DETERMINING AN INTEGRATED SOLID WASTE MANAGEMENT ACTION PLAN FOR URBAN HARARE CITY, ZIMBABWE: A SYSTEM DYNAMICS APPROACH

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Submitted in fulfillment of the academic requirements for the degree of Doctor of Philosophy in Bioresources Systems at the College of Agriculture, Engineering and Science, School of Engineering, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

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ABSTRACT

Addressing the Sustainable Development Goals (SDGs) is one of the challenges African countries are facing today. Of the 17 SDGs, 11 are either directly or indirectly linked to waste management. Solving waste management issues is thus one of the best ways to improve the global movement towards attaining the goals. Rampant illegal waste dumping, open waste burning, irregular waste collection, the sprouting of informal housing, public littering, and mismanaged dumpsites seem to doom Harare's hope of reaching its vision of 'achieving a world-class city status by 2025'. Decision-making in HSW management ought to account for uncertainty and the system's complexity. This study thus uses case study, network analysis (NA) techniques, and the system dynamics (SD) methodologies to explore the interactive relationships between various components of Harare's household solid waste (HSW) management system. This was done to ultimately assess the material recovery potential of a community-based waste management (CBWM) approach to managing HSW. This is the gap in knowledge the study aimed to fill as identified in literature. A CBWM strategy implementation chart (CBWM-SIC) which proposes four strategy implementation levels for Harare's next municipal period of 2022-2026 was developed. All food leftovers are composted in the proposed CBWM system, while 50% of paper and plastic waste is recycled. These strategies will improve the efficiency and integrative nature of the city's HSW management system.

The study results show that Harare's HSW management system comprises three main components: waste generation, waste collection and transport, and waste disposal. Generating 207 635 294±56 027 040kg of HSW annually, waste generation per capita in Harare is 0.38±0.1kg. Collecting 170 385 600±33 384 209kg.yr^{-1} the municipality has a collection efficiency of 72.4±7.5%. While all collected waste in the city is dumped in the Pomona dumpsite, waste recovery efficiency at the dumpsite is around 9.5±2.8%. (recovered waste as a percentage of collected waste). NA using R revealed that some of the key issues plaguing Harare's HSW management system are uncollected waste, waste collection efficiency, illegal waste dumping, the state of the country's economy, and financial capacity. The low network density of 1.5% also suggested that various strategies implemented in different components of the HSW management system are required to cause significant improvements.

The impact of introducing the CBWM system was assessed using an SD model developed in STELLA. The study suggested that composting of food leftovers is better prioritized in high-density (HD), medium-density (MD), and low-density (LD) suburbs, respectively. On the other hand, recycling paper and plastics is better prioritized in HD, LD, and MD suburbs, respectively. The findings for the projected five-year municipal period of 2022-2026 show that composting of food leftovers can improve Harare's recycling rate from 5.2% to about 34.1%, 41.6%, 51.8%, and 63.1% at each level of strategy implementation. Uncollected waste and controlled waste treatment are potentially reduced and increased by about 62.3% and 38.3%, respectively. Additionally, the amount of illegally dumped waste is likely to be reduced from 224 854tons.yr^{-1} to 186 009tons.yr^{-1}, 178 496tons.yr^{-1}, 147 440tons.yr^{-1}, and 112 866tons.yr^{-1}, at each implementation level respectively.

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I, Phyllis Rumbidzai Kwenda, declare that:

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PUBLICATION 1 (Published)

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KPR was the principal writer of the manuscript. GL, ES, and VRB contributed to paper writing and the interpretation of results.

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KPR was the principal writer of the manuscript. PRK, GL, ES, and VRB contributed to model building, interpretation of results, and paper writing.

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LIST OF ABBREVIATIONS

MSW	Municipal Solid Waste
HSW	Household Solid Waste
HD	High-Density
MD	Medium-Density
LD	Low-Density
NA	Network Analysis
SD	System Dynamics
SWM	Solid Waste Management
HCC	Harare City Council
LI	Lower-Income
HI	High-Income
UKZN	University of KwaZulu-Natal
ISWM	Integrated Solid Waste Management
WMH	Waste Management Hierarchy
3Rs	Reduce, Reuse, and Recycle
3Ss	**S**anitation, **S**ubsistence economy, and **S**ustainable
NRF/SASAC	National Research Foundation/South African Systems Analysis Centre
GHG	Green House Gas

1. INTRODUCTION

Annual global production of Municipal Solid Waste (MSW) is expected to increase by about 0.9billion tonnes (tons) by the year 2025 (Sukholthaman and Sharp 2016). The management of MSW is thus a serious and pressing issue that most urban cities, especially in developing countries, face today (Guerrero *et al.* 2013, Welivita *et al.* 2015). More significant unplanned population growth and hence urban household solid waste (HSW) generation is expected in developing countries (Azevedo *et al*. 2021). Compared to other waste streams, HSW is not homogeneous thus the most complex to manage (Troschinetz and Mihelcic 2009). In developing countries, HSW usually makes up the majority of MSW (Welivita *et al.*, 2015). In Zimbabwe, HSW is becoming a serious public health scare (Chikowore 2021). Over 100 people in the country lose their lives annually due to poor HSW management-related issues (Mandevere and Jerie 2018).

Over 60% of HSW generated in Harare is organic. While there is no waste separation at source practiced in the city, about 90% of all collected waste is disposed of in Pomona dumpsite white the rest is recycled (Mandevere and Jerie 2018). The waste management strategies mainly used in the city are ineffective, illegal, and require revision. Developing countries must adopt tailor-made HSW management strategies and policies (Azevedo *et al*. 2021). Nhubu *et al.* (2019d) proposed a decentralized approach to waste management in Harare. Decentralization entails the involvement of stakeholders in waste management, especially the system users. This study thus aims to assess the potential impact of community-based waste management (CBWM) for HSW management in developing countries, using Harare as a case study. Recycling is one of the initiatives scholars have proposed to combat the waste management crisis in developing countries (Azevedo *et al*. 2021). Recycling reduces the amount of waste in landfills (Kattoua, Al-Khatib and Kontogianni 2019).

An integrated waste management plan (IWMP) is a framework used as a reference when designing and implementing new waste management systems (Seadon 2006). Developing and implementing IWMPs is mainly performed in three stages, as shown in Figure 1.1 below. In Zimbabwe, practical assessment or IWMP implementation procedures are done over 5-year periods. However, annual estimates of progress are supposed to be done and reported annually. Due to time constraints and setbacks caused by the COVID-19 pandemic, this research study focused on the first two stages producing a CBWM-strategy implementation chart (CBMW-SIC) for Harare.

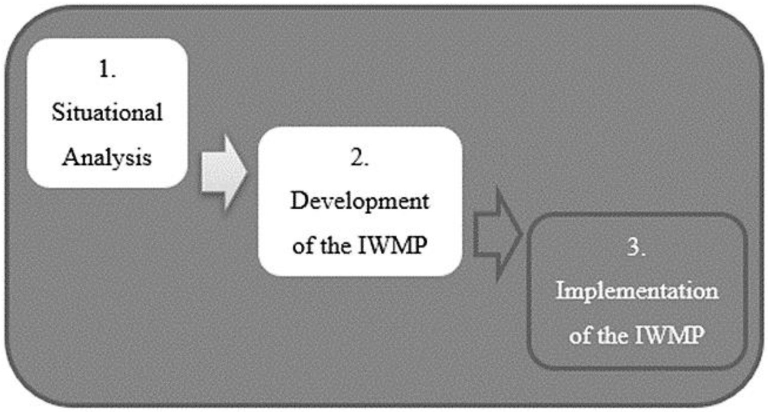

Figure 1.1 Three main stages in developing and practically assessing the effectiveness of an Integrated Waste Management Plan.

Most waste management-related studies in developing countries do not provide quantitative information (Guerrero *et al*. 2013). This study combined the qualitative and quantitative research methods by using the exploratory sequential mixed methodological approach. This is a two-staged approach in which data collection and analysis begins with a qualitative study using NVIVO (Phase 1), which feeds into a quantitative study using R and STELLA (Phase 2), as shown in Fig. 1.2 below (Chaerul *et al.* 2008). A research methodology is an account of the techniques used and their logic in systematically solving a problem. Two study objectives were addressed in Phase 1 and the remaining two in Phase 2. These are a) conduct a literature review to understand and identify the relevant elements of the HSW management system in Harare, b) conduct a literature review to identify the issues affecting the HSW management system in the city, c) use network analysis (NA) to visualize and quantify relationships between HSW management issues, and d) transforming relationships between HSW management issues into an SD model for scenario analysis.

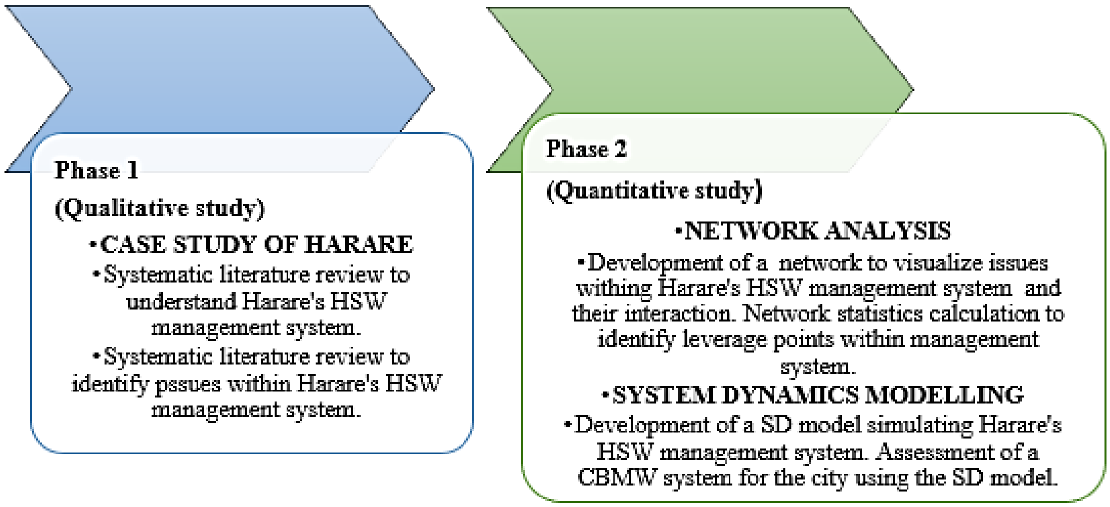

Figure 1.2 Research phases of the study.

In this study, to investigate HSW management in Harare, a case study method is used. This method allows for an in-depth analysis of the HSW management phenomenon in the bounded system of Harare's residential areas. It involves the use of various research techniques to gather information. However, due to disruptions caused by COVID-19, which proved face-to-face interviews challenging, this study only used literature search (journal papers, newspapers, archival records, reports) and observations as data sources. The cleansing superintendent at the waste management department in Harare provided access to the city's HSW management data. Waste management systems in developing countries exhibit higher complexities than those in developed countries (Marshall and Farahbakhsh 2013). To ensure informed decision-making in these countries, it is essential to first understand the nature of their waste management systems. This allows for the formulation of local-level solutions that more efficiently address the waste management needs of each particular area (Nhubu et al. 2019d). Chapter 2 thus presents findings of a systematic literature review conducted to understand the HSW management system in Harare. On the other hand, identifying the system's key problems aids in estimating future waste management conditions and, hence, develop appropriate solutions (Khan *et al.* 2016, Mazzanti and Zoboli 2008). Chapter 3 thus details the results of a systematic review to identify issues affecting the city's HSW management system.

NA explores the structure and patterns of network relationships. This technique clarifies the roles and influence of various actors within a network (Duygan *et al.* 2020, Ghinoi *et al.* 2020). NA and SD modelling are potent tools that study the behaviour of complex systems. Chapter 4 presents the leverage points within Harare's HSW management system identified using NA techniques. Identifying the major bottlenecks affecting the system's efficiency will fuel future studies and alert authorities on immediate attention areas. R was used for network visualization and calculation of network statistics. SD is a methodology used to develop computer simulation models that attempt to replicate complex systems characterized by feedbacks (Homer and Hirsch, 2006). This modelling technique works on the basis that the individual behaviour of components cannot explain the behaviour of the whole system. According to Meadows (2008), the structure of the system explains its behaviour. Chapter 5 thus presents the results of a study where CBWM was assessed for Harare using a SD model simulating the city's HSW management system.

2. A MINI-REVIEW ON HOUSEHOLD SOLID WASTE MANAGEMENT SYSTEMS IN LOW-INCOME DEVELOPING COUNTRIES: A CASE STUDY OF URBAN HARARE CITY, ZIMBABWE

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Abstract

Among other African cities, in terms of solid waste management (SWM), Harare has been ranked as one of the poorest. The municipality struggles to efficiently provide SWM services to its residents. Considering that SWM systems are complex, the individual behavior of its components (waste generation, collection, and disposal) determines the system's overall performance.

This mini-review thus aims to understand the management system of the urban city's biggest source of solid waste which is household solid waste (HSW). The systematic literature review methodology using NVIVO was used to analyze the literature. Out of a selected sample size of 500 journal articles, 26 were selected based on their relevance to the study. The uncertainty of the data provided by the Harare City Council (HCC) and of HSW generation data harvested in the literature was calculated. According to the HCC data records, Harare has an average daily waste generation per capita is on average 0.38±0.1kg producing about 207 635 294±56 027 040kg of HSW generated annually. With the waste collection efficiency in Harare at about 72.4±7.5%, the city collects approximately 170 385 600±33 384 209kg of HSW annually. All the collected HSW is disposed of in the city's major Municipal Solid Waste (MSW) dumpsite called Pomona and only about 23 498 400±3 988 817kg MSW is recovered annually with the average recovery efficiency at around 9.5±2.8%. where most of the waste recovery is done by the waste pickers.

Keywords: Household solid waste, household solid waste management, household solid waste management system, waste generation, waste collection, waste disposal, Harare, Zimbabwe

2.1 Introduction

Worldwide, the unprecedented rate of urbanization, increasing volumes of waste being discarded, and the growing complexity of solid waste composition has posed challenges on municipalities who are expected to manage waste in environmentally and socially acceptable ways (Guerrero *et al*. 2013, Vergara and Tchobanoglous 2012, Nhubu *et al.* 2019c, Nhubu *et al.* 2019d, Powell *et al.* 2018, Das *et al*. 2019). In Lower Income (LI) countries like Zimbabwe, solid waste generation rates and management costs will more than double in the next 20 years and increase five-fold in the next 5 years, respectively (The World Bank 2020). The 3.5 billion urban dwellers estimated in 2010 worldwide are expected to almost double thus estimating 2/3 of the world population to reside in urban areas by the year 2025 (Seto *et al*. 2013, Troschinetz and Mihelcic 2009).

When compared to rural residents, urban residents generally have lower reuse and recycling tendencies, are more reliant on processed and packaged foods and have a higher income hence show higher waste generation rates (The World Bank 2020). However, despite being a global concern, Solid Waste Management (SWM) strategies are better handled locally. This is because waste characteristics, climate, accessibility of waste, environmental regulations, population, as well as the technical and financial capacity of the municipality in charge determines the feasibility and effectiveness with which waste management strategies are employed in any given area (Beede and Bloom 1995, Sakai *et al.* 1996, Henry *et al.* 2006, Matter *et al.* 2013).

Solid waste can be classified based on waste streams. For example, residential, commercial, industrial, medical, agricultural, construction, or demolition waste and academic solid waste (Babayemi and Dauda 2009, Chowdhury 2009, Damghani *et al.* 2008, Nhubu *et al*. 2019a). Waste from agricultural and industrial waste streams is homogenous while municipal solid waste is the most complex (Troschinetz and Mihelcic 2009). For example, slight changes in income levels among residents can result in drastic changes in consumer patterns, waste volumes, waste types, and waste composition thus presenting greater challenges for municipalities to effectively handle the waste (Troschinetz and Mihelcic, 2009).

Municipal solid waste (MSW) is defined as solid waste from commercial enterprises, government buildings, offices, hospitals, households, supermarkets, restaurants, street sweepings, and other public places managed by or on behalf of the municipality (Naidoo 2009, Zurbrugg 2003, Nhubu *et al*. 2019b, Nhubu and Muzenda 2019). However, household solid waste (HSW) generally makes up the greater composition of MSW, approximately 55-80% (Hargreaves *et al*. 2008, Nhubu *et al*. 2019a, Nhubu *et al.* 2019b). The focus of MSW management is on activities around the generation, collection, transport, treatment, and disposal of this MSW (Beigl *et al*. 2008, Henry *et al.* 2006, Zhang *et al*. 2010, Moghadam *et al*. 2009).

Generally, MSW management systems in developing countries are characterized by inadequate service provision, low waste recovery, operational inefficiencies, and poor waste disposal (Zurbrugg 2003, Henry *et al*. 2006, Marshall and Farahbakhsh 2013, Moghadam *et al.* 2009). Despite their systems exhibiting higher complexities than those in developed countries, most developing countries do not use systems analysis techniques in SWM (Marshall and Farahbakhsh 2013). The first step in making informed decisions that can better the waste management system in these countries would involve understanding the nature of their waste management systems, hence the importance of this study. This allows for the formulation of local-level solutions that more efficiently address the waste management needs of each particular area (Nhubu *et al.* 2019d). This paper reviews the household solid waste (HSW) management system in Urban Harare city, Zimbabwe as a case study of a city in a LI developing country. The aim is to identify how HSW is handled, the SWM strategies used, and thus identify research gaps around the city's management system for future studies.

2.2 Methodology

To gain an understanding of the HSW management system in Harare a systematic literature review approach was used. This methodology has been widely used in the field of SWM (Beigl *et al*. 2008, de Souza Melaré *et al.* 2017, Gonçalves *et al*. 2018, Ma and Hipel 2016, Merli *et al*. 2018, Ncube *et al.* 2017, Pietzsch *et al*. 2017, Porta *et al.* 2009, Reyes-Torres *et al.* 2018, Sassanelli *et al.* 2019). Three main steps are involved in following the methodology namely Literature Search (described in Section 2.2.1), Literature Selection (described in Section 2.2.2), as well as Literature Review and Synthesis (described in Section 2.2.3).

