Human Health and Environmental Hazards Associated with Plastic Waste: A Review and Spatial Mapping in Informal Settlements of Kampala, Uganda

A thesis submitted by

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ABSTRACT

Rapid urbanization, population growth, and changing consumption patterns have led to a significant increase in municipal solid waste (MSW) generation worldwide, with plastic waste (PW) comprising a substantial portion. This thesis investigates the human health and environmental hazards associated with MSW and PW in the informal settlements of Kampala, Uganda, using Acholi Quarters, Kifumbira, and Ggaba as case studies. The research employed a multi-method approach, including a systematic literature review, Google Street View (GSV) imagery analysis, and ArcGIS spatial mapping. The literature review revealed that MSW and PW pollution is linked to increased risks of urban flooding, vector-borne diseases, soil and water contamination, and air pollution from open burning in informal settlements. It also highlights the lack of effective policies and enforcement mechanisms to address waste management challenges. The GSV analysis assessed the presence of MSW and PW in the case study settlements to provide insights into the geographical locations of pollution accumulation. The ArcGIS spatial analysis mapped the clustering of MSW and PW to identify areas where the problem is chronic and requires immediate attention.

The results indicated distinct patterns and clusters of pollution distribution, with higher concentrations observed within a 0.5-mile radius from the settlement centroids in two of the three settlements. The Local Moran's I analysis identified statistically significant clusters of high and low waste presence, as well as outliers to suggest the influence of local factors. The thesis concludes by proposing recommendations to support effective MSW and PW management in the informal settlements of Uganda and other developing countries.

ACKNOWLEDGMENT

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LIST OF ACRONYMS

BFRs: Brominated Flame Retardants

DRC: Democratic Republic of Congo

DRCs: Dioxins and Related Substances

GBDD: Global Burden of Disease Database

GSV: Google Street View

IHME: Health Metrics and Evaluation

Programme

IOM: International Organization for Migration

IPEN: International Pollutants Elimination Network

IUCN: International Union for Conservation of Nature

KCC: Kampala City Council

KCCA: Kampala Capital City Authority

LDPE: Low Density Polyethylene

MSW: Municipal Solid Waste

NEMA: National Environmental Management Authority

OAG: Office of Auditor General

PAHs: Polycyclic Aromatic Hydrocarbons

PM: Particulate Matter

POPs: Persistent Organic Pollutants

PW: Plastic Waste

SSA: Sub-Saharan Africa

UN: United Nations

UNEP: United Nations Environment

PET: Polyethylene Terephthalate

VOCs: Volatile Organic Compounds

WHO: World Health Organization

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CHAPTER 1: INTRODUCTION

Rapid urbanization, population growth, rising economic activities and changing consumption patterns have resulted in a colossal amount of municipal solid waste (MSW) generated worldwide, especially in urban centers. By 2025, it is estimated that cities worldwide will produce a staggering 2.2 billion tonnes of MSW per year (Hoornweg and Bhada-Tata, 2012); thus, it has emerged as one of the most pressing challenges today (Oates et al., 2019). The rate of MSW generation is expected to triple by 2050 in some regions of the world, such as Sub-Saharan Africa (SSA), largely due to the rapid population sprawl that characterizes urban centers (Kaza et al. 2018). According to a United Nations report, MSW generation is growing quickly, and any decrease in other regions globally will be overshadowed by SSA (UN Environment, 2021). For example, SSA generation of MSW is expected to double by 2025 from about 125 million estimates in 2012. It is estimated that MSW comprises over 13% of plastic waste (PW) across SSA countries (UNEP, 2018a). Additionally, a Nature paper projected the demand for plastics in Africa to increase by 375%, surpassing the global average of 210% by 2060 (Lebreton and Andrady, 2019). This will mean a lot of byproducts and PW on the continent.

Considering global level projections of about 9% of all plastics produced are recycled and 12% incinerated, most PW (79%) ends up in landfills or is released into the environment (Figure. 1), where they accumulate as near-permanent materials with adverse impacts (Geyer et al., 2017, Sadan and DeKock, 2021), such as the release of carbon emissions over its lifespan (OECD, 2022). Globally, it is estimated that some 4.8 and 12.7 million tonnes of PW enter the oceans annually from land-based sources, with some other studies reporting lower data (Lebreton et al., 2017;

Meijer et al., 2021; Veiga et al., 2023). The accumulation of PW in the environment far exceeds the rate of natural removal and global clean-up efforts combined (MacLeod et al., 2021). It is anticipated that increasing economic growth in developing countries such as SSA will increase the production of plastics, resulting in 710 million metric tonnes of PW accumulation in the environment by 2040 (Wen et al., 2021).

The rural-to-urban migration in SSA increases the rate of urbanization and population densities with its concomitant MSW generation in cities, making it overwhelmingly difficult for authorities to address (Oteng-Ababio et al.,2013). This is due to the limited budget for MSW management in the space of competing priorities such as hunger, water shortages, unemployment, and hunger that state governments need to grapple with ((Zurbrugg, 2002). Further, this issue is connected to the lack of policy implementation and enforcement of regulations. MSW collection in SSA countries is inadequate, with collection rate of about 55% for 90% disposal at uncontrolled landfills and dumpsites (UN Environment, 2021). It is confirmed that 19 of the world's biggest dumpsites are located in SSA (Waste Atlas, 2014). The inadequate collection, transportation, treatment, and disposal of MSW pose dire consequences and risks to the economy, society, and the environment, especially in poor urban settings with insufficient MSW disposal infrastructure, such as informal settlements (Hoornweg and Bhada-Tata, 2012). In these poor urban areas, MSW, including plastics, are left uncollected for weeks (Oteng-Ababio et al., 2013). The abandoned waste ends up in storm drains and canals, burned in the open or left to decompose, thereby attracting breeding pests and animals to cause potential health problems and exacerbate environmental hazards such as flooding, soil and groundwater contamination, and contributing to marine plastics (Jin et al., 2006; Ferronato et al., 2019).

This situation of mismanagement of MSW, particularly PW in SSA exemplifies a stark case of environmental injustice. This injustice is characterized by the disproportionate burden of waste-related environmental and health hazards placed on the urban poor, especially those in informal settlements (Nzeadibe & Mbah, 2015). Several studies confirm that in both the developed and developing countries, residents of poor settlements and disadvantaged geographical locations suffer environmental injustice with regards to waste management (Bullard 2005; White 2005). In the United States where there is a high correlation between race and socio-economic status, black and brown communities, and minorities are usually victims of environmental injustice associated with toxic waste exposure (Timney, 1998; Bullard, 2005).

This inequality stemmed from a combination of deliberate actions and neglect by urban authorities, who often failed to address or mitigate environmental problems in the poor and marginalized areas. The resulting disparities in environmental quality and health outcomes between different socioeconomic groups sparked discussions and debates about fairness, equity, and social justice in environmental policy and urban planning (Agyeman *et al.,* 2003). Research has therefore focused on the racial composition and socio-economic statuses of communities living near to toxic MSW landfills and hazardous waste facilities (White, 2005; Bullard, 2005). In SSA, environmental injustice with regards to waste can also be seen in the siting of disposal locations in and around poor communities in the cities (Hardy *et al*., 2001), which confirms my observation with the location of Kiteezi and Mpererwe landfills during project field visit to Kampala, Uganda. Additionally, the the collection of MSW and disposal in cities have shown that municipal authorities are unable to render efficient collection services in their jurisdictions and therefore focus their effort in weathy communities and important public areas while depriving the poor communities such as the informal settlements of their services. This usually result in great spatial disparities in environmental and air quality between wealthy and poor communities.

The impacts of MSW, including PW, on wildlife, Oceans, and freshwater ecosystems have been well researched globally (IUCN, 2021; Meijer et al., 2021). The problem of MSW and PW has received considerable attention in coastal cities in developing countries (Sadan and DeKock, 2021, Akshey Bhargava., et al., 2022). However, in inland cities where informal settlements are rapidly expanding due to urban migration and climate change impacts (Tietjen et al.,2023), there is scanty research to no evidence on the human health and environmental hazards associated with MSW and PW.

This thesis is a result of my research experience on a Tufts and Woodwell Climate Research Center funded project in Kampala, Uganda. I worked as a Research Assistant for over a year on the project and had an opportunity to travel with the research team to Kampala in May 2023 as part of a scoping mission to investigate the impacts of plastic pollution in informal settlements. During our field visits, we interacted with multiple stakeholders including government officials, academics, community leaders, small to medium-scale recycling businesses, and informal settlement residents. One of my goals for the project was to understand the problem from the perspective of the residents. Most of the first-hand information I collected from the local residents indicated that, the lack of proper waste management have contributed to the flooding of their communities during excessive rainfalls. Additionally, there is the lack of community engagement and empowerment from city authorities in finding lasting solutions to their plights. These concerns and my observations of the presence of indiscriminate dumping, poor drainage systems, evidence of flooding and poor settlement planning made me curious to investigate further the challenge of PW and MSW in informal settlements, hence the formulation of my research questions. I anticipate that this thesis outcomes will add to discourse and stimulate community engagement in addressing the problems. Furthermore, the outcomes will fit into the larger Tufts and Woodwell Kampala "Climate Hazards in Inland African Cities" project goal of supporting plastic collections and recycling efforts in informal settlements.

Against this backdrop, this thesis explores the problem of MSW and specifically PW in informal settlements of Kampala, Uganda, using three settlements, namely Acholi Quarters, Kifumbira, and Ggaba, to understand its link to human health and environmental hazards. This was done through the systematic review of published literature on the subject. Also, I reviewed literature to understand the policies or regulations that address the problem in informal settlements. Additionally, I utilized Google Street View (GSV) Imagery to locate the presence or absence of MSW and PW in the informal settlements. Furthermore, GIS mapping techniques were used to analyze the clustering of MSW and PW in the case study settlements for city authorities to prioritize interventions in areas where the problem is chronic and requires immediate attention.

Lastly, the outcomes of this thesis were combined to propose recommendations that will feed into national action plans and policies of Uganda for effective management of MSW and PW in informal settlements. These results would also serve as a model for other African cities to address the problem.

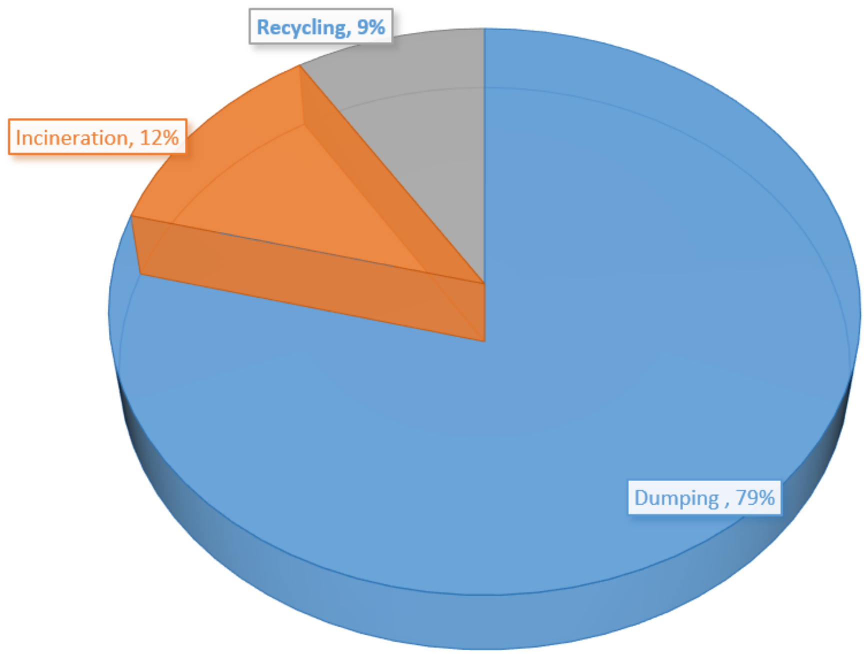


Figure 1. Life Cycle of Plastic Waste (PW) around the world
Data Source: Sadan Dekock, 2021
Image Source: Mensah, 2024

1.1 Author's Note

My interest in studying urban planning stems from a lifetime experience navigating urban challenges in Accra, Ghana. I grew up in a low-income suburb of Accra where my community was faced with problems such as waste management, flooding, extreme heat, lack of consistent access to electricity and potable-piped water. As I progressed through school, I slowly learned more about these issues and how I could contribute to addressing the problems. One of my contributions, thus far is the co-creation of a nonprofit called Keep Ghana Beautiful, that empowers local volunteers in Ghana to take proactive actions that will address solid waste and climate change impacts in their communities while waiting for government support.

