Thu, N. T. (2017). The Effects of Socio-Economic Factors on Household Solid Waste Generation and Composition: A Case Study in Thu Dau Mot, Vietnam. *Energy Procedia, 107,* 253-258. https://doi.org/10.1016/j.egypro.2016.12.144

UNEP, IETC, & CSIR (2018). *Africa Waste Management Outlook* (p. 8).

UN-HABITAT (2018). Indicator-11.6.1-Training-Module_Solid-waste-in-cities_23-03-2018.pdf. https://unhabitat.org/sites/default/files/2019/02/Indicator-11.6.1-Training-Module_Solid-waste-in-cities_23-03-2018.pdf

Visvanathan, C., & Trankler, J. (2003). Municipal Solid Waste Management in Asia: A Comparative Analysis. In *Workshop on Sustainable Landfill Management* (p. 11). https://www.researchgate.net/publication/242220878_Municipal_Solid_Waste_Management_in_Asia_A_Comparative_Analysis

Williams, M., Schroeder, P., Gower, R., Kendal, J., Retamal, M., Dominish, E., & Green, J. (2018). *Best Practice Interventions for the Circular Economy in Developing Countries.* ECHO Community.

World Bank (2022). *Solid Waste Management.* World Bank. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management