2.2.1 Literature search

The research question guiding the study was key in informing Literature Search. This study purposes to answer the question: What is Harare's HSW management system? This paper reviewed articles from journals and data provided by the Harare City Council (HCC). The journal articles were accessed using the Google Scholar web search engine via the University of KwaZulu-Natal (UKZN) library database. No 'year of publishing' limitation was placed to screen articles during the search. The keywords used in the literature search are 'Household solid waste management, household solid waste management system, household solid waste management strategies, Harare, Zimbabwe'. These words were selected as the researcher understood that they were broad enough to allow for all relevant articles to be identified yet narrow enough to limit the number of articles that fall out of the research context from appearing during the search. One other excel document with SWM data was accessed from the HCC.

2.2.2 Literature selection

This part of the study included the identification of the inclusion criteria and the selection of the relevant articles based on these criteria. The inclusion criteria used stated that the articles should:

a) Entirely or partly focus on municipal solid waste management,
b) cover research is done in Harare city as a whole or certain areas within Harare, and
c) only or partly discuss solid waste management from the domestic waste stream.

Journal articles were first screened based on the relevance of their titles to the study. The second selection round was based on the abstract while the final round was based on the relevance of the entire article. Upon running the keywords into the search engine, 18 100 articles were retrieved. However, the study only used a sample size of the first 500 journal articles. It also investigated the Microsoft Excel municipal document on solid waste management.

In the first round of screening which was based on the relevance of the research article title, 461 of the 500 articles were disqualified. Of the 39 articles which qualified for abstract screening, 13 were disqualified (7 based on the non-relevance of the abstract content, 5 were not accessible and 1 was a duplicate). The remaining 26 articles were screened based on their content and all of them qualified for review and synthesis. The 27th document reviewed for this study was the municipal document.

2.2.3 Literature review and synthesis

Following the literature selection, 27 documents (Muswere and Rodic 2004, Mubaiwa 2006, Mbohwa and Zvigumbu 2007, Chikobvu and Makarati 2011, Chirisa 2012, Tsiko and Togarepi 2012, Mlanda Zvikaramba 2008, Makwara and Magudu 2013, Pawandiwa 2013, Tirivanhu and Feresu 2013, Zamba 2014, Mahamba 2015, Mandevere 2015, Chihanga 2015, Nemadire *et al*. 2017, Tanyanyiwa 2015, Kharlamova *et al*. 2016, Mafume *et al.* 2016, Nyatsanza and Kudzai 2016, Mandevere and Jerie 2018, Jerie 2018, HCC 2019, Makarichi *et al*. 2018, Nhubu *et al.* 2019f, Nhubu *et al.* 2019a, Nhubu *et al.* 2019b, Nhubu *et al*. 2019c) qualified for the full article in-depth review. Information around the HSW management system in Harare was then extracted and reviewed under the categories Waste Generation, Waste Collection and Transport, Waste Disposal, and Failed Strategies as presented in the review results.

2.3 Results

Harare still uses a predominantly traditional closed municipal solid waste management system i.e not much waste is diverted from the landfill. This approach in managing solid waste does not solve the complexity of the system but rather creates other problems (Nhubu *et al*. 2019d). However, there have been reports on the involvement of the HCC in the implementation of community-based integrated waste management systems in

Mbare, one of Harare's low-income suburbs (Mubaiwa 2006). No more information on the success of these projects was found. Results on Harare's HSW management system components are as described in the subsections that follow.

2.3.1 Case study area

Harare is the capital city of Zimbabwe. Although quite debated in the literature, the population in the city is approximated at 1.5 million (Muswere and Rodic 2004, Mubaiwa 2006, Nemadire *et al*. 2017, Mandevere and Jerie 2018, Madungwe and Sakuringwa 2007, Kamusoko *et al*. 2013, Nhubu and Muzenda 2019). Nhubu *et al*. (2017e) however, estimated the population at 2 123 132 as of 2012 having increased from about 1.5 million in 1992. In contrast, Tsiko and Togarepi (2012) estimated the population in the city as of 2012 to have already reached 3 million.

The total residential housing stock in Harare is about 181 199, 67% of which is housing in High Density (HD) suburbs (Kharlamova et al. 2016). The rate of population increase in the city, as a result of both urbanization and natural population increase, is about 6-8% (Tsiko and Togarepi 2012). This increase in population in Harare has contributed to an increase in waste volumes generated (Chikobvu and Makarati 2011, Tsiko and Togarepi 2012, Chirisa 2013, Mada and Kharlamova 2014). As implied by the Urban Councils Act [Chapter 29:15], the responsibility of the management of the city of Harare falls in the hands of the city's urban council/ municipality (Nhubu *et al*. 2019c, Mubaiwa 2006, Kharlamova *et al*. 2016, Mahamba 2015). Although Harare is failing to meet its solid waste management requirements, according to Section 83 of the Public Health Act Chapter 15.09 of 1996, all local authorities are mandated to ensure that their areas of jurisdiction are kept clean and sanitary thus preserving people's health (Mandevere and Jerie 2018).

2.3.2 Waste generation

The composition of MSW in Harare generally has high biodegradable and plastic content of about 42% and 33%, respectively (Nhubu *et al*. 2019e, Nhubu *et al*. 2019c) while the city's HSW is composed of over 50%-62% of biodegradable matter (Tirivanhu and Feresu, 2013, Nhubu *et al*. 2019a, Zamba 2014, Kharlamova *et al*. 2016). Generally, there has been an increase in the volume of HSW being produced in Harare (Makwara and Magudu 2013, Mandevere and Jerie 2018, Mubaiwa 2006). In 2013, daily waste generation per capita in the city was estimated to be about 0.36kg while the household generation rate at 2.1kg (HCC 2019, Kharlamova *et al*. 2016). In the same year, Pawandiwa (2013) suggested daily waste generation was 0.48 kg while in 2017 Nemadire et.al. (2017) stated it was 0.43kg. An estimated 371 697 000kg and 198 793 000kg of total MSW and HSW are produced annually in the city, respectively (Nhubu *et al.* 2019d, Kharlamova *et al*. 2016). On the other hand, Nhubu and Muzenda (2019) state that the annual MSW generation is 325 266 000kg while Zamba

(2014) estimated HSW volumes produced in the city at about 150 000 000kg. Others estimate HSW generation to be 233 000 000kg (Nemadire *et al*. 2017) and 279751000kg (Nhubu *et al*. 2019a). Variations in the annual HSW volumes reported in the literature and those recorded in the HCC records are illustrated in Fig. 2.1 below.

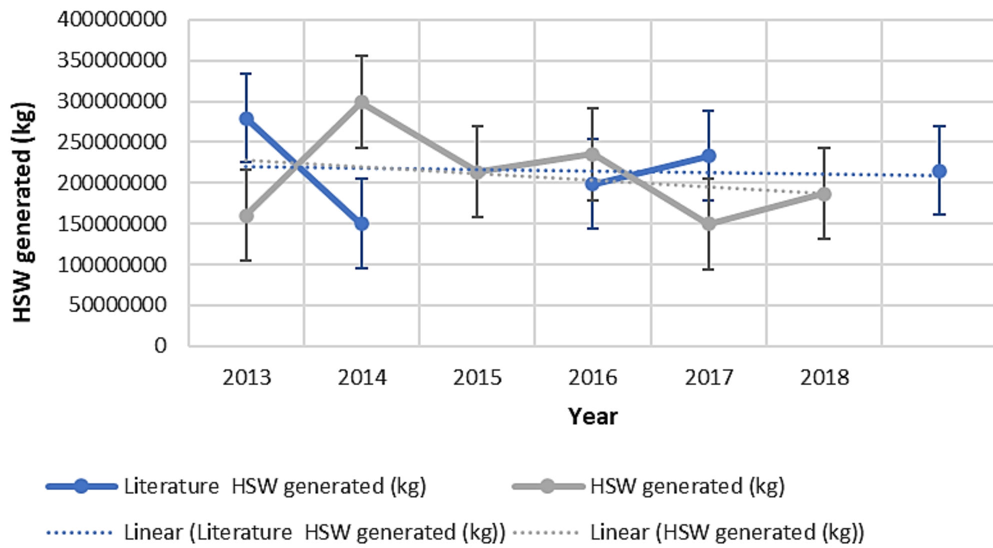

Figure 2.1 HSW generated annually: literature versus HCC records.

Although the trendlines observed in both the literature and HCC datasets are similar in slope and values, individual values reported for each data set annually are very different. The highest difference in the datasets of 125 048 119kg was observed for the year 2014 as shown in Fig. 2.1 above.

Fig. 2.2 below shows the HSW generated, MSW generated, and daily waste generation rate per capita data from the HCC records over the years 2014-2018. According to the records, daily waste generation rates per capita decreased over the years and so did the volumes of waste HSW generated. This is expected as the HCC reportedly calculates its HSW volume by multiplying the waste generation rate by the city's population of 1 485 231 as last calculated in the 2012 census. The MSW volume has however been increasing thus implying that the cause of waste volume increase in the city is not as a result of an increase in HSW but rather other waste streams. However, this observation is questionable as there is a vast literature that has reported an increase in population in the city over the years (Chikobvu and Makarati 2011, Tsiko and Togarepi 2012, Chirisa 2013, Mada and Kharlamova 2014, Mandevere 2015, Kharlamova *et al*. 2016, Mandevere and Jerie 2018). If these reports are true then HCC has been using the wrong population figures to estimate its HSW generation.

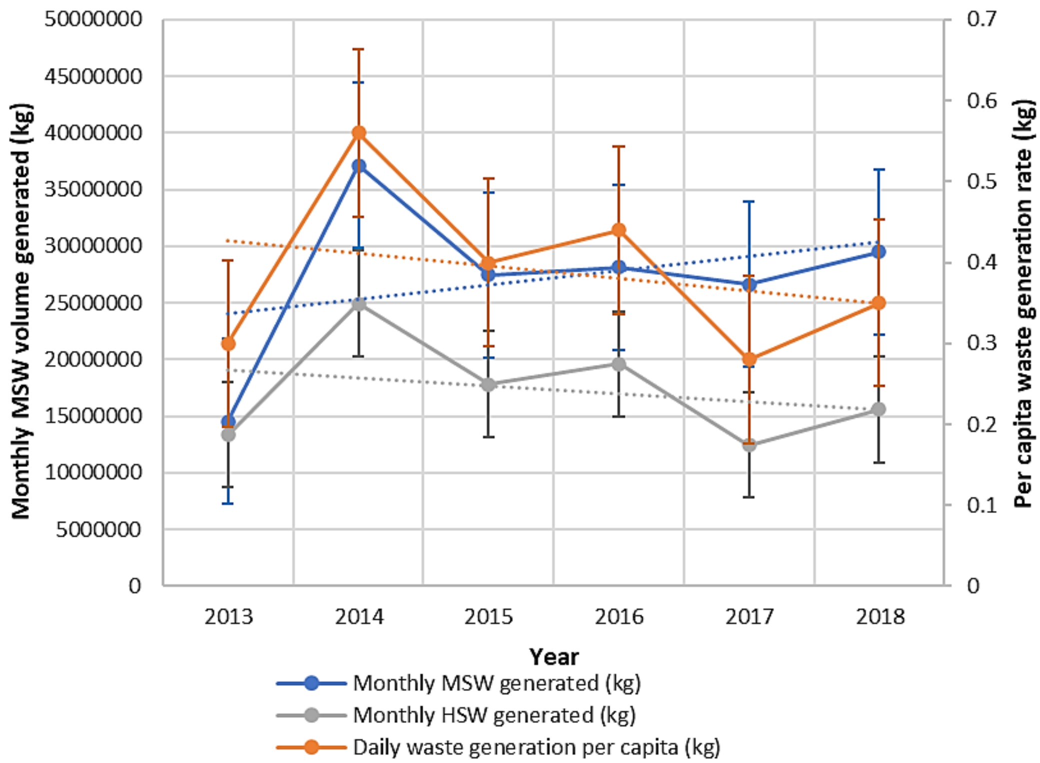

Figure 2.2 MSW generated, HSW generated, and waste generation rate in Harare (HCC 2019).

Fig. 2.2 above also shows the standard uncertainty of each of the values in the graph in the form of error bars. The exact uncertainty values are shown in Table 2.1 below.

Table 2.1 Waste management indicator values in Harare (HCC,2019).

Waste management indicator	Year 2013	2014	2015	2016	2017	2018	Average	Standard Uncertainty
MSW generated (kg)	174576000	445764000	329952000	337896000	319452000	354312000	326992000	87485219.2
HSW generated (kg)	160404948	299422570	213873264	235260590	149711285	187139106	207635294	56027040
Daily waste generation per capita (kg)	0.30	0.56	0.40	0.44	0.28	0.35	0.39	0.10
MSW collected (kg)	-	331692000	251268000	273516000	195456000	246528000	259692000	49359956.8
HSW collected (kg)	-	214008000	156636000	197328000	145596000	138360000	170385600	33384208.6
MSW collection efficiency (%)	-	74	76	81	61	70	72.4	7.5
HSW collection efficiency (%)	-	71.5	73.2	83.9	97.3	73.9	80.0	10.8
MSW recovery (kg)	-	17268000	23328000	24204000	24336000	28356000	23498400	3988817.0
MSW recovery (%)	-	5.2	9.3	8.8	12.5	11.5	9.5	2.8

Standard uncertainty (*u*) is the estimated standard deviation of each of the indicators. This value implies that there is a 68% level of confidence that all indicator values which will be recorded for the city fall within the range $y^{av} \pm u(y)$, where y^{av} is the average value of the indicator data set while y is the indicator. The large uncertainty values observed for MSW generated, HSW generated and waste generation rate shows that there is large variability between the indicator recorded values annually. It also suggests that it would be more difficult to accurately predict these values. Although the average HSW generated in Harare estimated in the literature of 215 383 500±54 784 714kg was higher than that recorded by the HCC of 207 635 294±56 027 040kg its standard uncertainty was lower thus signifying less variability in annual HSW generated values in the former.

2.3.3 Waste collection and transport

Waste collection and transport in Harare consume about 70% of the municipal budget (Nhubu *et al*. 2019c). There are two types of waste collection methods practiced in the city, namely the Kerbside collection and communal (block) collection. The most used one for residential areas is the former (Mandevere and Jerie 2018, Kharlamova *et al*. 2016). The Local Authorities by-laws, Rural District Councils Act [Chapter 29:13], and the Urban Councils Act [Chapter 29:15] stipulate that local authorities should offer door-to-door services in urban centers (Kharlamova *et al*. 2016). Since the HCC does not timely communicate on waste collection times soon as residents are aware that waste collection is taking place, they stand outside each with their (Tsiko and Togarepi 2012). This practice was developed by residences who, as they cannot afford receptacles, wait to collect them for reuse.

The waste collection workers serve on a task-and-finish arrangement. This entails having the workers knock off from work as soon as they complete their tasks of the day. Also, when vehicles are dispatched for waste collection, the drivers are not prescribed with collection routes to follow and so go about their duties haphazardly. (Mandevere and Jerie 2018). Moreso, the waste collection system in Harare does not cover unregistered residential areas as well as illegal settlements while low-income suburbs are more prone to the irregular provision of waste collection services (Chikobvu and Makarati 2011). There was a reduction in waste collection efficiency in Harare to 48.7% in 2016 from about 52% in 2011 (Makarichi *et al*. 2018, Nhubu *et al.* 2019b). Another report by Rinke *et al.* (2014) agrees and identifies that waste collection efficiency in the city has dropped from about 80% in the 90s to about 50%. Tsiko and Togarepi (2012) further supports these reports and states that the HCC is only able to collect about 54% of the total solid waste generated in Harare while Nhubu *et al.* (2019b) and Nhubu *et al*. (2017e) states that the waste collection efficiency in the city is about 60%. The MSW collected in Harare is mostly from the household waste stream. The volumes of waste collection as well as the efficiency with which it is collected however varies annually as shown in Fig. 2.3 below.

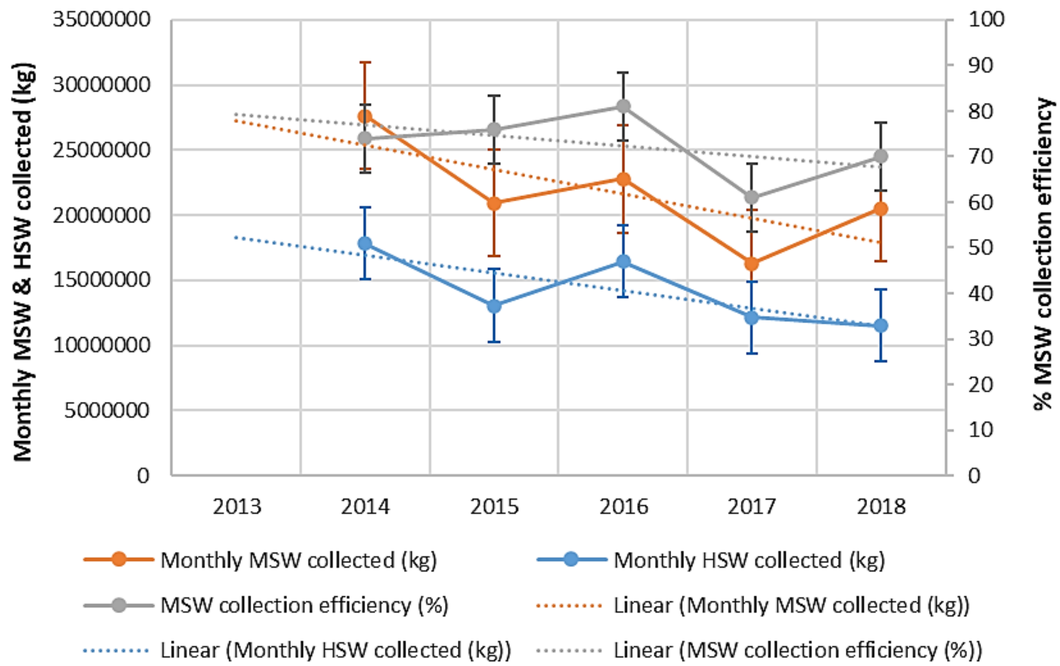

Figure 2.3 MSW collected, HSW collected, and MSW collection efficiency in Harare (HCC 2019).

All waste collection indicators are shown in Fig. 2.3 above decreases over the years. This is very concerning as this suggests that more waste is being left uncollected in the city. The large standard uncertainty, as also summarized in Table 2.1 above, for these indicators, especially for MSW and HSW collected signify a high variability in the records year after year thus making it more difficult to accurately predict future values.