Obtaining a graduate degree in urban and environmental planning is a step further to acquire knowledge that will enable me to contribute to national development and tackle urban problems, especially in vulnerable communities.

I chose this topic for my thesis because I identify with the problem of MSW and PW from my own experiences and hope the results of my research will contribute to calls for urgent interventions to effectively manage the problem in developing countries.

1.2 Research Questions

In order to narrow my research to understand the issue of MSW and PW and its association with human and environmental hazards in informal settlements, I developed the following two central questions to guide my research.

1) What are the human health and environmental hazards associated with MSW and PW pollution in informal settlements?
    a) Are there policies that address the concerns of MSW and PW in informal settlements?
2) What is the spatial distribution and clustering of MSW and PW in the case study informal settlements namely Acholi Quarters, Kifumbira and Ggaba?

Considering the research questions above, I developed the following specific objectives;

1) Conduct a literature review of the human health and environmental hazards associated with PW pollution and policies that address it in informal settlements.
2) Explore the geographical locations of MSW and PW in the case study informal settlements using GSV imagery.

3) Map the spatial distribution and clustering of MSW and PW in the case study informal settlements.
4) Develop recommendations to support the effective management of MSW and PW in informal settlements of Uganda and developing urban cities.

1.3 Thesis Outline

In Chapter 1: Introduction, this thesis begins with an overview of the MSW and PW from the global perspective and then sets a context for the management problem in SSA. Chapter 2: Background provides an overview of the MSW and PW generation and management in Uganda and delves into the peculiar issues in Kampala and the informal settlements. Chapter 3: Literature review carries the audience on a journey of research done on the subject of MSW and PW and its association with human health and environmental hazards, and the policies that mitigate them in informal settlements. Chapter 4: Methodology and Data Collection introduces the various methods and data used in answering the research questions and objectives of this thesis. Chapter 5: Results, discusses and presents the outcomes of the analysis of data. Lastly, Chapter 6: Conclusion and Recommendations summarizes and highlights key findings of the thesis and provides direction for future research. Additionally, this section suggests actionable steps and recommendations to decision and policymakers for a more efficient and effective management of MSW and PW in Uganda.

CHAPTER 2: BACKGROUND

2.1 Country Overview

Uganda, also known as the "Pearl of Africa" for its beautiful scenery, is a landlocked country located on the east coast of Africa. It borders Rwanda to the southeast, the Democratic Republic of Congo (DRC) to the west, Kenya to the east, South Sudan to the north, and Tanzania to the south. The country is the eighth-largest African country by population, estimated at around 47 million in 2022 (Data Commons, 2023), with a total MSW generation of 6.6 million per annum (Table 1 and Figure 2). According to the National Environmental Management Authority (NEMA), Uganda produces about 600 tonnes of plastics daily (Muganga, 2022) with little to no recycling infrastructure in the country (Geneva, 2019). Over 60% of PW which is generated is left uncollected thereby posing health and environmental threats (Singh et al., 2023). The increasing economic activities and consumer demand across the country have led to the importation of several packaging materials, constituting about 80-90% plastics (Table 2). The most common types of PW in Uganda are plastic sachet water (made from thin LDPE) and soda bottles (made from PET), which are usually thrown away after use (Water Aid, 2011). From my field visit and experience in Kampala, Uganda, I conceptualized the flow of PW in the country (Figure. 3). It is estimated that each individual in the country consumes up to 43kg of plastic annually (CARE, 2019). This demand is expected to rise due to population increment and the proliferation of small-scale to medium industries that need easy and innovative ways of packaging (Ggoobi, 2020). The Figure 4 presents the estimated generation of PW across major districts in Uganda.

According to Natures, 8.6 million tonnes of PET bottles are imported into Uganda every day. About 40% (3.4 million tonnes) are commercialized in the Greater Kampala Metropolitan Area (GKMA) each day equalizing an amount of 62.9 tonnes per day of plastics. From this, 57% of the PET PW generated is collected, 17% is sent to disposal dumpsites, 35% is transported to recovery facilities for processing and exportation, and 5% is leaked during collection and transportation (Figure 5). A total of 43% of all PET waste are not collected translating to 9.948 tons of uncollected plastic per year (Natures, 2021). This PW ends up in drains, land and water bodies (Figure 6). Uganda has previously banned the use of single-use plastic such as PET and LDPE but enforcement mechanisms are not implemented (Vanapalli et al., 2021). Since China and India have stopped the importation of PW, most of the recycling companies in the country have loads of PW piling up and spilling over, especially because of their low levels and lack of capacity for recycling.

Statistics on Uganda	
Population	47 Million
Area	241,55 sq km
Total MSW Generation	6.6 Million Tonnes Per Annum
Estimated PW Generation	0.6 Million Tonnes Per Annum
Rate of Recycling	Unclear
Disposal Methods	Dumping, Burying and Burning

Table 1.
Data Source: Singh et al., 2023
Image Source: Mensah, 2024

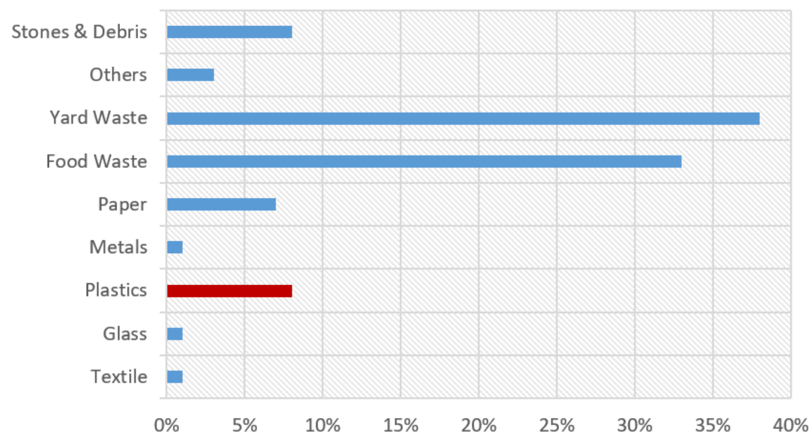


Figure 2. Waste Composition in Uganda
Data Source: Rotich et al., 2006
Image Source: Mensah, 2024

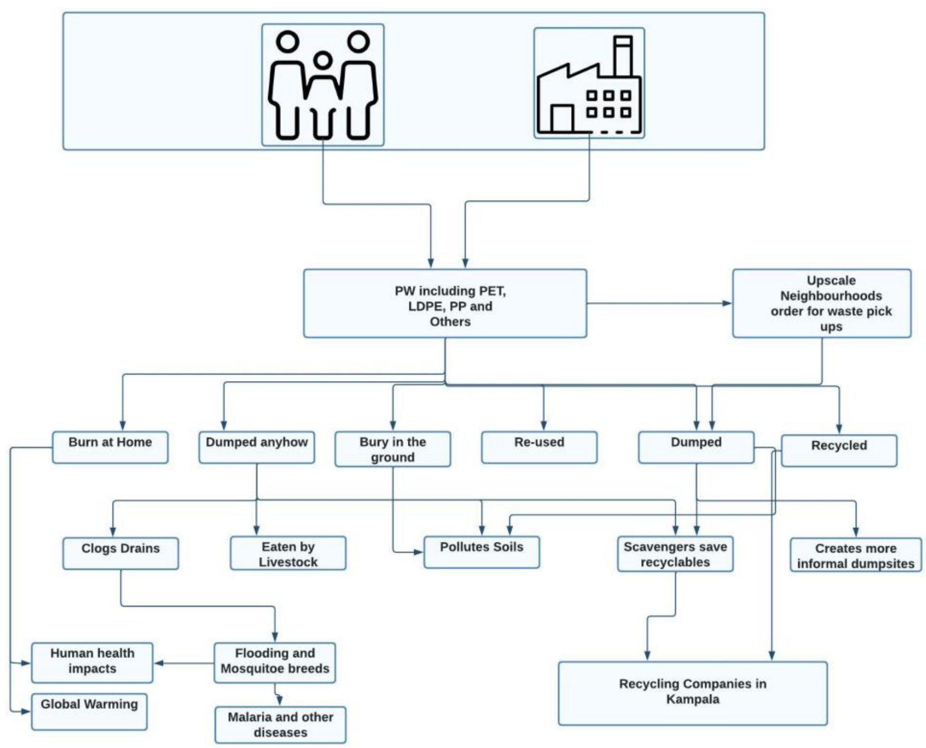


Figure 3. The Flow of PW in Uganda
Image Source: Mensah, 2024

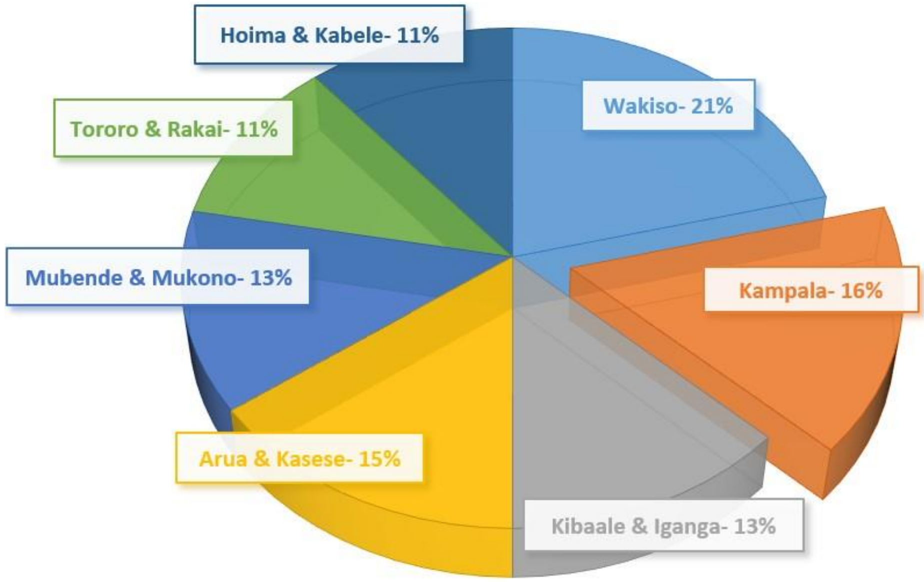


Figure 4. Estimated Distribution of PW in Uganda Districts
Data Source: Owusu et al., 2017
Image Source: Mensah, 2024

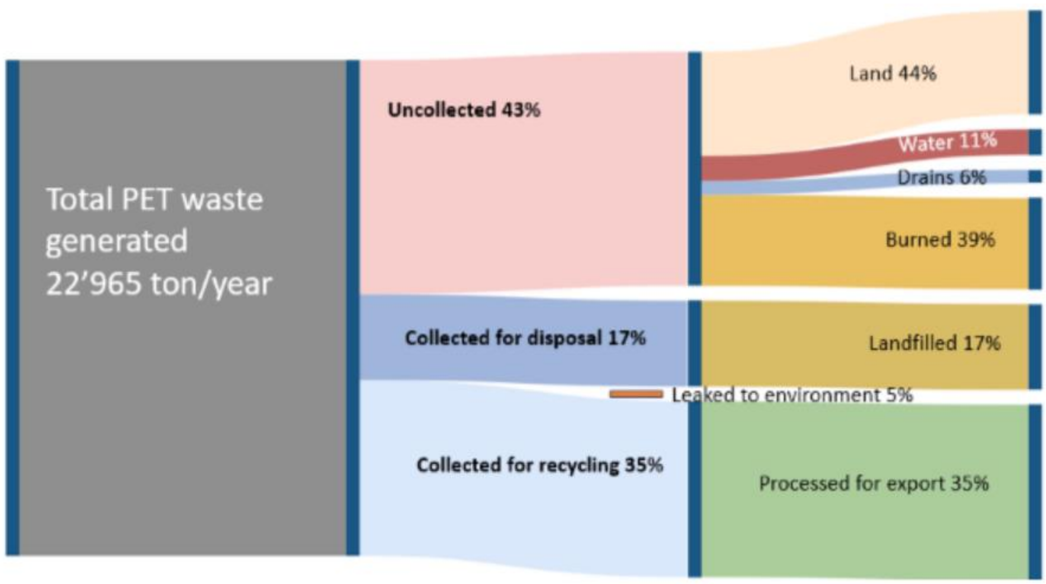


Figure 5. PET PW Flow in GKMA visualized using the Sankey Diagram
Source: Natures 2021: https://nature-stewardship.org/countries/uganda/pet-plastic-waste-flows-in-greater-kampala/