The low waste collection efficiency can be partly explained by the HCC's waste collection policy that states that HSW in the city is collected once a week (Pawandiwa 2013, Tsiko and Togarepi 2012, Tanyanyiwa 2015). However, in some instances, the HCC reschedules waste collection frequency from once a week to once a month (Nyatsanza and Kudzai 2016, Mandevere and Jerie 2018). Other studies have also shown that some areas in Harare have gone 2-3 weeks, 2 months, or even up to 6 months without refuse collection (Tsiko and Togarepi 2012). However, various stakeholders which include the HCC, other paid private waste collectors, and individual residents are involved in waste management in the Low-Density (LD) suburbs while Medium-Density (MD) or High-Density (HD) suburbs are heavily dependent on the HCC (Mandevere and Jerie 2018, Chikobvu and Makarati 2011).

Low waste collection frequency in the city can also be explained by that the HCC does not have sufficient waste collection equipment and financial capacity to efficiently manage its waste (Mubaiwa 2006, Tanyanyiwa

2015). According to Mandevere and Jerie (2018) and Mahamba (2015), HCC possesses 47 vehicles out of the 60 required refuse vehicles to provide waste collection services to the city's 46 wards. However, Nemadire *et al*. (2017) state that the Council has 40 HCC-owned vehicles that transport waste to the Pomona waste dump each with a carrying capacity of about 10 tons while Tanyanyiwa (2015) identifies a waste collection fleet of less than 20. Waste collection vehicles operate from the Kelvin Depot where the Harare Waste Management Department is situated. The Central Workshops and the Central stores are responsible for repairing and purchasing vehicle material for the HCC, respectively. This, however, poses a challenge in that amid their day-to-day activities, HCC refuse vehicles are seldom given priority (Mandevere and Jerie 2018). In turn, this results in the use of the vehicles until they breakdown and hence are more costly to repair.

2.3.4 Waste disposal

Dumping is the most practiced form of waste disposal in Harare. There are no engineered landfills but two officially used waste dumps in the city, Pomona and Golden Quarry (Kharlamova *et al.* 2016). The latter is mainly used for the disposal of municipal solid waste. Since these are not properly engineered landfills, they lack leachate and gas control systems. Upon dumping waste into the dumpsite, front-loaders are used to spread and compact it. It is then either covered with soil, or not, and sometimes incinerated (Nemadire *et al.* 2017). Identification of suitable landfill sites in Harare has however been done but attempts to build the landfill that should have come into operation by 2018 have been hindered by a lack of funds and expertise (Pawandiwa 2013, Nhubu *et al.* 2019b, Kharlamova *et al.* 2016). The approximate daily disposal rate at the Pomona dumpsite falls between 270 000kg and 500 000kg or about 10 000 000kg per month (Nemadire *et al*. 2017, Mandevere 2015). Pomona, which covers an approximate area of 1 000 000 m^2, is expected to reach the end of its service life by 2020 (Nhubu and Muzenda, 2019). About 90% of the waste collected by the HCC ends up in the dumpsite (Mandevere 2015).

Although it is estimated that about 90% of MSW produced in Harare is either recyclable or reusable, 10%-13.6% is recycled, composted, reused, etc. (Makarichi *et al*. 2018, Nhubu *et al.* 2019b, Kharlamova *et al*. 2016, Nhubu *et al.* 2019d, Mandevere 2015). Approximately 49% of the MSW is plastic and paper (Mahamba 2015). Around 4.1% of MSW is haphazardly disposed of in the environment and 37.6% is burned or buried at the source (Makarichi *et al*. 2018, Nhubu *et al.* 2019b). This information tallies with reports made by Nhubu *et al*. (2019a) that about 40% of solid waste in Harare is illegally dumped. Of the waste recycled in the city, waste pickers at Pomona dumpsite are responsible for recovering 6-10% of solid waste, 29% of which is plastics (Nemadire *et al.* 2017). Fig. 2.4 below shows waste recovery data from the HCC records. It is commendable that there has been a steady increase in recovery over the years.

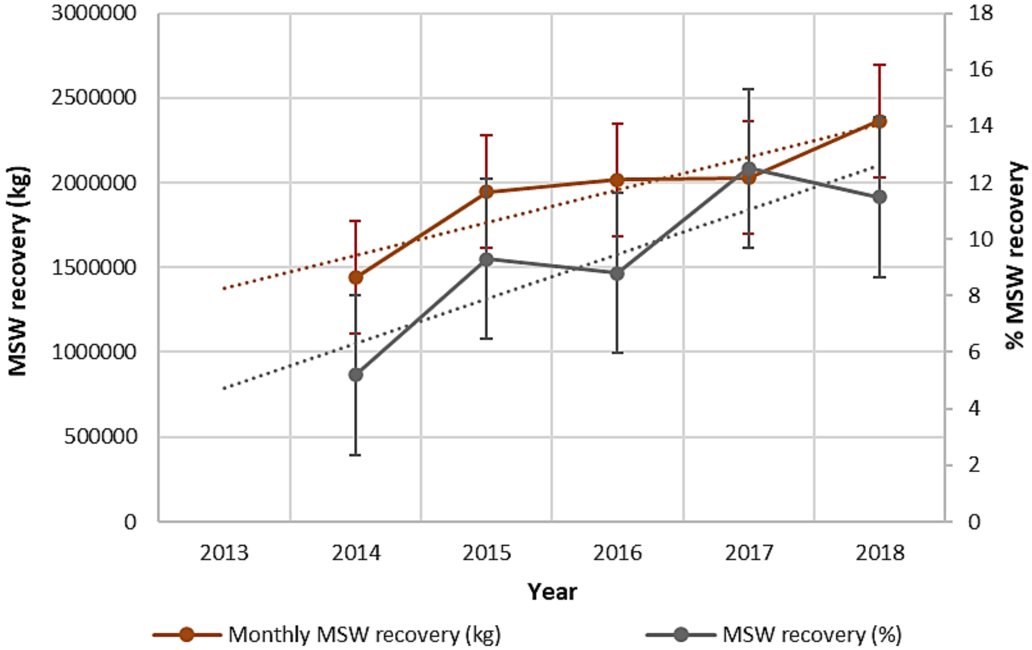

Figure 2.4 MSW recovery in Harare (HCC, 2019).

Most waste is collected for recycling is done informally by unemployed people, HCC waste collection crew members en-route, and waste scavengers at Pomona dumpsite (Nemadire *et al*. 2017; Mandevere and Jerie 2018). In 2018, Mandevere and Jerie (2018) reported that the HCC had issued individuals with 300 recycling licenses while about 150 waste scavengers are operating at Pomona dumpsite. Nemadire *et al*. (2017) and Mahamba (2015) on the other hand estimates that about 200 waste pickers work at Pomona and the latter proposes the integration of informal recycling into the city's solid waste management system.

2.3.5 Harare's unsuccessful strategies

In response to solid waste mismanagement in Harare, the HCC has unsuccessfully attempted to employ several strategies that could have potentially improved waste management. Harare is however not the only city that has faced challenges in successfully and profitably implementing some strategies. Lohri *et al.* (2014) reported a case of Bahir City in Ethiopia where the local authorities outsourced a private company to manage municipal waste but faced financial difficulties after 2 years of operation. This highlights the need for performing cost-revenue and feasibility analysis on proposed operations beforehand to ensure sustainability.

Between the years 1996-1998, it is reported that the HCC hired private waste collectors on a contract-based system to collect waste in some parts of the city. However, poor waste collection efficiency resulted in the termination of the contract and the council resuming operations. The inefficiencies, however, were said to be caused by cash flow problems within the council which resulted in delayed service delivery (Chikobvu and Makarati 2011, Muswere and Rodic 2004, Mandevere and Jerie 2018). In 2006, a waste management strategy themed 'A clean environment is everybody's responsibility' was developed. Although the revival of this strategy was attempted again in 2008, due to economic challenges, not much was achieved through this strategy (Mandevere and Jerie 2018, Chikobvu and Makarati 2011). Moreso, in preparation for the development of the national Integrated Solid Waste Management (ISWM) plan, a baseline study was successful conducted in 2011. Although the ISWM plan detailing waste minimization and recovery strategies to be used over the 5 years of 2014-2018, no records on the successful implementation of this plan were found (Mandevere and Jerie 2018, Nhubu *et al*. 2019b).

2.4 Discussion

The research gaps identified in Harare's HSW management system seem to be mainly around waste management planning. This is expected as the city does not have a waste planning and monitoring unit. The absence of a proper Waste Planning or Monitoring Unit is a possible hindrance to strategic and efficient solid waste management planning. Proper management of solid waste in the city would be encouraged by the informed development and implementation of an effective ISWM plan that closely follows the Waste Management Hierarchy (WMH) observing the 3Rs (Reduce, Reuse, and Recycle) or in the case of economically challenged countries like Zimbabwe, the 3Ss (**S**anitation, **S**ubsistence economy, and **S**ustainable landfilling) of sustainability (Mandevere and Jerie 2018, Lavagnolo and Grossule 2018). However, presently, the country's HSW management strategies do not seem to be prioritizing sanitation and creating a subsistence economy.

2.4.1 Waste generation

There are no HSW generation control measures set in Harare. The refuse collection rate in the city is charged to residents at a flat rate irrespective of the volumes of waste they produce (Chikobvu and Makarati 2011). Despite this, due to financial constraints, residents sometimes even fail to pay these fees (Mandevere, 2015, Mandevere and Jerie 2018). This payment system does not encourage residents to responsibly generate waste. It would be beneficial if awareness is raised among residents and the HCC considers a charge-by-weight system where the refuse collection fees charged per household are calculated from the volume of waste they produce.

Moreso, there is no separation at source systems operational in the city's residential areas. The HCC should provide residents with plastic receptacles which they use to store their waste in-between collection dates. Some researchers identified that due to financial reasons the authorities provide only one plastic receptacle per week (Mandevere and Jerie 2018). This allocation does not allow for waste separation and neither is it adequate for bigger families. In some areas, residents are not provided with receptacles.

Also, inconsistent waste generation data might hinder accurate planning in Harare. For example, reported waste generation values recovered from literature are like those given in the HCC data records in that they differ from year to year, however, the values reported are alarmingly different. According to the HCC records, although generally having been decreasing since the year 2016, waste generation rates in Harare are irregular as shown in Fig. 2.1 above. From 2013 to 2018, the lowest daily waste generation rate of 0.28kg.capita^{-1} was recorded in 2017. This value is contrary to the 0.43kg.capita^{-1} reported by Nemadire *et al.* (2017). The 0.481kg.capita^{-1} value reported by Pawandiwa (2013) is also different from the 0.3kg.capita^{-1} recorded in the HCC data records for the year 2013.

The higher the waste generation rate the higher the volumes of waste expected to be generated in that year as shown in Fig. 2.1 above. The increase in population, consumption patterns, and waste generation rates in the city are contributors to the increase in waste volumes (Chikobvu and Makarati 2011, Zamba 2014, Kharlamova *et al.* 2016, Nyatsanza and Kudzai 2016, Nhubu *et al*. 2017e, Nhubu *et al*. 2019a). However, despite the consistency in waste generation and waste volume data patterns, waste data records in Harare are generally unreliable (Nhubu and Muzenda 2019).

To address this issue, the HCC can work on establishing a more accurate data collection system or use simulation techniques to generate data that can be used reliably for decision making. This is important because accurate data availability or prediction of waste composition and generation is key in ensuring the efficient planning and designing of municipal solid waste management systems (Dyson and Chang 2005, Li *et al*. 2011, Fu *et al*. 2015, Intharathirat *et al*. 2015, Thanh *et al*. 2010, Moghadam *et al.* 2009, Nhubu *et al.* 2019a, Nhubu and Muzenda 2019). This data is used to effectively develop, for example, waste collection routes, decide on waste collection systems, select bin placements within the city, or forecast other facility needs depending on the generated waste volumes, waste accessibility, etc. (Chowdhury 2009).

2.4.2 Waste collection and transport

The Kerbside waste collection method mainly used in Harare is very effective as it receives full cooperation from the residents, especially in MD and HD suburbs. It limits stray-dog-spilled refuse that occurs when waste is left unattended. On the other hand, although the task-and-finish approach that governs how the waste collectors work promotes a target-based work ethic among personnel, they sometimes end up rushing through their work to embark on other personal endeavors (Mandevere and Jerie 2018). Moreso, upon deployment for waste collection, drivers are not given any specific routes to follow for the day but rather areas to cover. This approach is ineffective in that sometimes there is the duplication of trips or streets and so some areas are not served. This issue can potentially be solved by using computer models that can identify and suggest the most cost-effective waste collection routes drivers can take while also ensuring that the intended areas of the collection are fully covered.

Generally, the HCC has failed to provide efficient waste collection services to its residents (Chikobvu and Makarati 2011, Jerie 2018, Mafume *et al*. 2016, Makarichi *et al.* 2018, Mandevere and Jerie 2018, Mandevere 2015, Mlanda Zvikaramba 2008, Rinke *et al*. 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012). The increase in waste volumes being produced in the city has created problems for the local authorities as their capacity is not being improved to parallel the solid waste volume changes (Mangundu *et al.* 2013). Additionally, as the formal waste collection system in the city does not provide waste collection services to unregistered properties, illegal settlements, and partially to low-income suburbs (which carry the highest population in the city and produce the highest waste volumes) large volumes of waste remain uncollected in these residential areas (Mubaiwa 2006, Nhubu *et al*. 2019a, Pawandiwa 2013).

The higher the waste collection efficiency is, the higher the volumes of solid waste collected by the HCC. It is however interesting to note that although the MSW collection efficiency recorded for the year 2015 was 1.8% higher than the 74.4% recorded in 2014, the MSW collected by the HCC in the year 2015 was approximately 24% lower than that in 2014 as shown in Fig. 2.3 above. This is also despite that the 2015 MSW generated was 9 674 000kg lower than that recorded in 2014 as shown in Fig. 2.2 above. There might have been an error in recording data. However, the decrease in waste generated can be partly explained by the fact that there was a drop in the daily waste generation rate from 0.56kg.capita^{-1} in 2014 to 0.40kg.capita^{-1} in 2015 as shown in Fig. 2.1 above. This decrease in waste volume ideally should have seen a larger increase in waste collection efficiency by the HCC as they would have, in this case, a potentially improved capacity to handle the waste. However, if the data recorded is accurate then there might have been other factors that not only affected the city's waste generation rate but the HCC's collection efficiency.

According to Fig. 2.3 above, there was a general decrease in the volume of HSW being collected by the HCC between 2016 and 2018. Although this trend was complemented by a decrease in volumes of HSW generated during the same period, there is a wider gap between the HSW generated (shown in Fig. 2.1 above) and HSW collected graphs (shown in Fig. 2.3 above) signifying that larger monthly volumes of HSW of up to about 7 692 000kg and 5 036 000kg were being left uncollected in Harare's residential areas in the years 2017 and 2018, respectively. This contrasts with the up to 4 077 000kg estimated uncollected waste in the city's residential areas between the years 2015 and 2016. It is however refreshing to note that the increase in MSW generated in 2018 (shown in Fig. 2.1 above) also saw a 13.7% increase in waste collection efficiency (shown in Fig. 2.3 above) as well as a 26% increase in the volume of municipal solid waste collected by the HCC.

Overall, there is a need to develop an efficient and accurate waste collection data system around waste collection and transport in Harare. This will aid the relevant personnel to make more accurate and informed decisions. Considering the limited capacity of the HCC to provide waste collection services, an immediate yet long-term strategy can be that of enforcing mandatory household-level compost pitting which will eliminate the majority of wet waste and hence reduce the total volume of waste to be collected (Nhubu *et al*. 2019d). However, due to the smaller size of stands in HD suburbs, few residents opt to conduct meaningful composting in their backyards. Moreso, most lack knowledge of the nature of the right waste to be composted to achieve proper compost. In contrast, gardeners in LD suburbs usually know about developing proper compost (Mandevere and Jerie 2018). Communal composting can be considered where household-level compost pitting is not feasible.

2.4.3 Waste disposal

In developing countries, limited technical and financial experience and resources limit the ability of relevant authorities to safely dispose of waste (Moghadam *et al*. 2009). The HSW management system in Harare mainly practices waste disposal and not much diversion. Not only is recycling minimally practiced but it is not yet officially incorporated in the city's formal waste management strategy (Nemadire *et al.* 2017). Moreso, despite the limited capacity of the municipality to manage all waste generated, residents are not significantly involved in sustainable waste disposal but rather pay fees for services they expect the local government to deliver (Mlanda Zvikaramba 2008). Incorporating the participation of residents into the formal waste management system in the city can help relieve the pressure on the HCC (Nhubu *et al.* 2019d).

All collected municipal solid waste is dumped in the city's official dumpsite, Pomona, irrespective of the nature, origin, and potential impact on the environment (Chirisa 2013, Chihanga 2015, Nyatsanza and Kudzai 2016, Nemadire *et al.* 2017, Mandevere and Jerie 2018). However, the composition of solid waste depends on the waste stream. As a result, waste management strategies need to be specific to the waste stream to ensure optimal efficiency (Tirivanhu and Feresu 2013). The development of ISWM plans that address the management of solid waste depending on their source might be more ideal for the municipality. For example, waste produced in High-Income (HI) suburbs has a higher composition of paper and plastics while that of Low-Income (LI) suburbs has a higher composition of biodegradable material and garden waste. This dynamic suggests the need to consider different income-generating, waste treatment, and disposal strategies depending on the socio-economic class under which a residential area falls as well (Tirivanhu and Feresu 2013).

There are several economic, social, political, institutional, or technical issues around inefficiencies in the HSW management system. Ideally, an ISWM plan is an optimum solution that considers and balances out the different aspects of waste management. However, without the application of computer modelling techniques, it is rather cumbersome and inefficient to holistically consider the entire waste management system and its interconnectivity during planning.

2.5 Conclusions

Although the country's waste laws mandate that all urban councils ensure that their areas of jurisdiction are kept clean and sanitary, the HCC has failed to meet the waste management requirements that its city demands. Various solid waste management strategies have been attempted in vain. The city's waste management system is mainly made up of the components waste generation, waste collection, waste transport, and waste disposal. Daily waste generation per capita is on average 0.38±0.1kg with a total of about 326 992 000±87 485 219kg and 207 635 294±56 027 040kg of MSW and HSW generated annually, respectively. Waste collection and transport consumes about 70% of the city's municipal budget. The HCC data records estimate that on average, the waste collection efficiency in Harare is 72.4±7.5% although various literature estimates it to be around 50%. The estimated volumes of MSW and HSW collected in the city are 259 692 000±49 359 957kg and 170 385 600±33 384 209kg, respectively. All the collected HSW is disposed of in the city's major MSW dumpsite called Pomona. About 23 498 400±3 988 817kg MSW is recovered annually with the average recovery efficiency at around 9.5±2.8%. Most of the recovery is done at the dumpsite by the waste pickers.

2.6 Future Recommendations

Future studies should consider using SD modelling to simulate the dynamics of Harare's HSW management system and understand the key driving forces of the system. Gaining this knowledge will inform the relevant authorities on setting priorities and how to effectively generate and implement strategies for better waste management. The SD is a methodology based on systems thinking that has been used worldwide for decision making, waste management simulations, and policy design (Sudhir *et al*. 1997, Rong 2004, Dyson and Chang

2005, Sufian and Bala 2007, Chi 2012, Escalante 2012, Wager and Hilty 2012, Lin 2012, Inghels and Dullaert 2011, Popli *et al*. 2017). The methodology is used to study or manage systems with complex feedbacks (Dyson and Chang 2005, Ahmad and Simonovic 2000, Minegishi and Thiel 2000, Homer and Hirsch 2006). Table 2.2 below also shows a summary of the results of this mini-review and the recommendations for each stage of the HSW management system component.

Table 2.2 Recommendations for Harare's HSW management system

HSW System Component	Results Summary	Recommendations	Benefits of recommendations
Waste Generation	• Increase in HSW volumes in Harare over the years • HSW makes up the greatest composition of MSW of ~55-80% • Average daily waste generation rate per capita ~ 0.35kg • 325 000 000- 400 000 000kg of MSW produced annually • 150 000 000- 200 000 000kg of HSW produced annually • Population estimated at 1.5-3 million as of 2012 • 6-8% population growth annually (including urbanization and natural increase • An increase in population causes an increase in waste volumes • Responsibility for waste management falls solely on the Harare municipality • The difference in socio-economic classes determine the volume and composition of waste generated • MSW biodegradable waste composition is ~ 42%; HSW biodegradable waste is ~ >50% • Data available on waste generation is inconsistent	- Develop HSW specific strategies since it's produced in higher quantities e.g. reduce the volumes of HSW produced by implementing waste minimization strategies like establishment and enforcement of strict environmental regulations, the introduction of weight-based billing (Dahlen and Lagerkvist 2010, Reichenbach 2008). -Share the responsibility of managing waste with the community by e.g. establishment of strict environmental regulations around illegal waste disposal, enforce the mandatory building of compost pits at all households for all wet and biodegradable waste disposal. -Since there is a difference in the composition of waste generated in suburbs of different socio-economic classes, different waste management strategies can be developed for High-Density, Medium-Density, and Low-Density areas in Harare.	- Potential reduction of waste generation rate and volumes, offers protection of workers, communities, and the environment, pollution control costs are minimized, the establishment of sustainable waste generation, conservation of resources, landfill space savings, etc. (Ramachandra 2006). -Protection of the workers, environment, and communities, reduction of waste volumes available for collection by the municipality, encourages the generation of bio-fertilizers at the household level for garden use, reduction of waste collection costs. -Ensures the implementation of custom-made and efficient waste management strategies.
Waste Collection and Transport	• Waste collection and transport consumes about 70% of the municipal budget • Kerbside collection is a commonly used waste collection method for residential areas • Waste collection workers serve on a task-and-finish arrangement • 7 waste collection supervisors serve Harare city, no vehicles provided • The waste collection system does not serve unregistered areas • Waste collection efficiency in the city is about 50% • Low-Income suburbs are more prone to receiving low waste collection services • Municipal HSW collection policy states that waste in residential areas is to be collected weekly. • Some areas go for 2 weeks, 2 months, or even 6 months without receiving waste collection services • There is a waste collection timetable but some HD areas are omitted • Data available on waste collection is inconsistent and inaccurate • 40-47 municipality owned waste collection vehicles each with a carrying capacity of about 10 tons • ~30 privately owned waste collection vehicles • Breakdown of vehicles common	-Introduce mandatory compost-pitting at the household level in Harare. Alternatively, organic waste buy-back/drop-off centers can be made mandatory for those without compost pits (Hettiarachchi *et al*. 2018, Gallardo *et al*. 2012). This will potentially remove all biodegradable and wet waste which constitutes >50% of HSW. As a result, there will be approximately 50% less HSW to be collected by the municipality. The high organic content of the waste and cheap labor is an advantage for developing countries (Hettiarachchi *et al*. 2018). Recyclable waste drop-off centers within communities can also reduce waste to be collected (Gallardo *et al*. 2012). -Develop strategies that encourage community participation in managing HSW especially in LD areas that receive minimal waste collection e.g establish waste buy-back/ refund centers within communities to encourage separation of waste at source (Manomaivibool and Vassanadumrongdee 2012, Meng *et al.* 2019). -Establish waste transfer stations across the city's residential areas (Nhubu *et al*. 2019c, Chatzouridis and Komilis 2012, Yadav *et al.* 2016, Kirca and Erkip 1988). -Strategically position waste collection bins. Use modelling techniques to identify waste collection bin positions and their capacities (Ghiani *et al.* 2012, Yadav *et al*. 2016). A negative relationship exists in the distance between the residence and the waste disposal/collection center (Wang *et al*. 2018). -Use optimization models to assess the economic, environmental, and social feasibility of proposed strategies (Juul *et al.* 2013).	-Encourages decentralization in the management of waste (Nhubu *et al.* 2019d). - Reduces the amount of waste to be collected by the municipality, reduces waste collection costs, and potentially increases waste collection efficiency. -it creates a shared burden of waste management between the municipality and the city residents. -encourages waste -Reduces the distance that at-source waste collection vehicles travel to collect and dispose of waste (Nhubu *et al.* 2019c, Chatzouridis and Komilis 2012). -Offers low-cost transportation of waste to distant waste disposal sites (Nhubu *et al*. 2019c). -Minimizes waste collection costs (Ghiani *et al*. 2012). -Optimal allocation of waste collection sites around Harare's residential areas (Ghiani *et al.* 2012). -Allows for the frequent collection of waste (Nhubu *et al*. 2019c). -Saves time and money while improving the probability of the successful implementation of strategies. Future waste management system costs and performance can be analyzed (Juul *et al.* 2013).
Waste Disposal	• Daily waste disposal rate ~270 000-500 000kg and about 10 000 000kg per month • Only about 13% of waste is recycled • About 29% of recycled waste is plastic • About 40% of waste generated is disposed of unsustainably (eg in the environment, burned, etc) • Landfilling is the biggest waste disposal method used in Harare • Pomona dumpsite is the main disposal site for HSW • No engineered landfills are serving Harare • Most waste diversion is done informally • No weighbridge at the dumpsite	-Secure a weighbridge at the dumpsite for accurate measurement of waste entering the dumpsite. -Create accurate data collection systems at the dumpsite. -Instead of developing a new engineered landfill (which Harare has struggled to do due to financial constraints and lack of technical resources), Harare city can consider making incremental improvements to the existing dumpsite in landfill design and operations (Joseph 2012). -Reduce the impacts of Pomona dumpsite by e.g harvest landfill gas emissions from Pomona, develop entry control systems around the dumpsite. -Design and ensure implementation of an Integrated Municipal Solid Waste Management System. -Establishment of waste to energy recovery systems (Mbohwa and Zvigumbu 2007; Makarichi *et al*. 2018, Nhubu and Muzenda 2019, Nhubu *et al.* 2019f, Nhubu *et al.* 2019d). Although this strategy was suggested in the 2014-2018 NIWMP, data to support strategy implementation is unavailable (Makarichi *et al.* 2018).	-Reliable data for planning purposes can be generated. -Reduction in greenhouse gas emissions -Landfill space is saved -Landfill life extended -More resources recovered - Increased renewable biofuel and electricity generation (Makarichi *et al.* 2018, Nhubu *et al.* 2019f). -Potential reduction of waste to about one-tenth if combustible solid waste is incinerated (Mbohwa and Zvigumbu 2007).

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3. A REVIEW ON THE CAUSES OF POOR HOUSEHOLD SOLID WASTE MANAGEMENT IN LOW-INCOME DEVELOPING COUNTRIES: A CASE STUDY OF URBAN HARARE CITY, ZIMBABWE

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Abstract

Of the different types of municipal solid waste (MSW) produced in Harare, household solid waste (HSW) is produced in the highest volumes. This type of waste is poorly managed driven by various factors. This literature study was formulated to inform future studies towards designing more informed solutions to HSW management in the city. The review aims to uncover the causes of poor HSW management in the city. The results show that the most reported causes of poor HSW management in Harare are increased population and population density, poor formal solid waste disposal, increase in waste volumes, open waste burning, low waste collection frequency, municipal incapacitation, low municipal waste collection efficiency, among others. Future studies can utilize these results to estimate the complexity of this phenomenon and thus propose appropriate solutions for the city's HSW management system.

Keywords: municipal solid waste, household solid waste, management, waste management system, Harare, Zimbabwe

3.1 Introduction

Municipal Solid Waste (MSW) refers to all solid waste generated within the bounds of a municipality (Periathamby 2011). Although definitions differ, MSW does not include industrial and fecal waste but rather residential, commercial, institutional non-hazardous waste, street sweepings, and demolition waste (Artiola 2019, Jayawardhana *et al*. 2016, Millati *et al*. 2019, Niazi *et al*. 2016, Periathamby 2011). Worldwide, the amount of MSW generated is growing at a rate that is faster than urbanization (Hoornweg and Bhada-Tata

2012, Jayawardhana *et al*. 2016, Ma and Hipel 2016). The earth's carrying capacity for waste has even been exceeded by 30% (Periathamby 2011). Moreso, particularly in developing countries, MSW is a major environmental problem (Khan *et al*. 2016, Pepe 2008, Salah and El-Haggar 2007).

Management of MSW is an operation that includes various aspects such as waste generation, recycling, collection, pre-treatment, treatment, and disposal (Periathamby 2011). The role of waste management authorities is thus to handle waste in an economic, environmental, and socially optimal manner (Hoornweg and Bhada-Tata 2012). There is a need for the cooperation of all stakeholders involved in solid waste management (SWM) to ensure the efficient provision of services. Management of MSW is a complex system driven by several important and interdependent components that include economic, technical, political, legal, governmental, environmental, and administrative aspects (Ma and Hipel 2016, Periathamby 2011, Salah and El-Haggar 2007). However, MSW management services are not generic but rather site-specific (Kalantarifard and Yang 2011, Periathamby 2011, Salah and El-Haggar 2007).

As for Harare city in Zimbabwe, waste management records dating back to the 1950s when about 280 000 people occupied the city. Although waste management services offered then were adequate, various waste management issues have since plagued the city (Mandevere and Jerie 2018). Multiple sources in literature have cited poor HSW management in the city (Chikobvu and Makarati 2011, Makarichi *et al*. 2019, Mandevere and Jerie 2018, Nhubu *et al*. 2017e, Nyatsanza and Ndebele 2016). This has contributed to the common occurrence of waste-related diseases and pollution (Nhubu *et al*. 2017e, Nyatsanza and Ndebele 2016). Poor HSW management has a local impact and an international one as it contributes to greenhouse gas (GHG) emissions (Hoornweg and Bhada-Tata 2012, Khan *et al.* 2016).

One of the primary inputs required for efficient waste management planning is identifying the influencing factors (Khan *et al*. 2016, Lebersorger and Beigl 2011). This helps estimate changes in future waste management conditions and develop efficient system approaches that meet the objectives of the area in question (Mazzanti and Zoboli 2008, Thomas *et al.* 1990). Influential decision-makers focus more attention on making few decisions but are of greater importance. Although there are more intense ways to identify key decision areas, an example of a simple decision-making tool used in management sciences is the '80/20 rule' called the Pareto principle (Craft and Leake 2002). According to Juran (1954), the Pareto principle is universally applicable in planning and monitoring. The principle is applied in problems with cause-and-effect relationships like waste management. It focuses on identifying the factors contributing to a phenomenon, arranging them in the order of their importance, and emphasizing the analysis of the top 20% to effect change (Basile 1996). To yield the greatest value to an organization and make the most of the available resources, it is thus important to prioritize issues in decision-making (Craft and Leake 2002).

A review article by Kwenda *et al*. (2021a) discussed the HSW management system in Harare. As an extension of this review, this study aimed to identify and understand the factors contributing to poor HSW management in the city. The results will potentially feed into future studies towards identifying key decision areas and developing efficient management strategies. The research question driving the review is thus 'What are the causes of poor HSW management in Harare?'.

3.2 Methodology

Any research project needs to conduct a literature review (Biolchini *et al.* 2005, Tranfield *et al*. 2003). This allows the researcher to navigate and understand the intellectual field and so help to appropriately add to the scientific pool of knowledge (Tranfield *et al.* 2003). It also prevents resources from being channeled into studies that are not necessary for decision-makers (Woodruff and Sutton 2014). More so, lack of adequate data and rightly processed data can offer inaccurate guidance and insights to policymakers and key decision-makers (Tranfield *et al.* 2003, Woodruff and Sutton 2014).

The systematic methodology of formulating reviews was developed in the clinical sciences over two decades ago and has been most widely used in the medical field but also in other fields like management, education, nutrition (Bearman *et al*. 2012, EFSA 2010, Fortin *et al*. 2012, Lichtenstein *et al.* 2008, McGrath *et al.* 2004, Smith *et al.* 2011, Tranfield *et al.* 2003, VanGeest *et al*. 2007, Woodruff and Sutton 2014). A systematic review is defined as a synthesis of evidence gathered using a specific methodology to answer a given research question (Bearman *et al.* 2012, Biolchini *et al.* 2005, EFSA 2010, Khan *et al.* 2003). This methodology is ideal because it eliminates bias in selecting articles the author reviews. It is transparent, structured, comprehensive, efficient, and reproducible (Bearman *et al*. 2012, EFSA 2010, Khan *et al*. 2003, Smith *et al*. 2011, Woodruff and Sutton 2014). The systematic methodology was used to analyze literature around HSW management issues and consequences in Harare, Zimbabwe, as described in Sections 3.2.1 and 3.2.2.

3.2.1 Sources and searching

Although systematic reviews take between 6-18 months, a realistic timeframe can be selected depending on several factors such as funding, the research question, availability of resources, scope, and time availability (EFSA 2010, Smith *et al*. 2011). For this study, the review was developed within a 3-month timeframe. Although being as specific as possible in the keywords entered into the search engine can ensure that particular material is quickly identified, it is recommended that the search words be clear yet broad enough to avoid missing relevant information (Smith *et al*. 2011). The search words 'Household solid waste management issues, Harare, Zimbabwe' were used for this study. Google Scholar through the University of Kwazulu Natal (UKZN) Library was the search engine used to search through literature. It is recommended that literature searches cover a few decades (Smith *et al.* 2011). As a result, no year of publication restriction was placed during the search.

3.2.2 Review selection and synthesis

Articles were excluded if waste management issues were generalized for the whole nation of Zimbabwe. The article inclusion criteria used was that the article should:

a) only or partly focus on solid waste management,
b) cover research is done in Harare city,
c) address the HSW management issues affecting Harare, and
d) only or partially address solid waste management from the domestic waste stream.

Journal articles were first selected based on the relevance of their titles, abstracts and then on the entire article. Of the 18 500 articles recovered in the search, only a sample size of 500 journal articles was selected. The study also investigated a Microsoft Excel municipal document on solid waste management and residential properties provided by the HCC. In total, 373 out of the 500 journal articles reviewed were disqualified based on their title. Moreso, ten articles were not accessible, although they seemed relevant to the study based on their titles. Also, 94 articles were disqualified based on their abstracts. The remaining 23 articles were found relevant for this study after going through the full articles. NVIVO, a computer-aided-qualitative-data-analysis software, was used to analyze the 23 articles relevant to the research question that guided this study. In NVIVO, waste management issues were used as the codes under which relevant portions of literature were collected from the 23 articles. For example, some of the codes used in this study are 'increase in population and population density', 'increase in waste volume', 'municipal incapacitation' etc. The results and discussions described in Section 3 were developed upon harvesting and synthesizing all the relevant information. Supporting literature was also added.

3.3 Results and Discussions

The results of a word frequency query ran for the 23 core articles reviewed in this study using NVIVO are presented in Fig. 3.1 below. These are the 50 most frequent exact words which appeared in the reviewed articles. The frequency with which each word appeared in the articles is relative to the size of the word, as it appears in Fig. 3.1 below.

Figure 3.1 Word frequency query on core reviewed articles.

The results confirm that the reviewed articles reported issues mainly around HSW management in Harare, Zimbabwe. They also show that much information was reported on the environment, dumpsites, landfills, population, community, data, recycling, waste generation, collection, and disposal. The HSW management issues identified in Harare from the reviewed literature are summarized in Table 3.1 below and discussed further in the following sections.

Table 3.1 HSW management issues in Harare, Zimbabwe.