Type of packaging	Quantity	Cost in UGX
Inserts	1,409	39,020,138
Sacks & bags of other plastics (bags for the foods & drinks)	5,131	127,580,878
Plastic tubes for packing of toothpaste, cosmetics and others	26,734	459,134,476
Empty gelatin capsules for pharmaceutical use	38,550	3,745,497,426
Sacks and bags (incl. cones) of polymers of ethylene	113,827	968,794,786
Sacks and bags (incl. cones) of other plastics (excl. ethylene)	282,582	2,898,238,071
Boxes, cases, crates and similar articles of plastics	771,308	7,469,082,989
Other stoppers, lids, caps and other closures	1,372,011	16,775,906,904
Articles of conveyance or packing of goods, of plastics	1,444,191	10,578,611,642
Spools, cops, bobbins and similar supports of plastics	4,712,360	24,005,171,359
Carboys, bottles, flasks and similar article	3,504,858	28,247,356,190

Table 2. Types of Plastic Packaging imported into Uganda.
Source: Uganda Revenue Authority, 2020

2.2 Study Area

This thesis focuses on the informal settlements of Kampala, Uganda (Figure 6). However, I explore the problem using three of the settlements, including Acholi Quarters, Kifumbira and Ggaba (Figure 7). Kampala is the administrative capital city of Uganda with a population of 1,619,900 people (UBOS, 2018) with approximately 53.6% living in crowded and informal settlements, most of which are located in low-lying zones and wetlands (United Nations, 2014). The wetland areas are attractive to the rural poor arriving in the city in search of greener pastures because they are cheap and relatively free from government policing, easily accessible, and provide economic opportunities for urban farming (Kabumbuli and Kiwazi, 2009). The informal settlements (Figure 8) are characterized by poor housing conditions, poverty, poor access to water, sanitation and hygiene (WASH), and poor solid waste management, among other challenges (Richmond, 2018; Ssekamatte et al., 2019). Kampala generates about 2,300 tonnes of

MSW daily, resulting in over 803,000 tonnes per year (Kabera et al., 2019). This amount is expected to double by 2030 (Oates et al. 2019). It is estimated that three-quarters of the MSW generated is organic and biodegradable, and 15% comprises plastic waste, glass, and paper (Okot-Okumu & Nyenje, 2011).

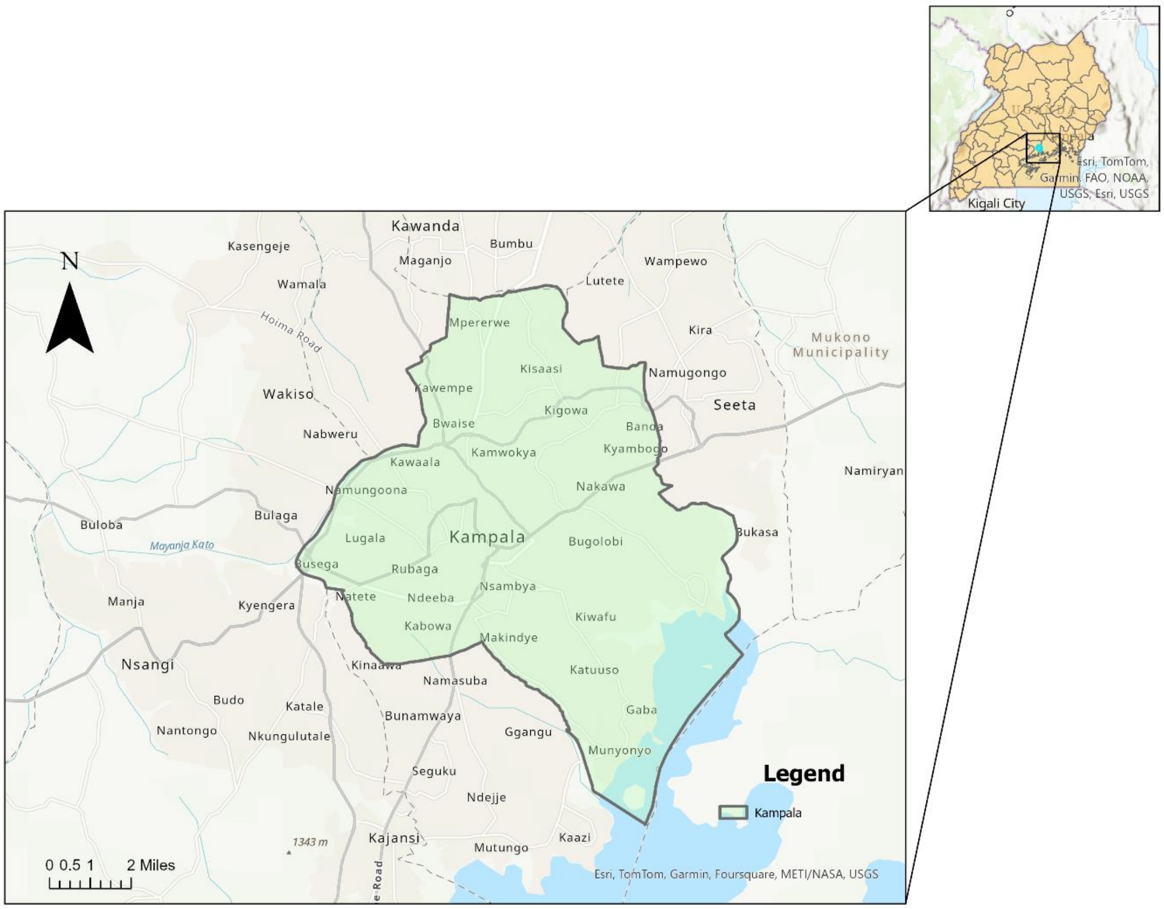


Figure 6. The study Area- Kampala

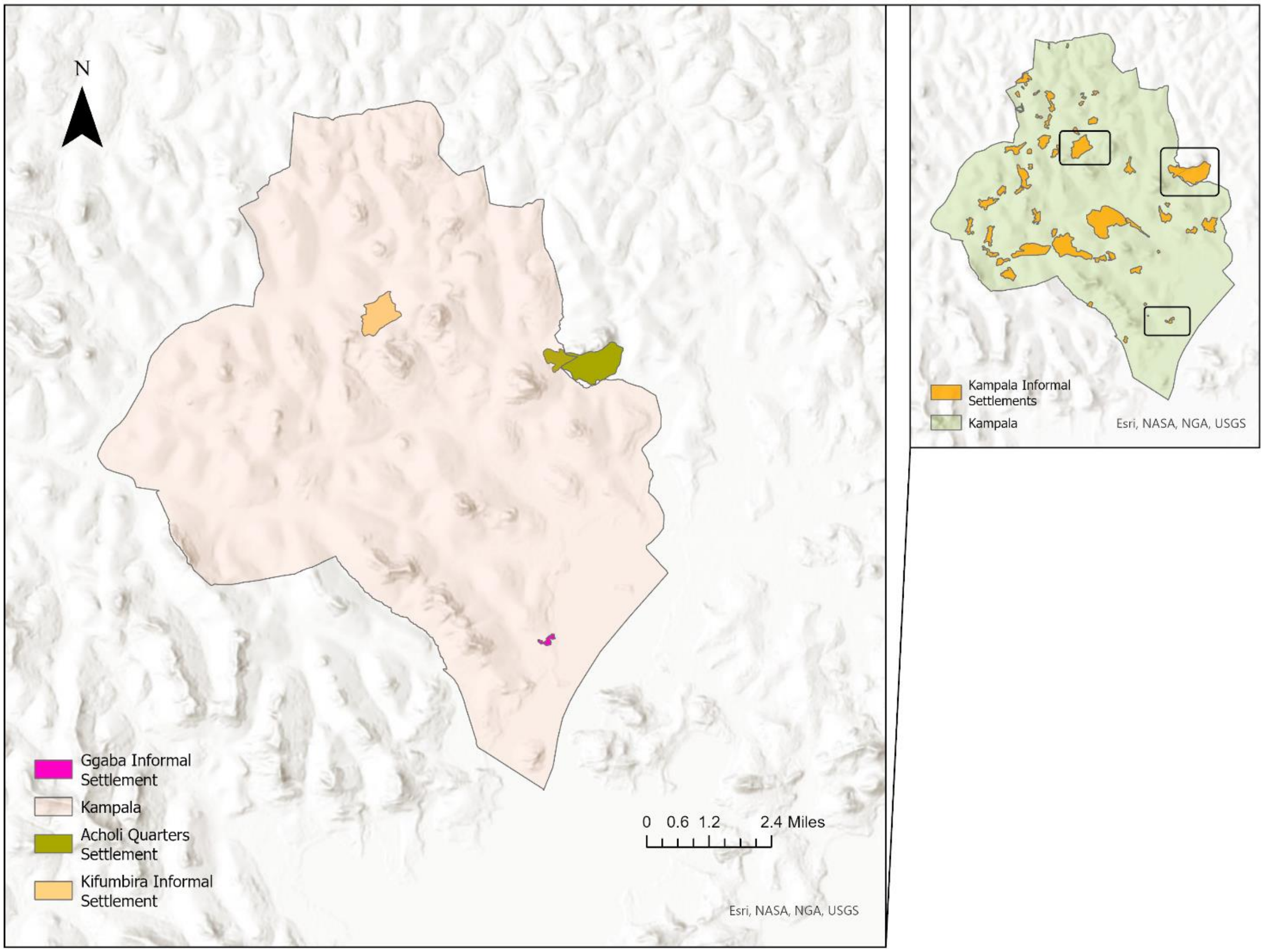


Figure 7. Map showing the case study sites- Acholi Quarters, Kifumbira and Ggaba

The Kampala Capital City Authority (KCCA) is mandated under the Local Government Act (1997) to provide MSW management services in the city (KCCA, 2012). KCCA provides services such as collection and disposal from households, hospitals, industries, city centers, and markets (National Environment Management Authority, 2000). Due to the increasing population of residents, economic activities and low funding from the central government, the efforts of MSW collection and disposal overwhelm the management authorities. In most situations, the services are not on schedule and are restricted to public spaces such as markets, and upscale residential areas and politically sensitive places ((Tumuhairwe et al., 2009).

In an effort to address the issues, KCCA contracts private sector MSW companies to help management to improve the cleanliness of the city. Despite this strategy, less than half of the MSW generated on a daily basis is collected (Office of Auditor General, 2010). The uncollected MSW is normally left in open areas, streams, open drainage canals (Figure 9), and other areas inaccessible to waste collection vehicles, thereby creating environmental and public health hazards for city residents (OAG, 2010).

Figure 8. Kifubira, an informal settlement in Kampala, Uganda
Source: Hammond, 2023

Figure 9. MSW and PW in drains, Kampala, Uganda
Source: Mensah, 2023

According to the National Environmental Management Authority (NEMA), the Kampala Metropolitan Area generates over 135,804 tonnes of PW per year. Of this 42% is uncollected, 15% is collected through the value chain, and 43% is collected by service providers. Approximately 21,728 tonnes are burned (Figure 10), and, 47,457 tonnes are landfilled, 27,160 and 13,580 tonnes find their way into land (Figure 11) and water systems respectively. "As a consequence of plastic pollution, we see increased unexplained cancers, floods, poor water quality, poor air quality, decreased soil fertility, siltation of waterbodies, death of livestock, fish and wildlife through ingestion and entanglement and above all, enhanced greenhouse gas emissions" (Executive Director, NEMA per comms with WWF, 2023). Informal settlements constituting about 88% of residents between the prime ages of 15-35 years (IOM UN Immigration, 2017), are the most vulnerable to suffering from these hazards such as flooding and vector-borne diseases (Oates et al., 2019). For example, eight people died in low-lying informal settlements (Figure. 12) in the peri-urban areas of Kampala as a result of flooding from extreme rainfall in 2019 (ReliefWeb, 2019). The floods were attributed to the blockage of drainage channels with MSW due to indiscriminate dumping and littering.