No.	HSW management issue	References	No. of references
1	Increase in population and population density	(Chikobvu and Makarati 2011, Chirisa 2013, Kambuzuma 2010, Kharlamova *et al*. 2016, Mada and Kharlamova 2014, Magwenzi 2013, Mandevere and Jerie 2018, Mandevere 2015, Milanzi 2014, Nemadire *et al*. 2017, Nhubu and Muzenda 2019, Nhubu *et al.* 2017e, Nhubu *et al.* 2019a, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Rinke *et al.* 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	19
2	Poor formal solid waste disposal	(Chihanga 2015, Chikobvu and Makarati 2011, Chisvo 2016, Kharlamova *et al*. 2016, Makarichi *et al.* 2019, Mandevere and Jerie 2018, Mandevere 2015, Nemadire *et al.* 2017, Nhubu and Muzenda 2019, Nhubu *et al.* 2017e, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Rinke *et al.* 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	16
3	Increase in waste volumes	(Chikobvu and Makarati 2011, Chirisa 2013, Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Makarichi *et al.* 2019, Mandevere 2015, Nemadire *et al.* 2017, Nhubu and Muzenda 2019, Nhubu *et al.* 2017e, Nhubu *et al.* 2019b, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Rinke *et al.* 2014, Tsiko and Togarepi 2012, Zamba 2014)	15
4	Open waste burning	(Chikobvu and Makarati 2011, Kambuzuma 2010, Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Magwenzi 2013, Makarichi *et al.* 2019, Mandevere and Jerie 2018, Mandevere 2015, Nemadire *et al*. 2017, Rinke *et al.* 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	13
5	Low waste collection frequency	(Chikobvu and Makarati 2011, Chirisa 2013, Kharlamova *et al*. 2016, Magwenzi 2013, Makarichi *et al.* 2019, Mandevere and Jerie 2018, Mandevere 2015, Nhubu *et al.* 2017e, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Tsiko and Togarepi 2012, Zamba 2014)	12
6	Municipal incapacitation	(Chikobvu and Makarati 2011, Chirisa 2013, Mada and Kharlamova 2014, Mandevere and Jerie 2018, Mandevere 2015, Milanzi 2014, Nemadire *et al.* 2017, Trust Nhubu *et al.* 2017e, Nhubu *et al.* 2019a, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	12
7	Low municipal waste collection efficiency	(Chikobvu and Makarati 2011, Mada and Kharlamova 2014, Makarichi *et al*. 2019, Mandevere and Jerie 2018, Mandevere 2015, Nyatsanza andand Ndebele 2016, Rinke *et al.* 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	10
8	Increase in waste generation rates	(Chikobvu and Makarati 2011, Kharlamova *et al.* 2016, Makarichi *et al*. 2019, Mandevere 2015, Nemadire *et al.* 2017, Nhubu *et al.* 2017e, Nhubu *et al.* 2019b, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Zamba 2014)	10
9	Inadequate receptacles	(Chikobvu and Makarati 2011, Magwenzi 2013, Mandevere and Jerie 2018, Mandevere 2015, Milanzi 2014, Nhubu *et al.* 2017e, Nyatsanza and Ndebele 2016, Tsiko and Togarepi 2012, Zamba 2014)	9
10	Large volumes of uncollected waste	(Chikobvu and Makarati 2011, Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Makarichi *et al*. 2019, Nyatsanza and Ndebele 2016, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014)	8
11	Inadequate planning and implementation	(Chikobvu and Makarati 2011, Mandevere 2015, Nhubu *et al.* 2019(b), Nhubu and Muzenda 2019, Nhubu *et al.* 2017e, Rinke *et al.* 2014, Tsiko and Togarepi 2012, Zamba 2014)	8
12	Cultural and personal attitudes	(Chikobvu and Makarati 2011, Chirisa 2013, Kambuzuma 2010, Mandevere 2015, Nhubu *et al.* 2019b, Nyatsanza and Ndebele 2016, Tanyanyiwa 2015, Zamba 2014)	8
13	Country's economic meltdown	(Chikobvu and Makarati 2011, Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Magwenzi 2013, Mandevere 2015, Tanyanyiwa 2015, Tsiko and Togarepi 2012)	7
14	Inadequate and unreliable data	(Magwenzi 2013, Makarichi *et al.* 2019, Mandevere 2015, Nemadire *et al.* 2017, Nhubu and Muzenda 2019, Pawandiwa 2013, Tsiko and Togarepi 2012)	7
15	Minimal community participation	(Mandevere and Jerie 2018, Nhubu *et al.* 2017e, Nhubu *et al.* 2019a, Nyatsanza and Ndebele 2016, Pawandiwa 2013, Tanyanyiwa 2015, Zamba 2014)	7
16	Limited recycling initiatives	(Kharlamova *et al.* 2016, Magwenzi 2013, Makarichi *et al.* 2019, Mandevere and Jerie 2018, Mandevere 2015, Nemadire *et al.* 2017, Tsiko and Togarepi 2012)	7
17	Waste burying	(Chikobvu and Makarati 2011, Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Magwenzi 2013, Makarichi *et al*. 2019, Tanyanyiwa 2015, Tsiko and Togarepi 2012)	7
18	Refuse vehicle and other equipment issues	(Chikobvu and Makarati 2011, Mandevere and Jerie 2018, Mandevere 2015, Pawandiwa 2013, Tanyanyiwa 2015, Tsiko and Togarepi 2012)	6
19	Inefficient or outdated waste policies	(Chikobvu and Makarati 2011, Chirisa 2013, Mtema 2016, Nhubu and Muzenda 2019, Nyatsanza and Ndebele 2016, Tanyanyiwa 2015)	6
20	Ineffective waste management strategies	(Mada and Kharlamova 2014, Makarichi *et al*. 2019, Mandevere and Jerie 2018, Mandevere 2015, Pawandiwa 2013, Zamba 2014)	6
21	Colonization and independence	(Chirisa 2013, Mandevere and Jerie 2018, Nyatsanza and Ndebele 2016, Rinke *et al.* 2014, Tsiko and Togarepi 2012, Zamba 2014)	6
22	Capital city	(Makarichi *et al.* 2019, Mandevere 2015, Nemadire *et al.* 2017, Rinke *et al.* 2014, Zamba 2014)	5
23	Increase in street vending	(Chikobvu and Makarati 2011, Kharlamova *et al.* 2016, Mtema 2016, Nhubu *et al.* 2017e, Zamba, 2014)	5
24	No proper enforcement of waste laws	(Kambuzuma 2010, Mandevere 2015, Mtema,2016, Nhubu *et al*. 2017e, Tanyanyiwa 2015)	5
25	Corruption and mismanagement of funds	(Chikobvu and Makarati 2011, Chirisa 2013, Mandevere and Jerie 2018, Tanyanyiwa 2015, Tsiko and Togarepi 2012)	5
26	Waste collection fee charged at a flat rate	(Chikobvu and Makarati 2011, Mandevere and Jerie 2018, Mandevere 2015, Tsiko and Togarepi 2012)	4
27	Limited environmental education	(Mandevere and Jerie 2018, Mandevere 2015, Tanyanyiwa 2015, Zamba 2014)	4
28	Changes in lifestyle and consumption patterns	(Mada and Kharlamova 2014, Nyatsanza and Ndebele 2016, Rinke *et al.* 2014, Zamba 2014)	4
29	Mushrooming of informal settlements	(Chirisa 2013, Mandevere 2015, Tsiko and Togarepi 2012, Zamba 2014)	3
30	Political issues	(Mandevere 2015, Tanyanyiwa 2015)	3
31	Poor communication and relationships between stakeholders	(Chikobvu and Makarati 2011, Tanyanyiwa 2015, Tsiko and Togarepi 2012)	3
32	Workers issues	(Chikobvu and Makarati 2011, Tsiko and Togarepi 2012)	2
33	Increase in standards of living	(Mandevere 2015, Nhubu *et al*. 2017e)	2
34	Small population with home ownership	(Chikobvu and Makarati 2011, Magwenzi 2013)	2

These causes of poor HSW management identified span the city’s waste management system described by Kwenda *et al*. (2021b), as shown in Table 3.2 below. The issues affecting two or more components of the waste management system are color-coded.

Table 3.2 Causes of inefficiencies in Harare's HSW management system.

<table>
<tr><th>Waste Generation</th><th>Waste Collection</th><th>Waste Disposal</th></tr>
<tr><td>Capital city</td><td>Increase in waste volumes</td><td>Waste burying</td></tr>
<tr><td>Increase in standards of living</td><td>Low waste collection frequency</td><td>Open waste burning</td></tr>
<tr><td>Increase in street vending</td><td>Low municipal waste collection efficiency</td><td>Increase in street vending</td></tr>
<tr><td>Limited environmental education</td><td>Large volumes of uncollected waste</td><td>Limited environmental education</td></tr>
<tr><td>Inefficient or outdated waste policies</td><td>Waste collection fee charged at a flat rate</td><td>Inefficient or outdated waste policies</td></tr>
<tr><td>Mushrooming of informal settlements</td><td>Minimal community participation</td><td>Mushrooming of informal settlements</td></tr>
<tr><td>Changes in lifestyle and consumption patterns</td><td></td><td>Changes in lifestyle and consumption patterns</td></tr>
<tr><td colspan="2">Increase in waste generation rates</td><td>No proper enforcement of waste laws</td></tr>
<tr><td colspan="2">Increase in population and population density</td><td>Poor formal solid waste disposal</td></tr>
<tr><td colspan="2">Colonization and independence</td><td>Small population with home ownership</td></tr>
<tr><td colspan="2">Cultural and personal attitudes</td><td></td></tr>
<tr><td></td><td colspan="2">Refuse vehicle and other equipment issues</td></tr>
<tr><td></td><td colspan="2">Worker issues</td></tr>
<tr><td></td><td colspan="2">Corruption and mismanagement of funds</td></tr>
<tr><td></td><td colspan="2">Municipal incapacitation</td></tr>
<tr><td></td><td colspan="2">Political issues</td></tr>
<tr><td></td><td colspan="2">Inadequate receptacles</td></tr>
<tr><td colspan="3">Inadequate planning and implementation</td></tr>
<tr><td colspan="3">Country’s economic meltdown</td></tr>
<tr><td colspan="3">Inadequate and unreliable data</td></tr>
<tr><td colspan="3">Limited recycling initiatives</td></tr>
<tr><td colspan="3">Ineffective waste management strategies</td></tr>
<tr><td colspan="3">Poor communication and relationships between stakeholders</td></tr>
</table>

3.3.1 Increase in population and population density

Harare has over the years seen a rapid increase in population resulting in a rise in consumption and hence the amount of waste produced (Chikobvu and Makarati 2011, Chirisa 2013, Kharlamova *et al*. 2016, Mada and Kharlamova 2014, Mandevere and Jerie 2018, Mandevere 2015, Milanzi 2014, Musemwa 2010, Nhapi 2008, Nhubu *et al.* 2019a, Nhubu *et al.* 2017e, Nyatsanza and Ndebele 2016, Tanyanyiwa 2015, Tsiko and Togarepi 2012). Population increase has been singled out as the primary source of waste management issues in Harare (Nemadire *et al*. 2017, Nhubu *et al.* 2017e). About 20 000 residents are added to the city annually (Pawandiwa 2013). Zamba (2014) pegs the urban growth rate in Zimbabwe at about 30%. According to Tsiko and Togarepi (2012), throughout the 1980s, major cities in Zimbabwe experienced high population growth rates of over 5% per annum. Harare is currently at about 6-8%, including the natural population increase since 2000. This agrees with Muchadenyika and Waiswa (2018) annual growth rate estimate of 5.8%. Urbanization has been the major driver of population increase (Chirisa 2013, Kharlamova *et al.* 2016, Nemadire *et al.* 2017, Sithole and Goredema 2013).

The population that Harare carries to date is not clear. However, many researchers over the years estimate it to be between 1,5-2 million (Bandauko and Mandisvika 2015, Dlodlo *et al*. 2011, Muchadenyika and Waiswa 2018, Nemadire *et al.* 2017, Nhubu *et al.* 2019b, Njaya 2014, Rinke *et al.* 2014, Schopfer *et al.* 2007, Tongesayi *et al.* 2018). In contrast, Tsiko and Togarepi (2012) state that around 1996, the population in Harare was already estimated at 1.5 million and increased to about 3 million in 2010. Also, Hove and Tirimboi (2011) and Love *et al.* (2006) peg the population at 2.3 million from about 1.4 million in 2002.

An increase in the Harare population also brought an increase in population density and thus an increase in the volumes of waste produced per given area (Chikobvu and Makarati 2011, Kambuzuma 2010, Mandevere 2015, Zamba 2014). Some properties provide residence to 3-6 families (Magwenzi 2013). Trust Nhubu *et al.* (2017e) estimate the population density in Harare to be about 2 435 persons per 1 000 000 square meters(m^2) from the <1 000 persons per 1 000 000 m^2 in 1982. Due to the high rural-urban migration recorded after Zimbabwe gained its independence in 1980, the population density in High-Density (HD) suburbs like Dzivarasekwa increased to about five people per household (Nyatsanza and Ndebele 2016). Some households in Mbare, one of the oldest HD suburbs in Harare, are overcrowded, housing approximately five or more people per room (Zamba 2014).

3.3.2 Poor formal solid waste disposal

Apart from the city's formal waste disposal system, waste management in Harare includes unsanitary practices like crude waste dumping, waste burying, and waste burning (Mandoga 2016, Nyatsanza and Ndebele 2016 Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014). The city's primary disposal method is landfilling (Odero *et al*. 2002). The formal waste disposal sites, Pomona and Golden Quarry, are non-engineered landfills (Kharlamova *et al*. 2016, Love *et al*. 2006, Makarichi *et al*. 2019, Tsiko and Togarepi 2012, Zamba 2014).

Also, Harare does not separate most of its HSW at the source, so the unseparated waste is officially dumped (Mandevere 2015, Rinke *et al*. 2014). The poorly managed dumpsite also lacks environmental guards such as leachate and gas collection systems or even fencing for controlled entry (Chisvo 2016, Makarichi *et al*. 2019, Mandevere 2015, Rinke *et al*. 2014, Tsiko and Togarepi 2012). Sanitary landfilling operations (controlled tipping, soil covering, and compaction) at the Pomona dumpsite depend on equipment availability as sometimes crude solid waste dumping is practiced (Mandevere 2015, Pawandiwa 2013, Rinke *et al*. 2014, Tsiko and Togarepi 2012, Zamba 2014). Although the Integrated Solid Waste Management (ISWM) plan developed in 2014 identified that the government would develop an engineered landfill that would come into operation by 2018, this has not been so to date (Makarichi *et al.* 2019). Mandevere (2015) pointed out that the city's lack of technical skills to construct landfills and the lack of financial resources to invite the relevant expertise has contributed to the delay in the construction of a sanitary engineered landfill for the city.

The Pomona dumpsite is Harare's major solid waste disposal site which receives about 460 000-700 000 kilograms(kgs) of waste daily (Chando 2015, Chihanga 2015, Chisvo 2016, Mandevere and Jerie 2018, Mandevere 2015, Nemadire *et al*. 2017, Nhubu *et al.* 2017, Tanyanyiwa 2015). Pomona dumpsite is an abandoned quarry mine commissioned in 1985 which is about 1 000 000 m^2 big, had already been 40% full in 2010 and expected to have been exhausted by 2020 (Chando 2015, Chisvo 2016, Nemadire *et al.* 2017, Nhubu and Muzenda 2019, Nhubu *et al*. 2017). Other sources predicted the exhaustion of Pomona dumpsite by 2018 (Nhubu *et al*. 2017). However, Pawandiwa (2013) pointed out that both waste disposal sites in Harare had already exceeded their waste handling capacities, thus posing a risk to human health and the environment. As of 2014, the council collected about 17 834 000kg of HSW every month, all of which was disposed of in Pomona dumpsite (Chisvo 2016). Although daily records of the waste received at the dumpsite are kept, there is no weighbridge. As a result, there are no accurate records on the volume of waste received at the dumpsite (HCC, 2019, Odero *et al*. 2002).

Moreso, since the Pomona dumpsite lacks proper control systems, the waste scavengers who freely access the area have been reported to cause accidents, fights, and fires (Chikobvu and Makarati 2011, Kharlamova *et al*. 2016, Rinke *et al*. 2014). As sanitary landfilling operations are often not carried out at Pomona, the HCC sometimes burns the waste in the dumpsite to reduce the volume and improve waste control (Tsiko and Togarepi 2012).

3.3.3 Increase in waste volumes

Annually, approximately 150 000 000kg of HSW comprises about 70% of food waste produced in Harare (Zamba 2014). The increase in waste volumes in the city poses pressure on the already weakened waste collection and disposal system (Chikobvu and Makarati 2011, Chirisa 2013, Makarichi *et al*. 2019, Tsiko and Togarepi 2012). Population increase and consumption patterns in the city have contributed to this rise in waste volume and changes in waste composition (Kharlamova *et al.* 2016, Mada and Kharlamova 2014, Mandevere 2015, Nemadire *et al*. 2017, Nhubu *et al*. 2019b, Nhubu and Muzenda 2019, Nyatsanza and Ndebele 2016, Rinke *et al.* 2014, Zamba 2014). Pawandiwa (2013) reported that the volume of waste produced differs depending on the socio-economic class under which the suburb falls. High-income areas generate more waste when compared to low-income areas. There is also a transfer of waste from the affluent suburbs of Harare to the low-income areas in the form of second-hand goods (Chirisa 2013). Moreso, the festive season sees a general increase in waste volumes generated during the celebrations (Chirisa 2013). An increase in urban agriculture to supplement household income has also contributed to the rise in waste volumes produced in the city (Drakakis-Smith *et al*. 1995, Tsiko and Togarepi 2012).

In 2005, a nationwide restore order operation called 'Murambatsvina' was launched, which aimed to demolish all illegal residential houses, businesses, and vending sites in the bid to regulate the rapid rate of urbanization (Benyera and Nyere 2015, Bratton and Masunungure 2007, Muronda 2008, Musoni 2010, Potts 2006, Sachikonye 2006, Tsiko and Togarepi 2012). Although there is limited data available on the total amount of this demolition waste, it is estimated that about 15 000kg.m^{-2} of total ground areas were generated. Despite that the waste collection efficiency had already dropped to below 30% in most cities, the government did not implement any demolition waste management strategies before launching the operation (Tsiko and Togarepi 2012). Individual households were responsible for managing their demolition waste.

3.3.4 Open waste burning

One of the waste disposal options that Harare city residents heavily depend on is burning their HSW in their backyards, in pits, by the roadsides, and in open spaces (Chikobvu and Makarati 2011, Juru *et al.* 2019, Kambuzuma 2010, Mada and Kharlamova 2014, Magwenzi 2013, Mandevere and Jerie 2018, Mandevere 2015, Nemadire *et al*. 2017, Rinke *et al.* 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014). In 2011, about 11% of solid waste in Zimbabwe was burnt (Kharlamova *et al*. 2016). In 2016, about 37.6% of municipal solid waste produced in Harare was either burnt or buried (Makarichi *et al.* 2019).