Figure 10. Burning Disposal Method, Kampala, Uganda
Source: Hammond, 2023

Figure 11. Open disposal on Land, Kampala, Uganda
Source: Mensah, 2023

Figure 12. Informal Settlement Housing in low-lying wetland, Kampala, Uganda
Source: Mensah, 2023

CHAPTER 3: LITERATURE REVIEW

This chapter discusses the environmental and health hazards of MSW and PW in SSA as collected from published literature. Additionally, it provides insights into policies and actions that are taken to address the problem of MSW and PW.

3.1 Urban Flooding and Plastics Waste (PW)

Flooding is considered a significant environmental hazard as it causes damage to infrastructure, ecosystems, and communities. Urban flooding is the inundation by water in densely populated areas that are usually dry. The growing quantities of PW as a result of mismanaged MSW and increased risk of urban flooding are said to be intertwined and urgent global problems (MacAfee and Löhr, 2023). The adverse impacts of PW pollution and urban flooding co-occur particularly in urban centers, especially in the context of climate change and rapid urbanization (Lincoln et al., 2022; MacAfee and Löhr, 2023). With the prediction of nearly 60% of people residing in cities by 2030 (United Nations, 2018), MSW generation is expected to rise in developing nations such as SSA, where governments are already struggling with management and resource allocation to match up with population growth (Breukelman et al.,2019). Relatedly, hydraulic infrastructure for flood mitigation and protection across these cities are lacking, thereby posing significant challenges to most of the population that live along flood-prone areas such as low-lying land and wetlands (Jongman et al., 2012).

PW and urban flooding are complex issues with a wide range of environmental and human health concerns that are linked to environmental justice, especially for vulnerable people who are least responsible for their creation (Stoett, 2022). If environmental justice is anything to go by, it is crucial to ensure the well-being of the vulnerable in society toward a sustainable future.

As asserted by Agyeman 2005, just sustainability is to ensure a better quality of life for all, now, and into the future, in a just and equitable manner, while living within the limits of supporting ecosystems. The problems of PW and urban flooding have frequently been treated as distinct from each other but there are recent developments of a strong link between the two. In their paper, the authors argue that there is an overlap between the drivers, impacts and locations of PW and urban flooding. They mentioned that changes made to one can influence the other, thereby providing an opportunity for synergy between MSW management and flood prevention mechanisms (MacAfee and Löhr, 2023).

In SSA where there is rapid urbanization and subsequent waste generation, PW gets into the environment through pathways of open indiscriminate dumping of MSW (UN-Habitat and NIVA, 2022). Once in the environment, PW can intensify the risk and occurrence of flooding, especially in urban centers. According to Nepal and Bharadwai, 2022, the accumulation of PW in the environment ends up in watercourses and canals, which reduces flow capacity and makes flooding more likely. Similarly, PW can block drains (Figure 13) and other hydraulic infrastructures, causing localized flooding and waterlogging (Lamond et al., 2012).

Figure 13. PW and MSW blocks storm drains leading to flooding during excessive rainfall, Kumasi, Ghana
Source: Mensah, 2023

Several studies in developing countries, including SSA, demonstrate the role plastic waste plays in increasing the risks of flooding in informal settlements. For example, a study in Kampala, Uganda indicate that indiscriminate dumping of waste in stormwater and canals block drains to cause floods and health hazards, and aesthetic impacts (Okot–Okumu, 2012). A more targeted study of informal settlements in Kampala, Lagos, Accra, Nairobi and Maputo confirmed that housing development in floodplains and inadequate waste management are potential causes of flooding. The authors cited that residents in these settlements dump solid waste haphazardly into valleys and natural drains (Douglas et al, 2008). In 1988, vast tracts of Bangladesh were submerged by floods attributed to plastic waste (UNEP 2018). Since then areas of Uganda, India and West Africa and India have all had similar experiences (Wilson et al, 2013). In 2011, floods in Accra, Ghana, leading to the destruction of 17,000 homes and related 100 cholera deaths and at least 150 drowned people was partly attributed to blockage of storm drains by plastic waste (Amoako and Boamah, 2015; Hinshaw, 2015). In January 2018, at least 45 people died from flooding in Kinshasa, Democratic Republic of Congo, and more than 5000 people were left homeless (Aljazeera News 2018). Many residents accused blocked drainage channels by plastic waste to account for the flooding (Wilson et al 2015).

In Dar es Salaam, Tanzania, inhabitants of Kinoni municipality and Tandale district expressed their discontent about the poor management of waste, which when dumped in streams resulted in blockages and heightened the impact of flooding (Dodman et al, 2011). According to Ojolowo and Wahab (2017) 27.2% of the waste produced in Lagos, Nigeria was dumped in waterways and lagoons. This indiscriminate dumping of waste was identified as a major cause of flooding within the city, resulting in the outbreak of water-borne diseases. Field experiments done in Indonesia found that trash racks in rivers blocked by plastic waste cause upstream water levels to rise at rates five times faster than those blocked by organic waste, possibly due to the higher density and lower number of gaps and voids in plastic waste compared to organic waste (Honingh et al., 2020).

According to a study documented by WasteAid to assess the impacts of plastic pollution on poverty, over 90% of development practitioners said waste had caused flooding in their area in the last two years (Tearfund and WasteAid, 2018). Over 56 % indicated that flooding caused by plastic was a serious problem in slums, with at least four or five incidents per year where plastic was a factor (Tearfund and WasteAid, 2018). Jha et al. 2012 pointed out that in Africa, waste can quickly block drain systems, causing flooding in communities with inadequate solid waste management or drain maintenance. Ziraba et al.2016, discussing flooding in urban cities in Africa, identified poor urban planning as a major culprit but added that the problem could also be attributed to rampant blockage of drainage systems by solid waste, especially non-degradable plastic bags. Further, they added that floods claim lives and damage sewerage systems, causing even wider environmental degradation.

In SSA, the use of sachet and bottled water is a growing economic trend due to the lack of access to potable quality drinking water (Nyarko and Adu, 2016). In their paper, the authors indicate, waste from bottle water (PET) and sachet water (LDPE) are major plastic leakage hotspots in developing countries such as Ghana and Nigeria ((Babayemi et al., 2019). The accumulation of PW from plastic water sachets and bottles has led to soil pollution in agricultural land, posing problems such as decreased water penetration into the soil due to blockages, contamination of groundwater and poor soil aeration (Nyarko and Adu, 2016).

3. 2 Human Health and Plastic Waste (PW)

Aside from the environmental hazards associated with PW, it is also indicated to drive human health problems. In their paper, the authors argued that blocked drains caused by PW collects standing water that have affinity to contribute to the spread of water and mosquito borne diseases such as dengue and malaria (Nor Faiza et al., 2019; Krystosik, et al., 2020). Similarly, PW, among other MSW in standing water, causes the leaching of chemicals into groundwater, which overall reduces the quality of groundwater (Akmal & Jamil, 2021). Additionally, Valsala and Asirvadam, 2022 presented an overview of the impact of chemicals from PW, specifically Bisphenol A (BPA), on stagnant water. They highlight that the presence of BPA in stagnant water results in a notable decrease in the hatching time and duration of larval instar in mosquitoes. This phenomenon contributes to an elevated population of mosquitos, potentially carrying diseases. Consequently, there is an associated increase in the incidence rates of diseases such as dengue, malaria, and other mosquito-borne illnesses. According to Legros et al., 2000, the environmental health risks associated with PW, including blockage of drainage channels, leading to flooding and the causes of breeding grounds for vectors such as mosquitoes and flies, escalate the transmission of infectious diseases such as cholera and diarrhea, especially in poor urban settings.

The indiscriminate dumping of MSW in urban areas especially informal settlements are common, creating an increased risk of environmental pollution, flooding and disease outbreak. One of the prime methods to control the likelihood of the aforementioned challenges is by disposal through open burning of MSW. This impacts human health, especially in poor urban settings (Edodi, 2023). A prominent study that was conducted on waste burning from the global perspective summarized the potential hazardous emissions of toxic substances in groups, including brominated flame retardants (BFRs), dioxins and related substances (DRCs), polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM) and volatile organic compounds (VOCs) (Lemieux et al., 2004). Similarly, Wiedinmyer et al.2014 presented a comprehensive global estimates of emissions from open burning of waste with Cogut, 2016 leveraging Wiedinnyer et al. model in the wider waste management sector. Moreover, Kodros et al. 2016 employed the Wiedinmyer et al. model and integrated it with a global burden of disease study conducted by Lim et al. to project a yearly estimate of 270,000 premature deaths worldwide (with a range from the 5th to 95th percentiles: 213,000 to 328,000) attributable to the open burning of waste. In a more recent investigation, these findings were aligned with data from the World Health

Organization (WHO) and the Institute for Health Metrics and Evaluation (IHME, GBDD, 2019), resulting in an estimate of premature deaths ranging from 270,000 to 270,500 associated with the practice of open burning of waste (Wiedinmyer et al., 2019). Ayeleru et al., 2020 highlighted that the incineration and landfill disposal of plastic waste in sub-Saharan Africa have significant detrimental effects on the environment and contribute to global warming, the depletion of natural resources, and harm to ecosystems caused by human activities. In their paper, the authors presented the risk of exposure to gas emissions from MSW, including PW, as a potential cause of respiratory, dermatological, and eye problems in informal settlers (Wilson et al. 2006). Also, Matter et al. 2013 mentioned informal settlers in urban centers are prone to common illnesses such as influenza, ulcers, bronchitis, musculoskeletal difficulties, and vermin-transmitted diseases as a result of MSW burning.

Several studies have revealed that humans are consuming microplastics due to their accumulation in various commercially harvested marine species (EFSA CONTAM Panel, 2016), as well as in other products such as bottled water (Common and Szeto, 2018), tap water, salt, fruits, and vegetables (Conti et al., 2020). A recent investigation conducted by Senathirajah et al. (2020) determined that humans ingest up to 5 grams of microplastics weekly through routine consumption of food and beverages. This quantity equates to approximately the size of one credit card made of plastic per week. This study represents an initial effort to establish a mass estimate of microplastic ingestion, contributing significantly to the evaluation of its potential impact on human health. While the health consequences of microplastic ingestion via food or air intake remain uncertain, it is evident that plastics are accumulating in human organs and tissues, raising concerns about future health implications due to the absorption of embedded toxins.

In 2021, IPEN published two reports detailing research conducted in Africa regarding the consequences of plastic waste in food chains on human health. The findings revealed that the levels of persistent organic pollutants (POPs) detected in free-range chicken egg samples indicate extensive contamination of the food chain due to prevailing plastic waste management practices such as sorting, dumping, and open burning in developing nations. Additionally, the recycling of PVC and e-waste was identified as another source of serious contamination with POPs (Petrlik et al., 2021a). Another study examined plastics found in children's toys and other consumer products for hazardous chemicals, including POPs (Petrlik et al., 2021b). The majority of the items analyzed exhibited elevated levels of POPs, surpassing the limits defined by the Stockholm Convention. These findings from both studies underscore the significant health risks posed by hazardous materials used as additives in plastic products.

3. 3 MSW and PW Policies in Informal Settlements

Uganda established the Finance Act 2009 that aims to protect the environment and restrict the use of polythene bags popularly called “Kaveera” in cities and rural areas (Singh et al., 2023). As a result, a plastic bag ban was announced in 2007 but was not implemented until 2009. According to Singh et al., (2023), the then minister announced in a speech to ban plastic materials of less than 30 microns and proposed an excise duty of 120% on the products. This led to public protests motivated by big businesses across the country. NEMA attempted in 2015 to also implement the ban on the same plastic materials, but was not successful. Over time, the NEMA intensified its efforts to address plastic pollution through stringent measures, including inspections and raids targeting shops selling plastic bags, as well as the closure of factories involved in the production of plastic products. In June 2018, the Ugandan government reinforced its commitment by implementing a ban on plastic bags, compelling 45 plastic manufacturers to cease the manufacture, distribution, sale, and use of plastic materials. Subsequently, the enactment of the National Environment Act in 2019 marked a pivotal moment, ushering in a comprehensive prohibition on the importation, exportation, local manufacture, use, or re-use of specific categories of plastics. Notably, the legislation also mandates the exclusion of single-use carrier bags with a thickness less than 30 microns.

Furthermore, Uganda has adopted Extended Producer Responsibility (EPR) as an integral component of the polluter-pays principle. This legal framework delineates the responsibilities and collaborative efforts of various stakeholders, including the Office of the Prime Minister, the National Bureau of Standards, Uganda Revenue Authority, and the National Environment Authority, in enforcing regulations pertaining to plastic pollution. In line with EPR principles, the government stipulates that all plastic manufacturers must establish recycling facilities and adhere to the entire lifecycle of the plastic products they produce and recycle.

Despite multiple attempts by Uganda to re-implement existing plastic bag ordinances, the enforcement of bans remains inefficient to this day. The country faces challenges stemming from a lack of state capacity and viable alternatives for plastic bags. Consequently, plastic pollution persists as a significant problem, posing ongoing environmental and social concerns for Uganda (Singh et al., 2023).

In their paper, the authors examined specific regulations to assess whether household in Kampala waste management practices were in compliance with or in violation of existing laws. These regulations encompassed the KCC Ordinance Act of 2000, the Penal Code Act Cap 120, and the National Environment Waste Management Regulations of 2020. The KCC Ordinance Act of 2000 expressly prohibits the disposal of waste in undesignated areas and strongly discourages illegal dumping to mitigate public health hazards (KCC, 2000). Individuals who dispose of waste in open spaces, streets, or undeveloped plots are deemed to be committing an offense under this ordinance. Section 12 of the ordinance explicitly states that "no person(s) shall bury, dump, or deposit, or cause to be buried, dumped, or deposited upon any street, alley, or premises, solid waste of any kind" (KCC, 2000). This regulation targets individuals, households, and communities at large, emphasizing the importance of proper waste management practices. Furthermore, the ordinance specifies that scattering or littering solid waste on any private or public property and storing solid waste in a manner not prescribed by the ordinance constitute offenses. Supplementing the ordinance is the Penal Code Act Cap 120, which stipulates that individuals commit an offense by intentionally polluting the atmosphere or the environment, potentially causing health hazards to neighboring individuals or others (Government of Uganda, 2007).

The implementation of waste separation at its source, as mandated by Section 18 of the National Environment Waste Management Regulations of 2020, remains relatively low and is often carried out solely for the associated benefits rather than being embraced as a preferred waste management practice. According to the authors, interviews with waste pickers confirmed that they frequent open dumping sites to collect waste while also visiting households to gather other types of waste as requested by recyclers they collaborate with. The examination of household waste management practices uncovered instances of non-compliance with the regulatory frameworks outlined in Section 4.1, which prohibit dumping, burying, burning, and littering of waste (Muheirwe et al., 2023).

3.4 Environmental Injustice and MSW

Environmental injustice in informal settlements has emerged as a critical issue in urban areas of developing countries, particularly in SSA. The literature reveals that residents of informal settlements and poor urban neighborhoods bear a disproportionate burden of environmental hazards and lack access to basic urban services, including proper solid waste management. The concept of environmental justice began in the United States in the late 1970s focusing specifically on the uneven distribution of environmental burdens along racial lines (Pollock and Vittes, 1996; Massey, 2004). In the context of developing countries, especially in SSA, environmental injustice manifests primarily through socioeconomic inequalities rather than racial divisions (Myers, 2008). The urban poor in informal settlements are particularly vulnerable to environmental injustices related to inadequate waste management, lack of sanitation, and exposure to pollution.

Solid waste management emerges as a key area where environmental injustice is evident in informal settlements. As many authors cite, municipal authorities in most African cities tend to concentrate their waste collection efforts in wealthy areas, while poorer neighborhoods receive little to no service (Cheru, 2002; Lohse, 2003; Binns et al., 2012). This disparity exists despite waste collection being funded through public resources. Okot-Okumu and Nyenje (2011) note that only 20-40% of waste is collected in many African cities, with the uncollected waste often ending up in poor neighborhoods and causing health hazards and environmental degradation. The literature also confirms that the improper siting of waste disposal facilities as another manifestation of environmental injustice. Bullard, 2005 observes that waste disposal facilities in SSA are frequently located in poor neighborhoods thereby subjecting vulnerable populations to various environmental risks. This practice illustrates how more powerful members of society shift the environmental burden onto the poor, exemplifying a clear case of environmental injustice (Kubanza and Simatele, 2015).

The lack of participation in decision-making processes further exacerbates environmental injustice in informal settlements. Venot and Floriane (2013) argue that poor and less powerful members of society are generally not consulted on decisions that have significant implications for their lives and environment. This exclusion from the decision-making process perpetuates the cycle of environmental injustice, as the concerns and needs of informal settlement residents are often overlooked in urban planning and environmental management strategies. Additionally, several factors also contribute to the persistence of environmental injustice in informal settlements. Simatele and Etambakonga, 2015 argues that weak institutional frameworks, lack of resources, and inadequate urban governance are key reasons for the failure to provide basic urban services, including proper waste management, in poor urban areas. Similarly, literature also highlights the lack of effective civil society action and community empowerment as factors that allow environmental injustices to continue unchallenged (Hashmi, 2007; Kwawe, 1995).

To address environmental injustice in informal settlements, scholars advocate for a rights-based approach to urban development. This approach emphasizes community participation, systematic empowerment of disadvantaged groups, and the creation of pro-poor institutions (Kubanza and Simatele, 2015). The right to access relevant information and participate in decision-making processes are identified as key components of environmental justice discourse. The literature also calls for improved policy implementation and enforcement of environmental regulations. Many Sub-Saharan African countries have environmental legislation, but weak implementation and lack of enforcement perpetuate environmental injustices (Kihangi, 2012; Faure and Du Plessi 2011). Therefore strengthening institutional capacity and increasing budget allocations for environmental management are crucial steps in addressing these issues.

CHAPTER 4: METHODOLOGY AND DATA COLLECTION

4.1 Literature methods

This thesis explores a systematic review of available published literature (Barbara et al., 2007) to integrate insights on the human health and environmental hazards associated with PW and MSW generation in SSA with an emphasis on informal settlements. This objective was accomplished through critical collection and evaluation of peer-reviewed articles, theses, dissertations and white papers on the subject. Using academic search engines including Google Scholar, Web of Science, ProQuest, and Taylor and Francis Online, I pulled information using the search strings such as plastic waste AND informal settlements, Environmental Hazards AND Solid Waste Management AND Informal settlements, Solid waste management AND Sub-Saharan Africa, Solid Waste management AND Kampala, Uganda, Flooding AND Plastic waste, Informal settlement AND Africa, Plastic waste OR Africa Urban Flooding, “Plastic waste issues associated with informal settlements”, “plastic health challenges in informal settlements of Africa”, “Plastic pollution in Africa”, “Plastic recycling in developing countries”, “Waste management Policy in Kampala”.

All article containing the above words were deemed relevant to my analysis and evaluation. The search yielded a total of 44,800 results on Google Scholar, 250 on Web of Science, 180 on ProQuest, and 192 on Taylor and Francis online (Total n= 45,422). These articles were sieved to include relevant articles from the year 2000 to date (N=25,000). Further, the articles were analyzed and categorized under the most relevant to my topic (n=453) and the rest was discarded (n=24550). The abstracts of the various papers were analyzed to select the ones that would guide me in answering my research questions (n= 205). A final review and analysis of (n= 102) was used in the synthesis of this document (Figure 14).

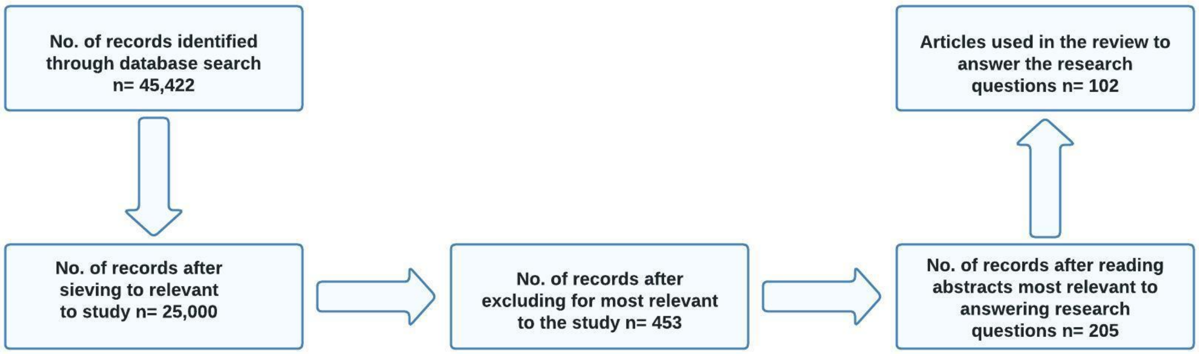


Figure 14. Literature Review Method
Source: Mensah, 2024

4.2 Google Street View (GSV) Data

GSV has emerged as a potential tool for assessing various environmental characteristics, including the MSW and PW in urban areas (Odgers et al., 2012; Kepper et al., 2017). GSV provides 360-degree panoramic imagery captured at the street level, which allows researchers to virtually explore and analyze the built environment without the need for study site visits (Rundle et al., 2011). This technology has been useful in the context of urban Africa, where data scarcity and logistical challenges often hinder traditional field-based data collection methods (Umar et al., 2023).

For this thesis, I used GSV imagery to assess the presence of MSW and PW in the case study sites namely Acholi Quarters, Kifumbira and Ggaba informal settlements of Kampala. First, I established the centroid (center/reference point) of the settlements from the GSV map (Figure

15, 16, 17). To establish a systematic sampling framework for data collection from GSV, a 50-meter grid was overlaid on each settlement (Figure 18) , using ArcGIS Pro software (ESRI, 2021). Two buffers were created around the centroid (represented with a hexagon icon) of each settlement, with radii of 0.5 and 1 mile in order to analyze the spatial distribution of MSW and PW at different scales and intervals (Figure 19) . I looked at the intersection of each grid on the road networks and manually checked for the availability of GSV using the Google Maps Platform. For each grid intersection with GSV availability, the presence or absence of MSW and PW was recorded following criteria a) PW and MSW should be within 50 feet (~15 meters) of the center of the road. b) the presence of PW and MSW is defined as either one piece greater than about 1 square meter or at least 10 smaller-sized pieces. I coded the presence of MSW and PW as “1” and absence as “0” for each GSV point.