3.3.5 Low waste collection frequency

The HD suburbs in Harare usually have multiple families renting a single property. As a result, the once-a-week waste collection frequency, especially in HD areas like Highfield, is inadequate (Chikobvu and Makarati 2011, Magwenzi 2013, Mandevere and Jerie 2018, Mandevere 2015, Zamba 2014). This collection frequency identified by other researchers agrees with the HCC waste collection policy, which identifies that HSW in the city is collected once a week (Pawandiwa 2013). Other researchers also identified that in some instances, the HCC rescheduled waste collection frequency from once a week to once or twice a month (Mandevere and Jerie 2018, Mandoga 2016, Nyatsanza and Ndebele 2016). Other studies have also shown that some areas in Harare have gone 2-3 weeks, two months, or even up to 6 months without refuse collection (Tsiko and Togarepi 2012). Tsiko and Togarepi (2012) also identified that house-to-house waste collection services by the HCC were even once suspended only to be re-introduced in 2010. Pawandiwa (2013) states that the reduction in waste collection frequency recorded between 2001 and 2010 can be attributed to the poor maintenance of refuse trucks. The low waste collection frequency has become a serious problem as residents are responsively dumping extra waste in undesignated areas in the environment (Chirisa 2013, Mandevere and Jerie 2018, Mandevere 2015, Nhubu *et al.* 2017).

3.3.6 Municipal incapacitation

The HCC cannot effectively and adequately provide waste collection services to its residents (Chikobvu and Makarati 2011, Mandevere and Jerie 2018, Milanzi 2014). This has been attributed to the failure of the HCC to expand its waste collection and disposal facilities as the population increased (Nemadire *et al*. 2017, Nhubu *et al.* 2017, Zamba 2014). Chirisa (2013) supports that the city's infrastructure was built for a smaller population. Due to a lack of financial muscle, the waste collection vehicles available to service Harare's residential areas are limited (Chikobvu and Makarati 2011, Mandevere and Jerie 2018, Tanyanyiwa 2015, Tsiko and Togarepi 2012).

Waste management is expensive, and the HCC does not have the financial capacity to support its operations (Chikobvu and Makarati 2011, Mandevere and Jerie 2018, Mandevere 2015, Nhubu *et al*. 2019b, Tsiko and Togarepi 2012, Zamba 2014). The cost of waste collection and disposal services in Harare exceeds the typical range of 20-70% of the municipal budget (Nhubu *et al.* 2019a. Other researchers attribute the decrease in service delivery to the withdrawal of external funding due to political instability (Tsiko and Togarepi 2012). This financial incapacitation has rendered the council unable to provide receptacles, equipment, and protective wear (Chikobvu and Makarati 2011, Mandevere and Jerie 2018). It also led to the collapse of the waste collection system in the city and a shortage of workforce (Kharlamova *et al.* 2016, Mandevere and Jerie 2018, Tsiko and Togarepi 2012). In the past, the HCC has even gone as far as acquiring a loan from a local bank to equip its waste management department (Tsiko and Togarepi 2012).

3.3.7 Low municipal waste collection efficiency

The HCC has seen a reduction in the efficiency with which it collects waste since 2000 due to the country's economic crisis (Mada and Kharlamova 2014, Tanyanyiwa 2015, Tsiko and Togarepi 2012). This has led to the accumulation of waste in the environment (Mada and Kharlamova 2014, Makarichi *et al*. 2019, Rinke *et al.* 2014, Tanyanyiwa 2015). According to Makarichi *et al*. (2019), there was a reduction in waste collection efficiency in Harare to 48.7% in 2016 from about 52% in 2011. Another report by Rinke *et al*. (2014) agrees and identifies that waste collection efficiency in the city has dropped from about 80% in the 90s to about 50%. Tsiko and Togarepi (2012) further supports these reports and states that the HCC can only collect about 54% of the total solid waste generated in Harare. The decrease in waste collection efficiency in the city comes despite increasing waste volumes (Nyatsanza and Ndebele

2016). Low-income areas, newly developed areas, and informal settlements mostly receive poor waste collection coverage (Chikobvu and Makarati 2011, Rinke *et al.* 2014, Zamba 2014).

Concerning the areas receiving house-to-house waste collection services, despite the increase in the number of occupied properties in the city, there is not much variation in the number of these receiving some form of waste collection, as shown in Fig. 3.2 below. This data is not limited to only residential properties but includes all other properties and establishments in the city. No waste collection data specifically for residential properties was available from the HCC records available for this research. However, about 97% of the properties in Harare are residential (HCC 2019). In the context of this study, properties receiving some form of collection receive collection either daily, once a week, twice a week, or once in more than a week.

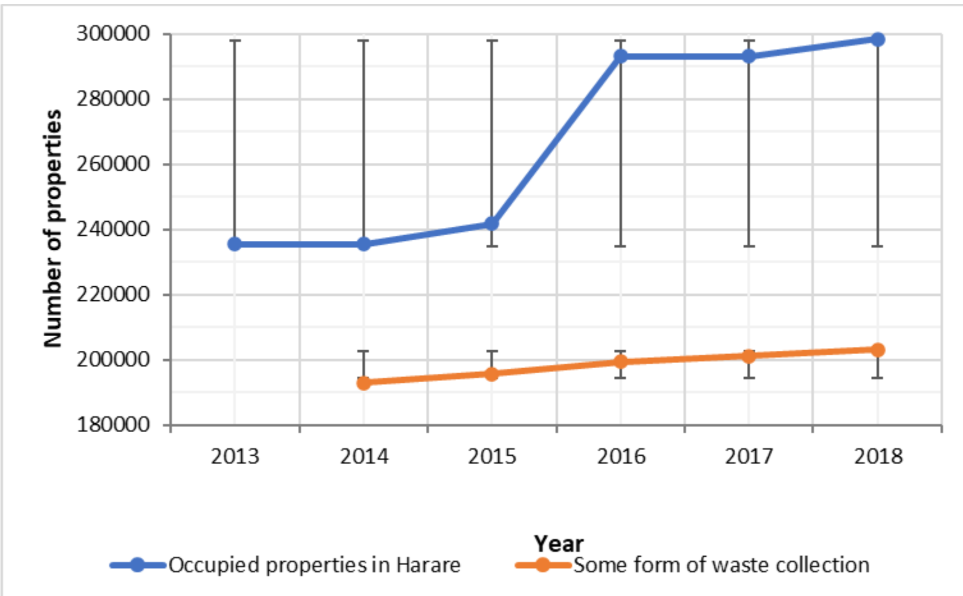

Figure 3.2 Coverage of Harare's Solid Waste Management services through the door-to-door collection of waste from occupied properties and establishments (residential, commercial, industrial, and others) (HCC 2019).

Table 3.3 below shows the waste collection patterns in Harare's properties over the years 2013-2018. On average, about 63% of the properties in the city receive weekly house-to-house services. Less than 1 500 properties receive daily solid waste collection services while none receive once in more than a week, and on average, about 26 414 receive twice a week collection.

Table 3.3 Number of Harare's properties and establishments covered by some form of waste collection (HCC 2019).

	Daily waste collection	Once a week	Twice a week	Once more than a week	No collection at all
2013	-	-	-	-	48092
2014	1407	165443	25992	0	235480
2015	1408	167425	26781	0	60690
2016	1454	171242	26664	0	48869
2017	1399	173279	26462	0	-
2018	1403	175475	26173	0	95377
Standard Error	22	4123	330	0	79378

However, house-to-house collection services have been rendered ineffective, especially in some HD suburbs like Highfield, where the roads are narrow and potholed, making it difficult for the refuse collection trucks to access waste (Chikobvu and Makarati 2011).

3.3.8 Increase in waste generation rates

An increase in the waste generation rates in Harare resulted in a general rise in the volume of waste produced (Chikobvu and Makarati 2011, Nemadire *et al*. 2017, Nhubu *et al*. 2019b, Nhubu *et al*. 2017e, Nyatsanza and Ndebele 2016). This mounts more pressure on the already compromised waste management capacity of the HCC (Chikobvu and Makarati 2011). The mean residential waste generation per capita and household in Harare is higher than that recorded for Zimbabwe. According to Kharlamova *et al*. (2016), in Harare, the former is estimated at 0.361kg.day^{-1} while the latter is about 2.108kg.day^{-1}. This also supports Mandevere's (2015) report that waste generation rates in low-income countries range from 0.3-0.6kg.day^{-1}. Nemadire *et al*. (2017) identify the waste generation rate in Harare as about 0.43kg.day^{-1}. On the other hand, Pawandiwa (2013) approximates the waste generation rate per capita at 0.481kg.day^{-1}. Zamba (2014) states that in 1996, the waste generation rate in Zimbabwe was 0.485kg.day^{-1} and increased to 0.58kg.day^{-1} in 2000.

3.3.9 Inadequate receptacles

Lack of proper receptacles affects waste's efficient collection and transportation (Chikobvu and Makarati 2011, Milanzi 2014). The HCC carries the duty to provide receptacles to the Harare city residents. However, due to financial constraints, there are reports that they only offer 1-2 receptacles per household per week (Magwenzi 2013, Mandevere and Jerie 2018, Nyatsanza and Ndebele 2016). This receptacle allocation does not allow for waste separation and is inadequate for households (Mandevere and Jerie 2018, Mandevere 2015, Zamba 2014). Moreso, the reality is that most households do not have or do not receive these receptacles at all (Nhubu *et al*. 2017e). According to Tsiko and Togarepi (2012), city residents generally don't get assistance from the HCC in the provision of receptacles but instead have to buy their own, receive donations from private companies or use empty shopping bags and containers. As a result, most residents have resorted to illegal dumping their waste (Mandoga 2016, Nyatsanza and Ndebele 2016). However, illegal dumping is not common in high-income areas as the people have environmental knowledge and can afford to buy proper receptacles (Mandevere and Jerie 2018).

3.3.10 Large volumes of uncollected waste

Significant amounts of waste are left uncollected in Harare (Chikobvu and Makarati 2011, Kharlamova *et al*. 2016, Mada and Kharlamova 2014, Makarichi *et al*. 2019, Nyatsanza and Ndebele 2016, Tanyanyiwa 2015, Tsiko and Togarepi 2012, Zamba 2014). Due to the higher occurrence of the irregular provision of waste collection services in lower-income suburbs like Highfield, this problem is more significant in these areas (Chikobvu and Makarati 2011). The national mean collection rate of residential solid waste in 2011 was about 52%, with only 3% recycled and the rest improperly disposed of (Kharlamova *et al*. 2016). Tsiko and Togarepi (2012) identify that the HCC can only collect and dispose of about 54% of solid waste generated in Harare. On the other hand, Makarichi *et al*. (2019) report that only 49% of solid waste in Harare is formally collected and about 13.6% recycled.

Harare uses two types of waste collection systems: house-to-house services and the central communal waste collection system (Kharlamova *et al*. 2016). For the latter, skip bins are placed at strategic and sanitary positions in low-income areas. Residents carry their waste to these skip bins, which are then emptied at designated times by the HCC (Kharlamova *et al*. 2016). Mada and Kharlamova (2014) state that approximately 42% of households in Harare dump their waste in undesignated areas, while only about 12.5% rely on the HCC for disposing of their waste. Another researcher identified that about 80% of solid waste in Zimbabwe is haphazardly dumped into the environment (Zamba 2014).

3.3.11 Inadequate planning and implementation

Although other issues also contribute to poor HSW management in Harare, poor planning and implementation of strategies on the part of the HCC is one of them (Chikobvu and Makarati 2011). Mandevere (2015) and Zamba (2014) identified that no proper strategies tailor-made for Harare are being developed towards the efficient management of HSW. One of the areas that need the attention of the HCC is how waste from different waste streams is managed. According to Tsiko and Togarepi (2012), irrespective of the source of waste, all solid waste is collected and dumped in the city's dumpsites, thus posing a great risk not only to human health but also to the environment. Moreso, with no proper recycling initiatives in place, the local authorities collect everything from the city residents as waste irrespective of their potential for recycling or reuse (Mandevere 2015). Rinke *et al*. (2014) describe the HCC's management of solid municipal waste as reactive instead of strategic. As the waste volumes generated continue to increase, the municipality is placing more focus on improving waste collection and disposal instead of devising a more integrated approach to the management of the waste. Nhubu *et al*. (2019b) identified that little to no research has been done so far using Harare as a case study to determine the city's most environmentally friendly integrated solid waste management options. Other studies have suggested the need for simulation-based studies to identify suitable waste management options for Harare (Nhubu *et al*. 2017e).

3.3.12 Cultural and personal attitudes

People's cultural and personal attitudes contribute to some of the HSW management problems experienced in developing countries like Zimbabwe (Mandevere 2015, Tanyanyiwa 2015). Perceptions and attitudes affect how waste is disposed of and determine the amount of waste generated (Zamba 2014). Nhubu *et al*. (2019b) identified the lack of cooperation between the HCC and the city residents as one of the factors hindering the effective management of waste. The Harare residents have developed a 'Throw-away-culture' and hold the perception that the municipality is solely responsible for managing all the waste they produce (Chikobvu and Makarati 2011, Chirisa 2013, Mandevere 2015, Nhubu *et al*. 2019b). Throwing away food signifies wealth to some people (Chirisa 2013).

According to Nyatsanza and Ndebele (2016), waste management perceptions even differ depending on gender. While more women are generally responsible for waste management than men, these differences in perceptions affect the implementation or the design of waste disposal strategies that are likely to be effective in a given area (Nyatsanza and Ndebele 2016). Research also shows a relationship between the level of education and the attitudes and perceptions of the residents on waste management (Kambuzuma 2010, Tanyanyiwa 2015). Environmentally educating people can create a shared waste management responsibility between individuals, the community, and the HCC (Tanyanyiwa 2015, Zamba 2014).

3.3.13 Country's economic meltdown

The land reform program that began in Zimbabwe in 2000 marked the genesis of the country's economic meltdown (Chikobvu and Makarati 2011, Kharlamova *et al*. 2016, Tsiko and Togarepi 2012). This program created a hyperinflation environment, contributed to a shortage of foreign currency, and generally financially crippled the HCC. This limited the council's ability to efficiently provide waste collection and disposal services (Kharlamova *et al*. 2016, Mada and Kharlamova 2014). The country's failing economy is causing the deterioration of household solid waste management and the accumulation of waste (Chirisa 2013, Magwenzi 2013, Mandevere 2015, Tanyanyiwa 2015). The shrinking economy could allow a collection of only 54% of the 1 400 000kg.day^{-1} total waste generated in Harare (Tsiko and Togarepi 2012). However, it is essential to note that the country's economy briefly improved after 2010 due to multicurrency. This move saw private companies once again contributing to waste management in Harare (Tsiko and Togarepi 2012).

3.3.14 Inadequate and unreliable data

Harare does not have adequate, up-to-date, and reliable data on HSW management (Mandevere 2015). Even data on measurements of the effectiveness of the waste management strategies implemented in the city are scarce. Moreso, due to the financial problems the municipality is facing, funding has not been made available for new research (Mandevere 2015). Even the exact quality and quantity of waste produced by the Harare city residents is unknown (Nemadire *et al*. 2017, Tsiko and Togarepi 2012). In areas where the HCC does not offer solid waste collection services, the residents illegally dispose of this waste in undesignated areas in the environment (Nemadire *et al*. 2017). As a result, some data recorded on paper does not correspond to the reality on the ground (Nhubu *et al*. 2019b, Tsiko and Togarepi 2012). Nhubu *et al*. (2019b) state that waste generation, waste quality, and composition data are essential in potentially helping waste management decision-makers strategize is either unavailable or unreliable. The official municipal waste records do not account for all other waste that is not handled by the municipality (HCC 2019). Moreso, the number of billed properties in some suburbs is 3-times less than the actual number of properties (Magwenzi 2013). This results in less revenue for the municipality and undermines the capacity needed by the HCC to provide services adequately.

3.3.15 Minimal community participation

Most MD and HD area residents rely on the HCC to provide receptacles and waste management services (Mandevere and Jerie 2018). This dependence has been attributed to the minimal environmental education among these people (Mandevere and Jerie 2018). The sole responsibility of managing solid waste and recycling lies on the HCC and whoever it contracts (Nhubu *et al*. 2019b, Nhubu *et al*. 2017e, Pawandiwa 2013). As a result, city residents have developed an attitude of ‘we dump, they collect’ and have very little involvement in waste management (Nhubu et al. 2019b, Nyatsanza and Ndebele 2016 Tanyanyiwa 2015, Zamba 2014).

3.3.16 Limited recycling initiatives

Kharlamova *et al*. (2016) reported that in 2011, despite the national average of about 45% of HSW was disposed of illegally, only 3% was recycled. On the other hand, Makarichi *et al*. (2019) identify that in 2013, although 90% of the 371 697 000kg of MSW produced in Harare is deemed recyclable or reusable, only 13.6% is recycled. According to Mandevere and Jerie (2018), Pomona dumpsite receives 90% of HSW dumped without separation, while only 10% is recycled.

The HCC does not formally carry out any recycling activities (Magwenzi 2013). However, it licensed about 300 metal recyclers in 2014 who, despite being too few to cover a big city like Harare, collect waste for recycling at the dumpsite and residential areas (Mandevere 2015). On the other hand, Nemadire *et al*. (2017) identify that only about 220 waste pickers work at Pomona dumpsite. However, private companies like Delta beverages have funded waste recycling projects in Harare (Magwenzi 2013 Tsiko and Togarepi 2012).

Table 3.4 below shows data on waste collection, disposal, and recovery in Harare. According to the records kept by the HCC, all the MSW collected is disposed of at the Pomona dumpsite as no engineered landfills serve the city. Despite the municipal recovery rates in Harare still being meager, there has been a general increase in waste recovery over the years. However, there have been drops in the recovery rates for 2016 and 2018, which recorded 8.8 and 11.5%, respectively. However, it is essential to note that the HCC calculations ignore waste recovery done at generation points as no reliable data can be obtained.

Table 3.4 Monthly average solid waste disposal and recycling data for Harare (HCC 2019).

	2014	**2015**	**2016**	**2017**	**2018**	**Standard Error**
Total waste collected (kg)	27 641 000	20 938 500	22 793 000	16 288 000	20 544 000	4 113 350
Total waste dumped in ‘compliant’ landfills (kg)	0	0	0	0	0	0
Total waste dumped in dumpsites (kg)	27 641 000	20 939 000	22 793 000	16 288 000	20 544 000	4 113 330
Amount of waste recycled or processed (kg)	1 439 000	1 944 000	2 017 000	2 028 000	2 363 300	33 2493
Waste recovery (%)	5.2	9.3	8.8	12.5	11.5	2.8

3.3.17 Waste burying

One of Harare city residents' informal waste disposal methods is waste burying (Chikobvu and Makarati 2011, Juru *et al*. 2019, Mada and Kharlamova 2014, Magwenzi 2013, Mandoga 2016, Tanyanyiwa 2015, Tsiko and Togarepi 2012). In 2013, 28% of HSW was buried (Kharlamova *et al*. 2016, Tirivanhu and Feresu 2013). Moreso, about 37.6% of MSW produced in Harare is either burnt or buried at the source (Makarichi *et al*. 2019).