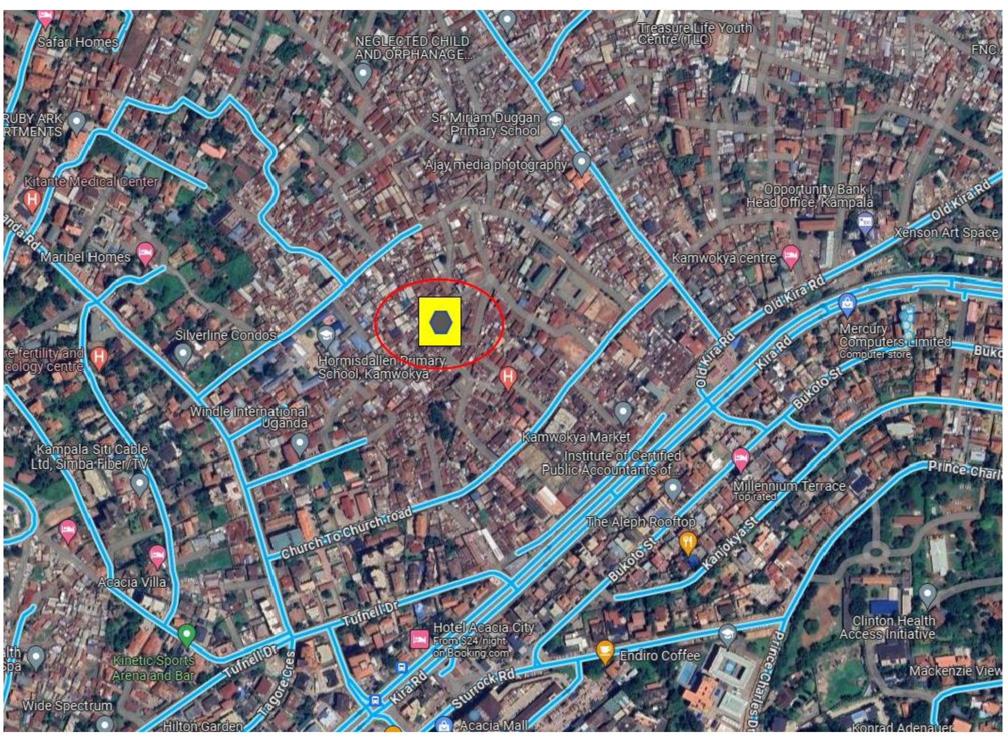


Figure 15. Kifumbira GSV with Centroid of settlement

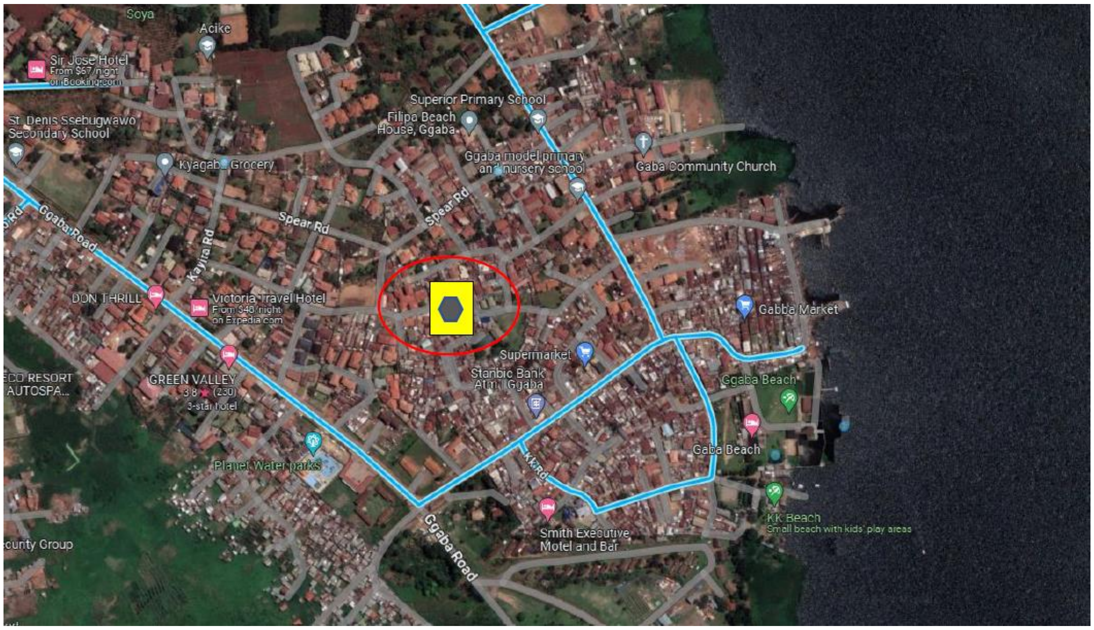


Figure 16. Ggaba GSV with Centroid of settlement

Figure 17. Acholi Quarters GSV with Centroid of settlement

I created a table with headers as grid intersection ID to contain all coded intersections with GSV, and a column header as pollution to contain either the presence of PW or MSW coded as “1” or “0”. Another column was created to contain the Latitude and longitude of each GSV point for each radius. The collected data was analyzed using spatial analysis techniques in ArcGIS Pro to focus on identifying patterns of the distribution. For each settlement, a map was generated displaying all GSV points, with red points indicating the presence of MSW and PW “1” and green points indicating the absence of MSW and PW “0”. Figures 20 and 21 show example representations of GSV of the presence or absence of MSW and PW.

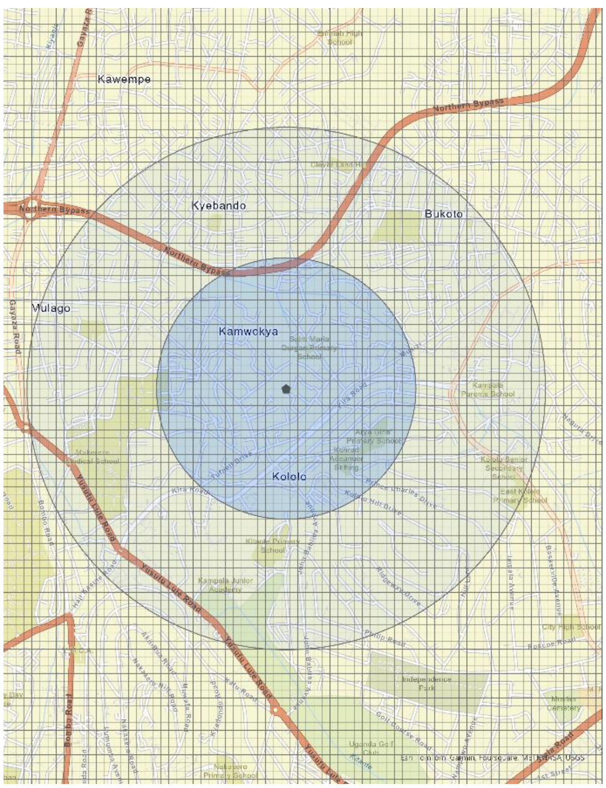


Figure 18. Grid on settlement (Cenroid)

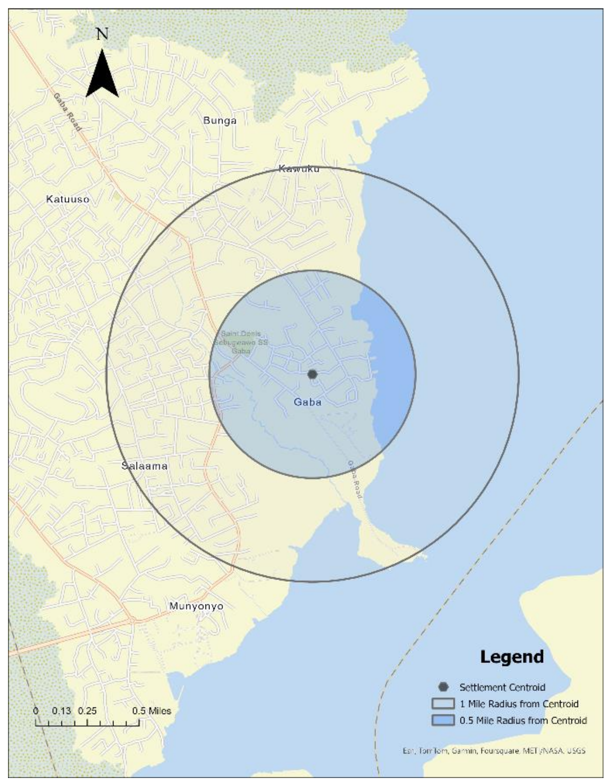


Figure 19. Buffer around settlement (Cenroid)

Figure 20. GSV showing presence of MSW and PW pollution

Figure 21. GSV showing absence of pollution

4.3 GIS data and Analysis

The primary data for my spatial analysis included the Ugandan country and informal settlements shapefiles. I sourced for the Uganda country data for which I extracted the boundaries of Kampala from GADM, Database of Global Administrative Areas. I also obtained data on informal settlements through the Climate Policy Lab at The Fletcher School, Tufts University.

For further analysis of the GSV data points, I imported the points of each settlement into ArcGIS Pro as a point feature class and conceptualized the spatial relationship of the points as inversely distant. I used the "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool to calculate the Local Moran's I values, z-scores, p-values, and cluster and outlier types for each GSV point. To run the tool, the input parameters were set as follows: a) Input Feature Class: GSV point feature class for each settlement b)Input Field: The waste presence field (0 or 1), c) Conceptualization of Spatial Relationships: Inverse Distance. d) Distance Method: Euclidean distance e) Standardization: None.The tool was run to generate maps of clusters and outliers within the 0.5 and 1 mile radii from the centroid.

CHAPTER 5: RESULTS AND DISCUSSION

The spatial analysis of MSW and PW presence in the three informal settlements, using both GSV data and GIS technique revealed distinct patterns and clusters of pollution distribution. As shown below for the Ggaba informal settlement (Figure 22), Map A illustrates the distribution of the presence (red) and absence (green) of MSW and PW along GSV road networks within 0.5 and 1 mile radii respectively. All of these points had GSV but inner settlements despite appearing to have a network of roads lacked access to GSV, therefore no data was collected along these sites. Map B shows a satellite view of a dense settlement within the 0. 5 mile radius where there is a split of data aggregation of the presence of MSW and PW (red points) and the linear distribution of the presence of no MSW and PW (green points). Though there is equally a dense settlement within 1 mile radius from the centroid, most of the data collected along the GSV had no presence of MSW and PW. There was an observation of less pollution along major roads such as Jinja, Northern Bypass, Yusufu Lule and others which may be attributed to the accessibility of the area. The easy accessibility to these areas may have facilitated the removal of MSW and PW, whereas the lack of access could mean more pollution. It was observed that many of the settlements within both the 0.5 and 1 mile with the presence of vegetation had no or low pollution. These areas appeared well planned, possibly depicting settlements of either the rich or above-average incomers.

Most of the informal settlements lacking access to GSV did not have access to green vegetation, which may show their vulnerability to climate change hazards and impacts. Moreover, the informal settlements within 0.5 and 1 mile showed signs of flooded areas, and less planned drainage systems. Most of the PW and MSW along GSV roads were found in open drains and other water canals. There was also the distribution of pollution that can be attributed to human indiscriminate dumping and incessant littering within most of the neighborhoods. There were views of disposal methods such as burning and dumping on open land. The GSV also showed a lack of public amenities in the clustered informal settlements as compared to the settlements near vegetation, as seen in Map B. The Maps A and B highlight the presence of PW and MSW in 0.5 and 1 mile radii of the centroid. There was a higher concentration of pollution (red points) within the 0.5 mile as compared to the area between 0.5 and 1 mile from the centroid (tables 3, 4,5,6,7,8).

Pollution Status	Count	Percentage
Pollution	9	40.90%
No Pollution	13	59.10%
Total	22	

Table 3. Ggaba Settlement- 0.5 mile radius

Pollution Status	Count	Percentage
Pollution	9	25.00%
No Pollution	27	75.00%
Total	36	

Table 4. between 0.5 and 1 mile radius

Pollution Status	Count	Percentage
Pollution	19	86.40%
No Pollution	3	13.60%
Total	22	

Table 5. Acholi Settlement- 0.5 mile radius

Pollution Status	Count	Percentage
Pollution	18	41.90%
No Pollution	25	58.10%
Total	43	

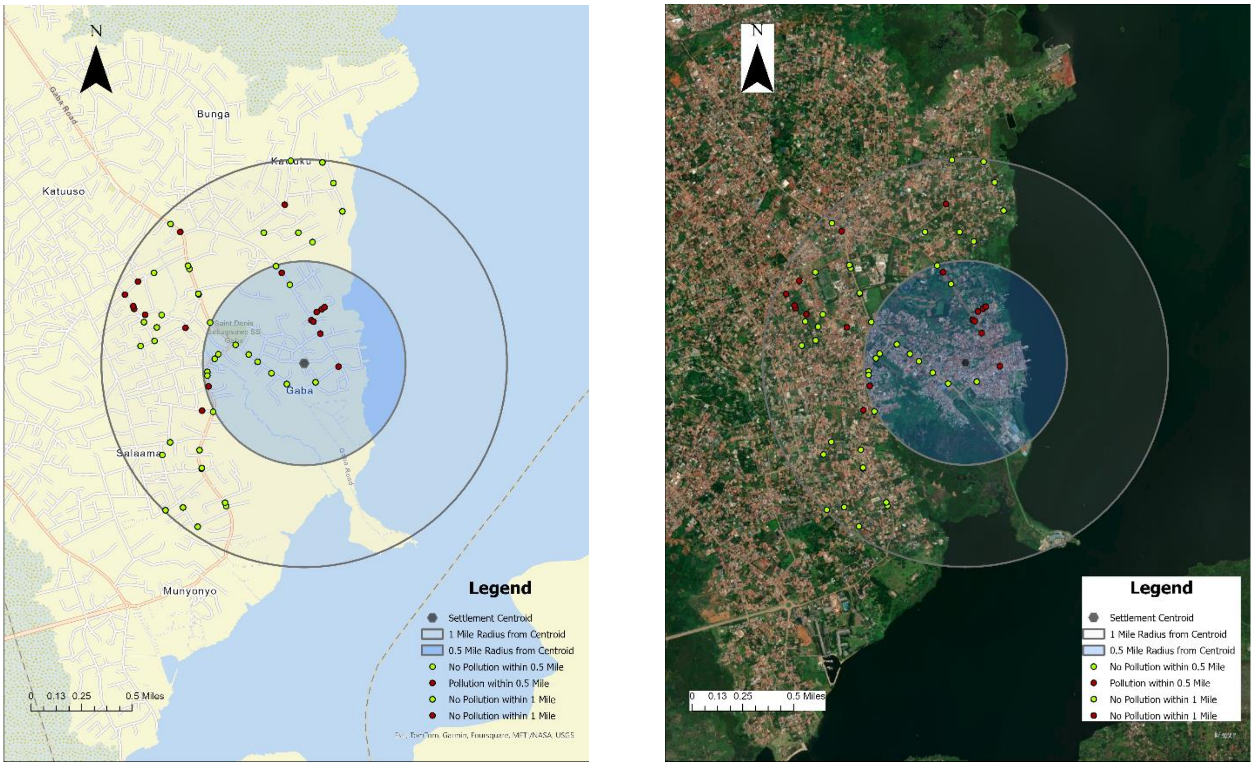
Table 6. between 0.5 and 1 mile radius

Pollution Status	Count	Percentage
Pollution	12	34.30%
No Pollution	23	65.70%
Total	35	

Table 7. Kifumbira Settlement- 0.5 mile radius

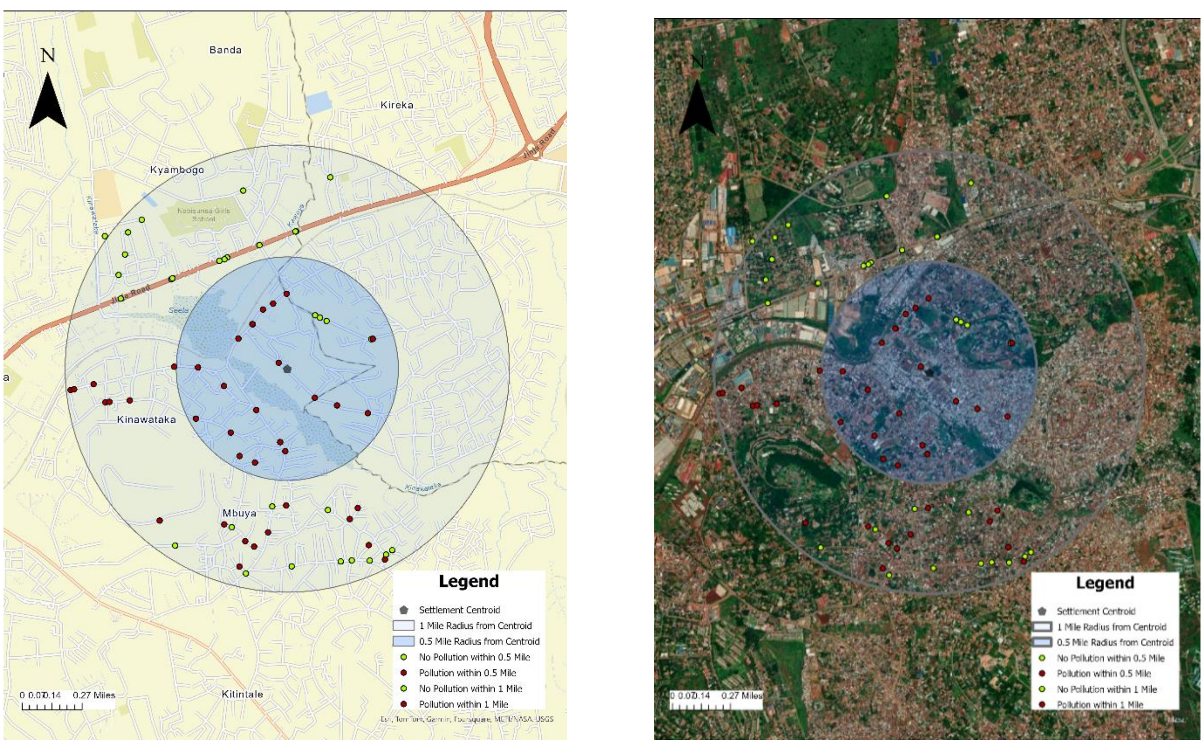
Pollution Status	Count	Percentage
Pollution	27	39.10%
No Pollution	42	60.90%
Total	69	

Table 8. between 0.5 and 1 mile radius



A. B.

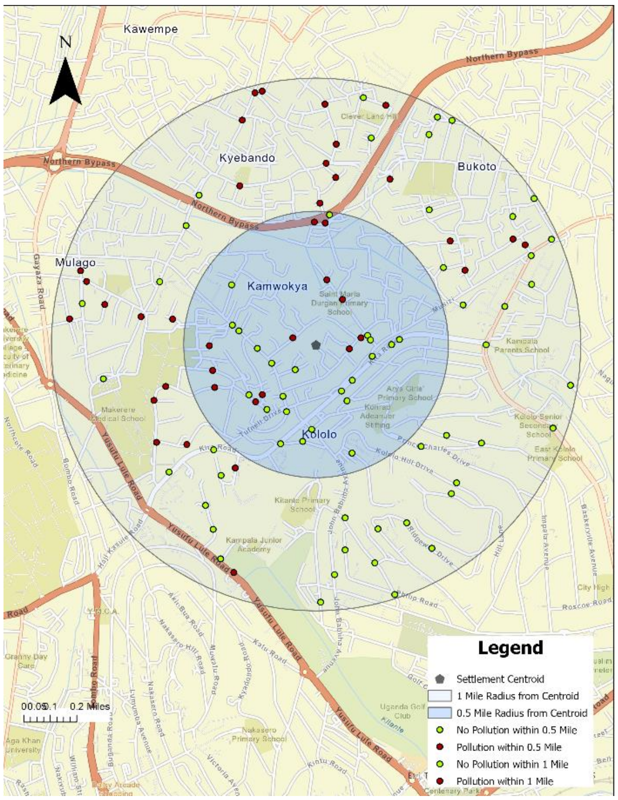
Figure 22. Ggaba informal settlement result Maps



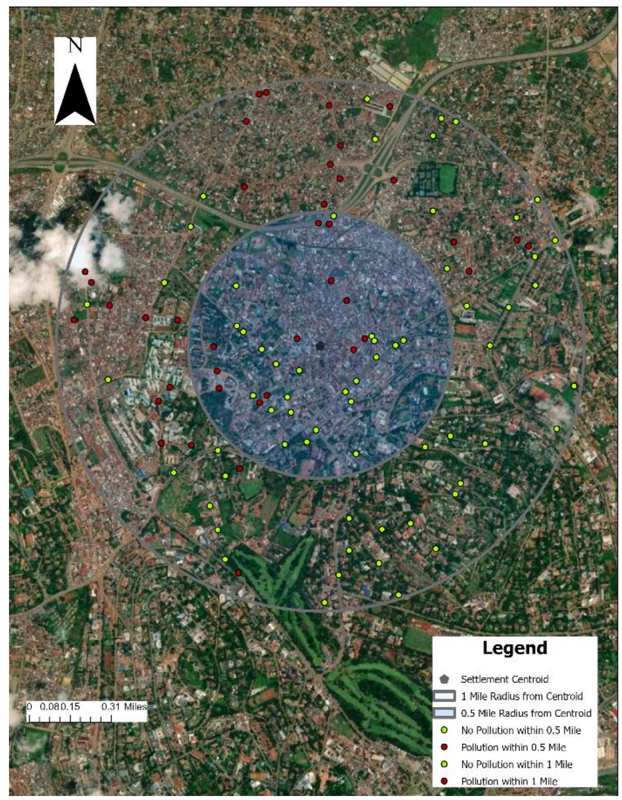
A. B.

Figure 23. Acholi Quarters informal settlement result Maps

There was no presence of pollution along major roads, which can also be attributed to accessibility and the availability of waste collection. Most of the informal settlements within 0.5 mile lacked GSV, and an observation of a denser, clustered area with similar characteristics as Ggaba and Kifumbira.



A.



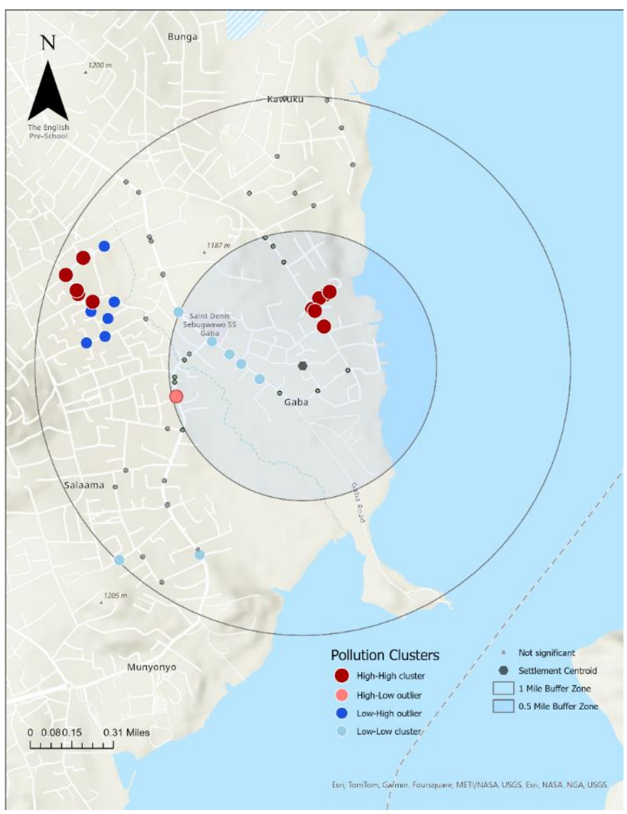
B.

Figure 24. Kifumbira informal settlement result Maps

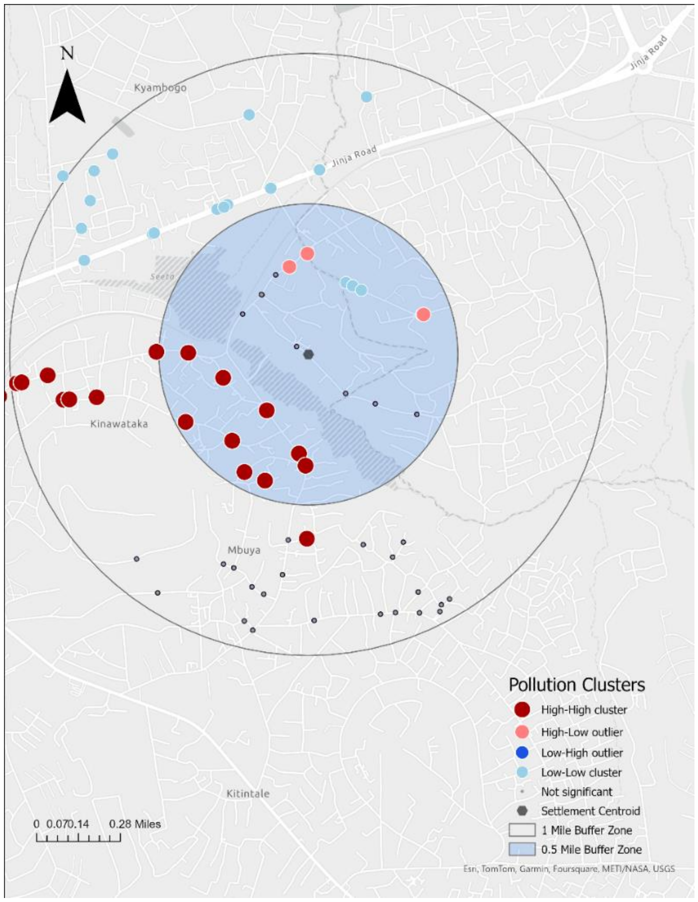
The GSV Map A for Kifumbira (Figure 24) had a more widely distributed presence and no pollution within the 0.5 and 1 mile respectively. There was an extensive availability of GSV signifying a higher accessibility to roads network. Generally, the GSV along the major roads like the highways like Jinja were clean. There was a great representation of pollution within the 0.5 mile radius of the settlements with similar characteristics as Ggaba and Acholi Quarters. As in

Map B, most of the places with vegetation had no to less pollution and showed well organized and planned settlements. The observation represented images of quality homes probably for rich to above- average income neighborhoods.