3.3.18 Refuse vehicle and other equipment issues

The HCC once used a loan to acquire more waste vehicles, thus allowing house-to-house waste collection services, which had long ceased in some parts of the city for years (Tsiko and Togarepi 2012). In 2017, one researcher identified that about 40 HCC waste collection vehicles and 30 other private vehicles deliver waste for disposal at Pomona dumpsite daily (Nemadire *et al*. 2017). Each HCC vehicle has a capacity of approximately 10 000kg. On the other hand, Mandevere and Jerie (2018) identified that only 47 waste collection vehicles serve the city of Harare. These, however, are reported to constantly break down and so frequently require servicing (Mandevere and Jerie 2018).

According to Tsiko and Togarepi (2012), in 1999, only about 7 of the 90 refuse trucks were operational, while after 2000, between 8 and 14 waste trucks were serving the city. In 2015, Tanyanyiwa (2015) identified that only about 20 vehicles were serving the city. This incapacitation was brought about by the lack of funds on the part of the HCC to train maintenance personnel and acquire maintenance equipment (Tsiko and Togarepi 2012). Poor refuse vehicle maintenance has been cited as one of the causes for the reduction in waste collection frequency between 2001 and 2010 in Harare (Pawandiwa 2013, Tsiko and Togarepi 2012).

Some researchers have identified a shortage of fuel as one of the issues crippling Harare's waste collection and disposal system (Chikobvu and Makarati 2011, Tsiko and Togarepi 2012). However, some reports suggest that Pomona dumpsite is located 12 000 meters(m) from the (CBD) Central Business District (Pawandiwa 2013, Tsiko and Togarepi 2012). Tanyanyiwa (2015) states that the dumpsite is about 30 000 m away from the CBD. This might be relative to the route taken by the vehicle. Tanyanyiwa (2015) further explains that with a long-distance as this, each refuse vehicle would require a costly allocation of approximately 0.1 m^3 each week.

3.3.19 Inefficient or outdated waste policies

Some researchers have blamed Harare’s waste management issues on inefficient, outdated, or lack of specific waste policies (Chikobvu and Makarati 2011, Tanyanyiwa 2015). Nyatsanza and Ndebele (2016) and Mtema (2016) pointed out the persistence of improper solid waste management in Harare despite the existence of policy, some of which is sound. Chikobvu and Makarati (2011) give the 2007 Zimbabwean Environmental Management Regulations on effluent and solid waste disposal as an example of an outdated waste policy that proposes meager penalty fees to waste law offenders. Meanwhile, poor waste management has become a culture for the majority in Harare. As a result, Chirisa (2013) proposed formulating waste policies and initiatives that promote better waste management in Harare. Moreso, Nhubu and Muzenda (2019) identified that there is little to no research on more efficient waste management strategies that can potentially inform waste policy in Harare.

3.3.20 Ineffective waste management strategies

Developing an efficient waste collection strategy is a solution to improving waste management in Harare. Also, improving the population's access to safe waste disposal facilities and educating the public on the consequences of improper HSW management can contribute to building this system (Mada and Kharlamova 2014). Although the city has employed other initiatives like developing waste management laws and environmental or educational campaigns, the poor solid waste management situation continues to worsen (Mandevere 2015).

According to Mandevere and Jerie (2018), the waste collection strategy being employed by the HCC is not feasible as most waste collection times are interrupted due to vehicle breakdowns. With only 47 vehicles that service all residential, commercial, and industrial areas in Harare, the waste collection system is built assuming 100% efficiency, thus giving no room for breakdowns (Mandevere and Jerie 2018).

More so, although proper and safe waste disposal is an important waste management strategy, Harare currently does not own an adequately engineered landfill but instead relies on dumpsites (Pawandiwa 2013). The municipality does not even have waste minimization or waste segregation strategies (Pawandiwa 2013, Zamba 2014). It lacks innovative waste management strategies as well as effective compliance initiatives (Zamba 2014). Since waste collection and disposal costs in Harare consume between 20-70% of the solid waste management budget. Nhubu *et al*. (2019b) suggest that a more strategic and cost-effective waste collection and disposal system be implemented. Also, despite the Zimbabwean government's effort in developing an integrated solid waste management plan in 2014, which highlighted waste intervention and energy recovery strategies, no data is available to support the successful implementation of these initiatives (Makarichi *et al*. 2019).

3.3.21 Colonization and independence

According to Tsiko and Togarepi (2012), the seeds of the waste management chaos currently being witnessed were planted during the British colonial period. Harare, formerly called Salisbury, was initially built for a smaller population (Chirisa 2013). However, soon after Zimbabwe gained its independence in 1980, regulations that prohibited most blacks in the city were lifted, thus resulting in a large influx of people due to rural-urban migration into major cities like Harare (Nyatsanza and Ndebele 2016). Nyatsanza and Ndebele (2016) identified that one suburb called Dzivarasekwa's population grew 100-fold since independence, yet the waste management system in the area remained untouched.

This uncontrolled increase in population in the capital city also increased the illegal settlements and squatters as some people could not afford to maintain life in the city. Blacks having access to more jobs also resulted in an increase in disposable income and hence expenditure. Moreso, everyone now had access to formerly prohibited goods (Chirisa 2013). These factors, among others, contributed to an increase in the volumes of waste produced in Harare (Chirisa 2013). This drastic increase in waste volumes choked the HCC as it could not expand its capacity at the same rate at which the population was growing. The increase in disposable income also came with an overreliance on industrially processed products, a change in consumer patterns, and hence a shift in the quality of waste produced from biodegradable to non-biodegradable (Nyatsanza and Ndebele 2016, Rinke *et al*. 2014, Zamba 2014).

Moreso, pre-independence, waste management services were offered based on racial segregation. High-density areas during this time received minimal waste collection services as compared to the low-density areas. This bias in providing waste collection services still exists 40 years post-independence (Tsiko and Togarepi 2012).

3.3.22 Capital city

Harare is the capital city of Zimbabwe (Hranov 2003, Makarichi *et al*. 2019, Mandevere 2015, Muchadenyika and Waiswa 2018, Nemadire *et al*. 2017, Nhapi 2008, Njaya 2014, Rinke *et al*. 2014 Schopfer *et al*. 2007, Wania *et al*. 2014). By virtue of this status, the city harbors a lot of economic activities and a vast population (Mandevere 2015, Muronda 2008, Wania *et al*. 2014). Makarichi *et al*. (2019) and Zamba (2014) even refer to the city as Zimbabwe's commercial and administrative hub. As a result, the resources that would be required to sustain such a city's waste management system are enormous.

3.3.23 Increase in street vending

Unemployment, poverty, lower-income, the surge in the HIV/AIDS epidemic, economic downfall, political instability, and population increase have encouraged an increase in street vending in unauthorized places by city residents to supplement household income (Chikobvu and Makarat 2011, Drakakis-Smith *et al*. 1995, Mtema 2016, Trust Nhubu *et al*. 2017e, Njaya 2014, Zamba 2014). The city has seen an increase in the unemployment rate from 12% in 2002 to 88% in 2012 (Bandauko and Mandisvika 2015). In general, Zimbabwe's informal economy relative to the national gross income is about 60% (Njaya 2014). The subsequent rise in informal activities has caused an increase in the amount of waste generated and the volumes of waste disposed of into the environment (Kharlamova *et al*. 2016, Nhubu *et al*. 2017e, Zamba 2014). Most people, especially in HD areas like Highfield, have a monthly income below the Poverty Datum Line (Chikobvu and Makarati 2011).

3.3.24 No proper enforcement of waste laws

The issues around poor HSW management in Harare have been partly attributed to inadequate enforcement of laws against illegal dumping rather than the absence or ineffectiveness of the waste laws (Kambuzuma 2010, Mandevere

2015). Poor waste law enforcement encourages illegal waste dumping (Mandevere 2015, Mtema 2016). However, Nhubu *et al*. (2017e) and Tanyanyiwa (2015) argue that the legislative structure in Zimbabwe supports sustainable waste management while it is only the implementation that renders it ineffective. Municipalities also do not carry any arresting powers over offenders, thus making it hard for them to enforce these laws (Mandevere 2015) directly.

3.3.25 Corruption and mismanagement of funds

Corruption can impede the efficient use of financial and infrastructural resources (Chikobvu and Makarati 2011). The HCC is plagued with corruption which sees the diversion, reduction, or misappropriation of funds or resources (Chikobvu and Makarati 2011, Chirisa 2013, Mandevere and Jerie 2018, Tsiko and Togarepi 2012). Mismanagement of funds by the HCC has also been identified as one of the issues affecting solid waste management in Harare (Chirisa 2013). Instead of using the prescribed 28-32% of funds on salaries, there have been reports that larger proportions have been used instead of placing more investments in waste management projects (Tsiko and Togarepi 2012).

3.3.26 Waste collection fee charged at a flat rate

The HCC charges Harare residents a flat waste collection fee. This implies that the fee does not vary with the waste generated (Chikobvu and Makarati 2011). As a result, city residents do not put much effort to minimize waste generation or recycling (Chikobvu and Makarati 2011). Despite the flat waste collection fee, ratepayers do not always pay due to financial constraints (Mandevere and Jerie 2018, Mandevere 2015). This fee differs depending on the socio-economic class the residential area is classified. According to Tsiko and Togarepi (2012), LD or MD areas and HD suburbs pay a monthly household average of US$12-US$15 and US$0.70-US$10, respectively. On the other hand, Mandevere and Jerie (2018) specify that HD and LD areas pay US$6 and US$9, respectively. However, the revenue generated by the HCC is not enough to support waste collection operations in the city (Mandevere and Jerie 2018, Tsiko and Togarepi 2012). More so, there has been no increase in waste collection revenue with the rapid rise in population (Mandevere 2015).

3.3.27 Limited environmental education

Limited environmental awareness contributes to the improper disposal of HSW management in the city (Mandevere and Jerie 2018, Mandevere 2015, Zamba 2014). Environmental education among people in lower-income areas is generally lower (Mandevere and Jerie 2018). There is a relationship between limited education and attitudes or perceptions that promote improper waste management (Tanyanyiwa 2015). When city residents are more informed, they manage their waste better.

3.3.28 Changes in lifestyle and consumption patterns

The increase in population in Harare has seen a reciprocal increase in the consumption of resources (Mada and Kharlamova 2014). Moreso, the changes in people's lifestyle and consumption patterns have contributed to the increase in the volumes of waste produced and caused the change in waste composition (Nyatsanza and Ndebele 2016, Rinke *et al*. 2014, Zamba 2014).

3.3.29 Mushrooming of informal settlements

The first ten years after Zimbabwe gained its independence, Harare saw a large influx of black people and a growth in illegal settlements (Chirisa 2013). Mandevere (2015) notes that the growth in informal settlements has made waste collection planning difficult for the HCC. Zamba (2014) also supports these reports citing Mbare as one of the suburbs in Harare where illegal settlements are widespread.

3.3.30 Political issues

The economic woes in Zimbabwe emanated from the political issues in the country (Mandevere 2015, Tanyanyiwa 2015). The resultant economic difficulties caused the solid waste management system to collapse in most urban cities like Harare (Mandevere 2015, Tanyanyiwa 2015). Tsiko and Togarepi (2012) also identified that the movement of waste management responsibility from one urban governance department to another on a political basis has contributed to the deterioration of the system in the city.

3.3.31 Poor communication and relationships between stakeholders

A poor relationship exists between the municipality and its various waste management stakeholders (Chikobvu and Makarati 2011). When waste collection problems arise, the city does not communicate this to the people in time (Chikobvu and Makarati 2011). Some of the problems being experienced in waste management service provision and management are rooted in the poor relationship between councilors, the Non-Governmental Organizations (NGOs), the private sector, and the citizens (Tsiko and Togarepi 2012). One of the issues affecting the smooth facilitation of waste transport in Harare is the poor relationship between the waste collectors and the city residents (Chikobvu and Makarati 2011, Tanyanyiwa 2015). Waste collectors are sometimes rude while city residents reciprocate the same attitude, thus becoming uncooperative during waste collection (Chikobvu and Makarati 2011, Tanyanyiwa 2015).

3.3.32 Workers issues

As Zimbabwe continued to face economic challenges, in 2009 about 7 000 employees could not afford to report for duty due to the high transport costs (Tsiko and Togarepi 2012). As a result, the Waste Management department was greatly affected. Citing poor salaries and unavailability of protective gear, council workers went on strikes (Chikobvu and Makarati 2011, Tsiko and Togarepi 2012). Chikobvu and Makarati (2011) and Mandevere and Jerie (2018) even identified a limitation in the municipal workforce, particularly skilled workers, as one of the issues contributing to poor waste management in the city. Tsiko and Togarepi (2012) say that the municipality lacks funds to train personnel responsible for maintaining waste management equipment.

3.3.33 Increase in standards of living

The people's standard of living determines the volume of waste they generate (Mandevere 2015). The rapid increase in solid waste volume in Harare has been attributed to the increase in living standards (Nhubu *et al*. 2017e).

3.3.34 Small population with home ownership

According to Chikobvu and Makarati (2011), in 2001, 78% of the Harare city residents were renting. Not owning the properties they reside in reduces the residents' sense of responsibility in adequately taking care of their environment by managing their waste in sanitary ways (Chikobvu and Makarati 2011, Magwenzi 2013).

3.4 Consequences of Poor Waste Management in Harare

There have been consequences to Harare's poor HSW management. This section of the study discusses some of these in descending order of how heavily referenced they were in the literature analyzed.

3.4.1 Waste in the environment or undesignated areas

Whenever their bins are full, Harare city residents discard their waste in undesignated areas like roadsides, drainage ditches, along footpaths, trenches, in streets or any open space near them (Kambuzuma 2010, Chikobvu and Makarati 2011, Tsiko and Togarepi 2012, Chirisa 2013, Magwenzi 2013, Mada and Kharlamova 2014, Rinke *et al*. 2014, Zamba 2014, Mandevere 2015, Tanyanyiwa 2015, Nyatsanza and Ndebele 2016, Nemadire, Mapurazi *et al*. 2017, Nhubu, Muzenda *et al*. 2017, Mandevere and Jerie 2018). According to Tirivanhu and Feresu (2013), in 2011, 6% of household solid waste was dumped in undesignated dumpsites. In one of Harare's oldest High-Density (HD) suburbs called Mbare, illegal waste dumping has increased from 1.9-16.5% from the year 2000 to 2013 (Milanzi 2014).

3.4.2 Pollution

In response to the poor waste collection and disposal services being offered by the Harare City Council (HCC), city residents have resorted to illegal waste dumping which in turn is causing environmental pollution (Chikobvu and Makarati 2011, Zamba 2014). About 41.7% of households dump their waste in undesignated places. As a result, most residential areas are ridden with bad odors (Mada and Kharlamova 2014, Rinke *et al*. 2014, Mandevere and Jerie 2018).

Water contamination is another consequence of the poor management of waste in Harare. According to a study conducted by Mada and Kharlamova (2014), only about 10% of interviewed city residents rely on water supplied by the HCC with 35% sourcing their water from both protected and unprotected wells and the rest use boreholes. The household solid waste disposed of into the environment is washed off into unprotected wells by runoff thus contaminating these (Mada and Kharlamova 2014). Mandevere and Jerie (2018) point out that the carelessness of the waste collection crew during operations also results in waste dropped into the environment. Rampant illegal urban agriculture has also been linked to the pollution of water bodies (Nhapi 2008).

Decomposition of some of this waste can release toxic chemicals that can be lethal to plants, contaminate ground or surface water and kill aquatic life (Tsiko and Togarepi 2012, Rinke *et al*. 2014, Mandevere 2015, Nhubu *et al*. 2017, Mandevere and Jerie 2018, Nhubu and Muzenda 2019). Leachate from the city's dumpsites, although insignificantly as cited by Chihanga (2016) at the time of research, also contribute to ground and surface water pollution with lake Chivero's eutrophication levels heightened partly due to poor waste solid management (Pawandiwa 2013, Rinke *et al*. 2014, Chihanga 2016, Chisvo 2016, Nhubu *et al*. 2017, Nhubu and Muzenda 2019).

Open waste burning and the fires that sometimes break out at the Pomona dumpsite also contribute to air pollution (Rinke *et al*. 2014). Waste burning can release smoke and harmful chemicals into the environment which not only can pollute the air, but also can be detrimental to human health, or cause the formation of acid rain (Rinke *et al*. 2014, Mandevere 2015).

3.4.3 Health risk

Children are more prone to poisoning or injury with some of the solid waste lying around the residential areas (Chikobvu and Makarati 2011). The burning of waste by residents as well as the fires that sometimes break out at Pomona dumpsite cause respiratory ailments (Chikobvu and Makarati 2011, Rinke *et al*. 2014, Kharlamova, Mada *et al*. 2016). Solid waste in undesignated areas also causes the spread of diseases, bad odors, and the infestation of vermin (Kambuzuma 2010, Tsiko and Togarepi 2012, Mada and Kharlamova 2014, Zamba 2014, Mandevere 2015, Tanyanyiwa 2015, Kharlamova *et al*. 2016, Nyatsanza and Ndebele 2016).

Over 100 people die each year as a result of diseases associated with poor household solid waste management (Mandevere 2015). Examples of these diseases include cholera, malaria, typhoid, diarrhea or dysentery (Kambuzuma 2010, Tsiko and Togarepi 2012, Milanzi 2014, Rinke *et al*. 2014, Mandevere 2015, Nhubu *et al*. 2017). One of Harare’s HD suburbs called Dzivarasekwa records about 500 disease cases and 23 deaths annually related to poor HSW management (Nyatsanza and Ndebele 2016). It causes the contamination of surface and groundwater thus causing harm to human health (Tsiko and Togarepi 2012, Mandevere 2015).

3.4.4 Breeding ground for mosquitoes, rodents, flies, etc.

The household solid waste dumped in undesignated places by Harare city residents has become a breeding ground for flies, mosquitoes, cockroaches, rats, and other creatures that can potentially spread diseases (Kambuzuma 2010, Tsiko and Togarepi 2012, Magwenzi 2013, Mada and Kharlamova 2014, Milanzi 2014, Rinke *et al*. 2014, Mandevere 2015, Tanyanyiwa 2015, Kharlamova *et al*. 2016). Although residents usually build trenches where they dump their waste, leaving these open creates more potential for infestation (Chikobvu and Makarati 2011). According to Zamba (2014), most of the open waste dumping sites in Zimbabwe attract vermin due to the stagnant water and fermenting waste.