The hotspot analysis and spatial autocorrelation results indicated that the spatial distribution of MSW and PW varied considerably among Ggaba, Kifumbira, and Acholi Quarters. There was a different exhibition of strong clustering of high pollution and dispersed or random patterns (Figures 25, 26, 27). The comparison of pollution distribution across different spatial scales (settlement level, 0.5-mile, and 1-mile buffer zones) revealed that the patterns were not always consistent showing the influence of local factors and heterogeneity within settlements.

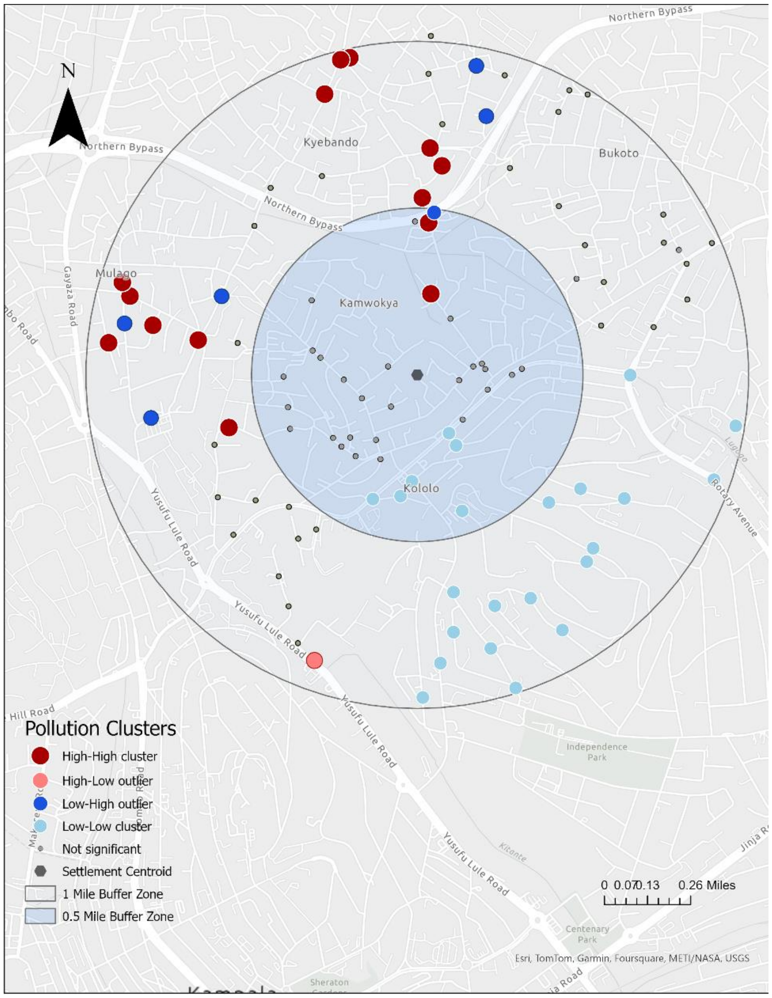


Figures 25. Clustering in Ggaba settlement



Figures 26. Clustering in Acholi Quarters settlement

These findings align with the literature on waste management challenges in informal settlements, which highlights the complex interplay of factors such as limited collection services, lack of infrastructure, and unplanned urbanization (Mugagga et al., 2021; Odonkor et al., 2020). The spatial variations in pollution likely reflect the differential access to waste management services, community awareness, and socio-economic conditions across these areas. For Clusters and Outliers of the presence of pollution, the Local Moran's I analysis provided a more nuanced understanding of the spatial patterns within each informal settlement.



Figures 27. Clustering in Kifumbira settlement

The results identified statistically significant (P-value between 0.02- 0.06) clusters of high waste presence (High-High or HH clusters) and low waste presence (Low-Low or LL clusters), as well as outliers (High-Low or HL and Low-High or LH) that deviated from the surrounding patterns. The HH clusters represent hotspots of PW and MSW concentration that may pose heightened risks to human health and the environment. As discussed in my literature review, these areas are likely to experience increased flooding due to waste-clogged drainage channels (Lamond et al., 2012; Okot-Okumu, 2012) and serve as breeding grounds for disease vectors like mosquitoes (Krystosik et al., 2020). The concentration of pollution in HH clusters may also contribute to soil and water contamination, as well as air pollution from open burning practices (Wiedinmyer et al., 2019; Wilson et al., 2006).

Conversely, the LL clusters may indicate areas with relatively better waste management practices or successful community-driven clean-up efforts. These clusters present an opportunity to learn from the strategies and factors that contribute to lower pollution and potentially replicate them in other parts of the settlements or Kampala at large (Odonkor et al., 2020). The outliers- HL and LH identified in the analysis suggest localized factors that influence pollution presence, such as proximity to busy activity centers such as markets and other public spaces or barriers to collection such as lack of road accessibility and general lack of roads These outliers warrant further investigation to understand the specific drivers of waste accumulation or absence in these areas and develop targeted interventions (Alam et al., 2018).

The spatial patterns and clusters of the pollution revealed by this study have important implications for waste management and public health in the settlements. The findings can inform targeted interventions and policies that prioritize the areas of greatest need and leverage the strengths of communities with lower pollution. In the HH clusters, urgent actions are needed to mitigate the health and environmental hazards associated with pollution accumulation. These may include increasing the frequency and coverage of waste collection services, conducting regular clean-up campaigns, and investing in drainage infrastructure to prevent flooding. Community education and awareness activities can also play a crucial role in promoting proper waste disposal practices and discouraging open dumping and burning. The LL clusters may offer valuable insights for waste management in informal settlements. By investigating the factors that contribute to lower waste presence in these areas, such as community engagement, partnerships with local organizations, or innovative waste collection models, can provide ideas for replication and scale-up. Addressing the outliers requires a more localized and context-specific approach. This may include increasing waste collection frequency and providing additional waste bins near markets and other busy public spaces to help manage the higher waste generation in these areas.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Limitations of the research

I encountered some constraints and limitations in conducting this research. Firstly, there was a limited availability of GSV coverage in the inner informal settlements, which posed a significant challenge to the comprehensiveness of the spatial analysis. I noticed that Many of the densely populated and vulnerable areas within the 0.5 and 1-mile radii from the settlement centroids lacked GSV imagery, therefore resulting in data gaps and potential underestimation of the extent of pollution. This limitation highlights the need for GSV expansion to cover these areas, as it was indicative that many road networks exist in the settlements. Further, it also highlights the need to include alternative data collection methods, such as drone imagery or participatory mapping to capture the realities of pollution in these underserved areas (Georganos et al., 2021; Thomson et al., 2019).

Additionally, I did not conduct any interviews specific to this research aside my initial visit and reliance on first-hand field notes. This constrained the depth and context of the findings, as interviews with the local residents and city officials could have provided valuable insights into the lived experiences, challenges, and perspectives surrounding waste management in the informal settlements (Muheirwe et al., 2023). Despite these limitations, this research provides important insights into the spatial patterns of MSW and PW pollution in the selected informal settlements of Kampala. However, future studies should endeavor to incorporate interviews, field observations, and alternative data sources to enhance the robustness and representativeness of the findings.

6.2 Conclusion

This thesis aimed to address two central research questions: 1) What are the human health and environmental hazards associated with MSW and PW pollution in informal settlements, and are there policies that address these concerns? 2) What is the spatial distribution and clustering of MSW and PW in the case study informal settlements of Acholi Quarters, Kifumbira, and Ggaba? The systematic literature review revealed that MSW and PW pollution in informal settlements is linked to increased risks of urban flooding, soil and water contamination, vector-borne diseases and air pollution from open burning practices. The review also highlighted the lack of effective policies and enforcement mechanisms to address the waste management challenges in these vulnerable communities and Kampala as a whole.

The GSV and GIS analysis provided valuable insights into the spatial patterns of MSW and PW distribution within the selected informal settlements- Acholi Quarters, Ggaba and Kifumbira. The results indicated varying levels of pollution presence across different spatial scales, with higher concentrations observed within the 0.5-mile radius from the settlement centroids for two of the three settlements. The results of the settlements within 1-mile radius suggest the farther away the centroids, the cleaner the settlements.This supports the environmental injustice argument that waste management and development were not equally prioritized in the informal settlements as compared to the surrounding wealthy communities. The Local Moran's I analysis identified statistically significant clusters of high and low pollution presence, as well as outliers, showing the influence of local factors on the distribution. However, further research is needed to fully understand the complex dynamics of waste management in informal settlements. Future studies should aim to incorporate interviews with the local residents, waste pickers, and city officials to capture the lived experiences and perspectives on the issue. Additionally, exploring alternative data collection methods, such as drone imagery or participatory mapping, can help overcome the limitations of GSV coverage in the inner informal settlements.

6.3 Recommendations

Based on the findings of this research, the following recommendations are proposed for policymakers and city authorities to address the challenges of MSW and PW management in informal settlements:

1. Prioritize waste collection and infrastructure in informal settlements: It is crucial to develop policies that prioritize the allocation of resources to increase the frequency and coverage of waste collection services in the most polluted areas identified through spatial analysis. In this research, it was observed that most of the settlements lacking GSV were the most polluted, possibly due to the lack of accessibility and road network. It would be essential to conduct a road accessibility analysis to strategically position effective and efficient waste collection hubs to decongest the accumulation of waste in those settlements.
2. Strengthen enforcement of waste management regulations and policies: There should be an effective implementation of existing policies and ordinances related to waste disposal, littering, and open burning, with a focus on informal settlements to defer people from irrational waste disposal habits (Muheirwe et al., 2023).
3. Investments in drainage infrastructure: There should be a conscious investment in improving and maintaining drainage systems in the informal settlements and Kampala as

a whole to mitigate the risks of flooding and associated health hazards exacerbated by waste accumulation (Lamond et al., 2012). My visit to the Kifumbira informal settlement demonstrated the vulnerability of the settlers to climate hazards such as flooding due to the poor planning and development of drainage systems. This observation cuts across several other places I visited during my stay in Kampala.

4. Promote waste segregation, recycling and incentives in households: Most of the GSV images revealed poor housing and land topography (as discussed in literature). This makes redevelopment and revitalization nearly impossible in the space of government competing priorities. It is therefore a matter of urgency to develop and implement policies that will support and improve partnerships in waste segregation, recycling and incentives at the household level across the settlements. This will enhance recycling rates and reduce the amount of waste reaching dumpsites (Matter et al., 2013).
5. Foster multi-stakeholder collaboration: Policies should be developed on the basis of environmental justice to encourage collaboration among local residents, city authorities, NGOs, the private sector, and academic institutions to develop participatory waste management strategies and innovative and context-specific solutions for waste management in informal settlements (Oates et al., 2019).
6. Conduct regular monitoring and evaluation: Authorities should develop a system for continuous monitoring and assessment of waste management practices and pollution levels in informal settlements to track progress and identify areas for improvement (Kabera et al., 2019).

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