3.4.5 Water drains and sewer blockages

To dispose of their HSW, Harare city residents sometimes dump their waste in drainage ditches (Chikobvu and Makarati 2011, Mada and Kharlamova 2014). This sometimes results in the blockage of these drains or sewer systems (Tsiko and Togarepi 2012, Mandevere 2015, Nyatsanza and Ndebele 2016). Nhubu *et al*. (2017) have attributed some of the flooding occurring in Harare to waterway and storm drain blockages caused by illegally dumped waste. With the inconsistency in the HCC’s provision of waste collection services, the frequency with which water drainage systems block in one of Harare’s HD suburbs called Dzivarasekwa increased from 13-113 and 34-150 each month between 2008-2009 and 2013-2014, respectively (Nyatsanza and Ndebele 2016).

3.5 Conclusions

Waste management records in Harare date back to the 1950s when about 280 000 people occupied the city. Although waste management services offered then were adequate, various waste management issues have since plagued the city as it grew to over 2 million residents over the years. Poor HSW management has become a critical issue in Harare. In this study, the most reported causes of poor HSW management are an increase in population and population density, poor formal solid waste disposal, increase in waste volumes, open waste burning, low waste collection frequency, municipal incapacitation, low municipal waste collection efficiency, increase in waste generation rates, inadequate receptacles, and large volumes of uncollected waste, among others. All the reported factors span the city’s entire waste management system, from waste generation to waste disposal, as summarized in Table 3.2. Although less frequently reported in the literature, inadequate planning and implementation, the country’s economic meltdown, inadequate and unreliable data, limited recycling initiatives, ineffective waste management strategies, poor communication, and relationships between stakeholders are issues identified to affect all components of Harare's waste management system. Some of the consequences of not properly managing HSW include posing a health risk, blockage of water drains, vermin infestation, and pollution.

Future studies can use network analysis techniques to understand further and measure the interconnectivity, complexity, and magnitude of influence of the HSW management issues in Harare. This will allow for the identification of leverage points within the waste management system whose address can simultaneously solve many other problems, thus bringing more significant positive changes to HSW management in the city.

3.6 Acknowledgements

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4. IDENTIFYING THE LEVERAGE POINTS IN THE HOUSEHOLD SOLID WASTE MANAGEMENT SYSTEM FOR HARARE, ZIMBABWE: USING NETWORK ANALYSIS TECHNIQUES

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Abstract

Insufficient knowledge is a significant hindrance to the efficient management of household solid waste (HSW) systems in developing countries. In Harare, the management of HSW has gone beyond what the local government can handle. Understanding the complexity of the system is critical to generate appropriate waste management strategies. Network analysis (NA) techniques visually and statistically show relationships between factors affecting a phenomenon. This study used NA to identify the main leverage points within Harare's HSW management system. The results show a low network density of 1.5%, implying that the city should generate effective solutions for specific components of its HSW management system, i.e., waste generation, collection, and disposal. Some of the leverage points within the HSW management system include uncollected waste, waste collection efficiency, illegal waste dumping, economy, financial capacity, workforce capacity, waste data, waste volume, street vendors, planning and monitoring among others. Application of the 3Rs concept to address these issues would require that the municipality develop strategies to reduce waste volume, waste collection trips, uncollected waste, amount of workforce, collection pressure, and illegal waste dumping.

Keywords: Household solid waste management, network analysis, leverage points, R, Harare, Zimbabwe

4.1 Introduction

While the world is urbanizing at an unprecedented rate, HSW management complexity is increasing (Hoornweg and Bhada-Tata 2012, Vergara and Tchobanoglous 2012, Kirkman and Voulvoulis 2017). The effectiveness of HSW management strategies depends on HSW characteristics, influenced by socio-economic variables, climate, cultural and institutional factors (Vergara and Tchobanoglous 2012). Waste management strategies should consider the system structure, environmental and financial costs (Jaunich *et al.* 2019). In most cases, the 3Rs (Reduce, Reuse and Recycle) policy guides strategy formulation (Ahmadi 2017, Mohanty 2011). The 3Rs policy distributes the responsibility of waste management among different stakeholders like the municipality, communities, and private organizations. Incorporating it in waste management creates jobs, minimizes illegal waste dumping, saves landfill space, and generates additional revenue for the city (Chiu 2010). This study thus attempted to identify how the 3Rs policy is vital in addressing the city's key HSW management leverage points.

NA techniques have been used in waste management research (Caniato *et al.* 2014, Xu *et al.* 2016, Bakshan *et al.* 2017, Xu *et al.* 2018, Harvey *et al.* 2020). They help better understand the role, driving force, and links among various actors, thus identifying bottlenecks affecting efficient strategic planning and implementation (Ashton 2008, Caniato *et al.* 2014, Duygan *et al.* 2020, Ghinoi *et al.* 2020). NA techniques explore the patterns and structure of network relationships over time (Xu *et al.* 2018). This study aims to identify the potential leverage points in Harare's waste management system. This technique allowed the complexity of the waste management phenomenon in Harare to be visualized, reduced to smaller structures, and assessed more easily (Knoke and Yang 2019). There are various software that can be used to analyse networks like NetDraw, Pajek, StOCHNET, STRUCTURE, UCINET, VOSviewer, and RStudio (Huisman and Van Duijn 2005). However, this study used R, which generates network graphs and calculates network statistics.

4.2 Methodology

Since the study aims to identify the leverage points within Harare's HSW management system, quantitative methods based on NA are adopted. NA techniques visualize network data as graphs where HSW issues are represented as nodes and their relations as edges. This study annotates nodes using the numbers representing the specific HSW management issues, as summarized in Appendix 8.1. A literature study done by Kwenda *et al.* (2021b) provided research data.

A network is defined as interactions or relationships among different entities (Bródka *et al.* 2011, Srinivas and Velusamy 2015). In this study, R software is used to investigate network structure. The researcher used the commands listed in Table 4.1 below to calculate network statistics. R is an environment that uses a programming language for graphics and data analysis. Network statistics are numerical values used to describe essential properties of parts or the entire network (Brinkmeier and Schank 2005).

Table 4.1 Commands used to generate network statistics in R.

Outcome	Command
Generating a Directed Network (kamada kawai layout and circular layout with nodes size at 5)	○ *library(igraph)* ○ *HHSWM_RData<-as.matrix(HHSWM_RData)* ○ *HHSWMNetwork<-graph.edgelist(HHSWM_RData,directed=TRUE)* ○ *HHSWMNetwork* ○ *plot(HHSWMNetwork)* ○ *kamadaLayout<-layout.kamada.kawai(HHSWMNetwork)* ○ *plot(HHSWMNetwork, layout = kamadaLayout, vertex.size = 5, vertex.color = "tomato", vertex.frame.color = NA, vertex.label.cex =.7, edge.curved = .1, edge.arrow.size = .3, edge.width = .7)* ○ *plot(HHSWMNetwork,vertex.label.cex=.6, vertex.label.color="black",vertex.color = "tomato", vertex.size = 5,layout=layout_in_circle)*
Degree centrality	○ *degree(HHSWMNetwork, mode = 'all')* ○ *degree(HHSWMNetwork, mode = 'in')*
Betweenness centrality	○ *betweenness(HHSWMNetwork,directed = TRUE)*
Average path length	○ *average.path.length(HHSWMNetwork, directed = TRUE, unconnected = TRUE)*
Network density	○ *edge_density(HHSWMNetwork, loops = F)*
Network diameter	○ *diameter(HHSWMNetwork, directed = F, weights = NA)*
Network edges	○ *ecount(HHSWMNetwork)*
Network size	○ *vcount(HHSWMNetwork)*
Generating a directed Network (kamada kawai layout and circular layout with node size according to degree centrality and betweenness)	○ *V(HHSWMNetwork)$degree<-degree(HHSWMNetwork)* ○ *plot(HHSWMNetwork,vertex.label.cex=.8, vertex.label.color="black",vertex.size= (V(HHSWMNetwork)$degree/1),layout=layout_in_circle)* ○ *V(HHSWMNetwork)$betweenness<-betweenness(HHSWMNetwork,directed = TRUE)* ○ *plot(HHSWMNetwork,vertex.label.cex=.8, vertex.label.color="black",vertex.size= (V(HHSWMNetwork)$ betweenness/25),layout=layout_in_circle)* ○ *plot(HHSWMNetwork,vertex.label.cex=.8, vertex.label.color="black",vertex.size= (V(HHSWMNetwork)$degree/1),layout= kamadaLayout)* ○ *plot(HHSWMNetwork,vertex.label.cex=.8, vertex.label.color="black",vertex.size= (V(HHSWMNetwork)$ betweenness/25),layout= kamadaLayout)*
Generating 300ppi Rplots (e.g degree centrality plot)	○ *setwd("C:/Users/KWENDA PHYLLIS/Desktop/")* ○ *jpeg(file = "RPlot_Degree.jpeg", width=2300, height=2000, res=300)* ○ *plot(HHSWMNetwork, vertex.label.cex=.8, edge.arrow.size = .2, edge.color = "green", vertex.label.color="black",vertex.color = "tomato", vertex.size= (V(HHSWMNetwork)$degree/1))* ○ *dev.off()*

The study used degree and betweenness centrality values calculated in R as measures of influence of the HSW issues within the network (Yan and Ding 2009, Maharani and Gozali 2014, Srinivas and Velusamy 2015, Ergün and Usluel 2016, Xu *et al.* 2021).

4.3 Results and Discussions

Complex systems are entities characterized by the interaction of multiple components (Hmelo-Silver and Azevedo 2006, Liu *et al*. 2013). They are often difficult to understand and forecast as they are usually multifaceted and dynamic (Hmelo *et al*. 2000, Hmelo-Silver *et al*. 2007, Skarzˇauskieneˊ 2010). However, network statistics estimate network complexity.

Fig. 4.1a) and b) below shows networks developed in R based on each node's degree and betweenness centrality values, respectively. The greater the degree centrality of a node, the greater the number of nodes linked to that given node (Yan and Ding 2009, Bródka *et al*. 2011, Srinivas and Velusamy 2015). Degree centrality is an easy method of identifying influential actors in a network (Maharani and Gozali 2014, Srinivas and Velusamy 2015). On the other hand, nodes with high betweenness centrality have a greater power to connect to other nodes and connect clusters within a network (Yan and Ding 2009). These are key in the flow of change or influence within a low-density network like that of Harare.

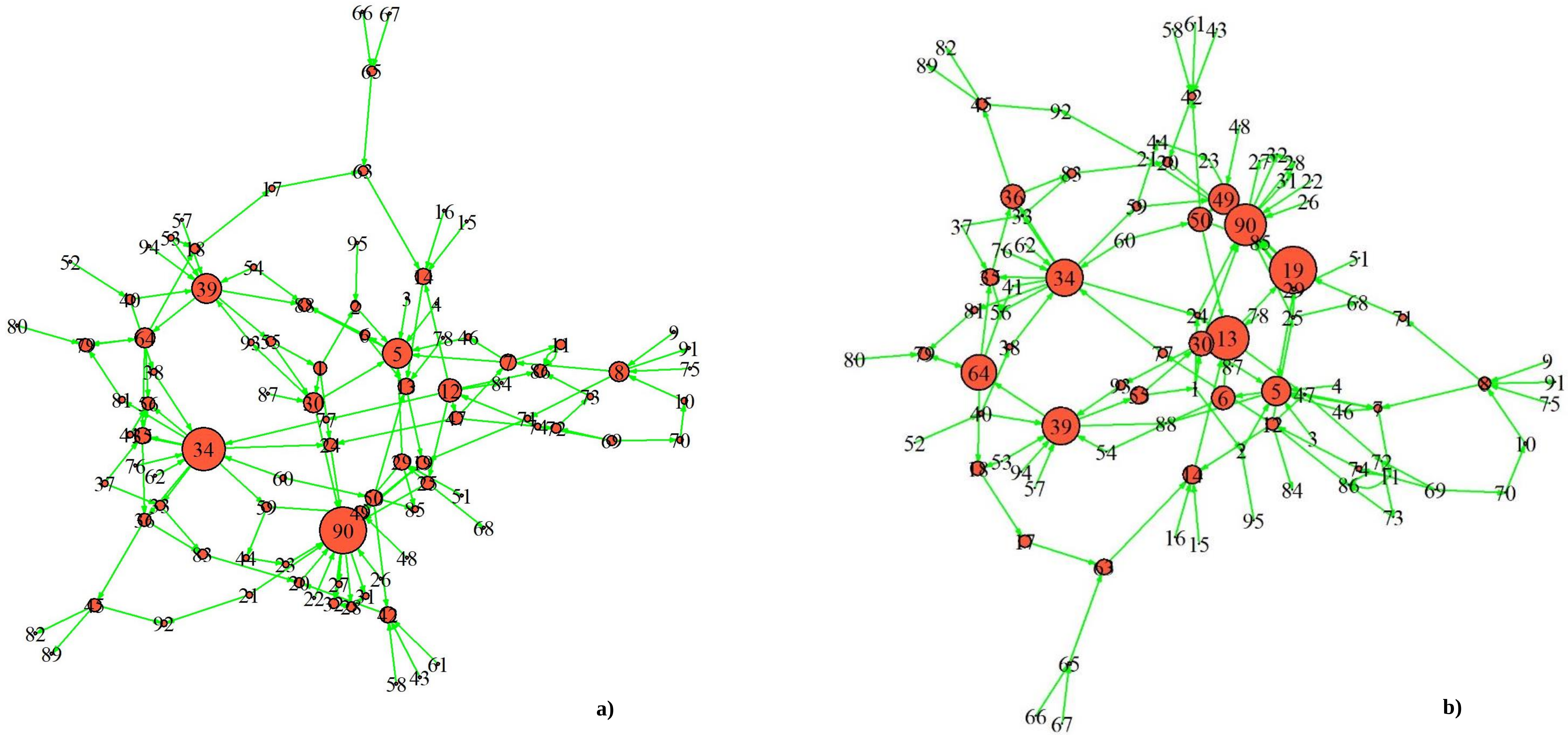

Figure 4.1 Network developed in RStudio with node size calculated from node degree centrality a), and betweenness centrality b).

As shown in Table 4.2 below, the difference in the order of some HSW management issues when ranked using degree centrality values instead of betweenness centrality values suggests that the degree centrality value does not reflect how much influence a node carries in the network.

Table 4.2 Top 20 HSW management issues in Harare in descending order of influence based on degree and betweenness centrality, respectively.

	Degree centrality	Betweenness centrality
1	Illegal waste dumping (14)	Uncollected waste (337.5)
2	Financial capacity (13)	Waste collection efficiency (316)
3	Economy (9)	Illegal waste dumping (300)
4	Waste volume (9)	Economy (269)
5	Socio-economic class (7)	Financial capacity (268)
6	Population (6)	Workforce capacity (253)
7	Street vendors (6)	Waste data (217)
8	Workforce capacity (6)	Waste volume (210)
9	Consumption (5)	Street vendors (181)
10	Waste collection efficiency (5)	Planning and monitoring (176)
11	Waste collection frequency (5)	No engineered landfills (173.5)
12	Perceptions (5)	Waste collection pressure (170)
13	Technical capacity (5)	Waste collection frequency (135.5)
14	Waste recovery (5)	Unemployment rate (126)
15	Planning and monitoring (5)	Technical capacity (124)
16	Uncollected waste (4)	Waste collection vehicles (117)
17	Waste data (4)	Vehicles maintenance (102)
18	No engineered landfills (4)	Socio-economic class (91.5)
19	Worker strikes (4)	Vehicles breakdown (91)
20	Access control (4)	Population (90)

The size of the HSW management network is 95, the number of edges 138, network density 1.5%, and the number of clusters 15. The low network density and the high number of clusters suggest that solutions must be implemented in various parts of Harare's HSW management system for significant impact.

The Pareto principle, also known as the 80:20 rule, states that fewer causes can be responsible for most effects within systems (Sanders 1987, Kiremire 2011, Teich and Faddoul 2013, Vishal and Bhattacharya 2013, Ivančić 2014, Rathi *et al*. 2016). This principle can be vital in improving the decision-making process as it helps identify the fundamental problems to prioritize (Izzard 2006, Grosfeld-Nir *et al*. 2007, Ivančić 2014). The Pareto principle has been previously applied in waste management decision-making (Contreras *et al*. 2008, Perera and Navaratne 2016, Rathi *et al*. 2016, Samuel *et al*. 2019). The principle suggests that prioritizing solving the top 20% of the critical issues in an organization will yield the most significant change within the system. The principle was applied in this study, and the results are as shown in Table 4.2 above.

To observe how the most significant issues (those ranked according to betweenness centrality values) are placed within the clusters that make up the network, Table 4.3 below was developed. The table shows the HSW management issues in each of the 15 clusters in the network, while the most influential issues are highlighted in red. At least one key issue is in each cluster except clusters 11, 13, and 14. This agrees with the interpretation of the low network density of 1.5%, which suggests that various strategies be 'seeded' within the network for effective change to be observed in the entire system. These results thus indicate that Harare should prioritize developing strategies that address these 20 issues to effect significant change as these are its key leverage points within the system.

Table 4.3 Clusters in Harare's HSW management network

Unemployment	**Cluster 2** (9)	**Cluster 3** (8)
11 Changes in waste consumption patterns 3 Operation Murambatsvina 4 Festive season 46 Waste generation rate 47 Disposable income 5 Waste volume 7 Consumption 72 Black access to goods and services 73 Processed products 86 Changes in waste composition patterns	34 Financial capacity 41 Municipal expansion 56 Municipal capacity 62 Loans 64 Workforce capacity 76 Corruption 79 Worker strikes 80 PPE 81 Salaries	1 Poverty 2 Urban agriculture 24 Receptacle availability 30 Street vendors 55 Unemployment rate 87 HIV/AIDS epidermic 93 National informal economy 95 Weather
Cluster 4 (8)	**Cluster 5** (7)	**Cluster 6** (7)
13 Waste collection efficiency 39 Economy 54 Hyperinflation 57 Multicurrency 6 Waste collection pressure 78 Communication 88 Cost of service provision 94 National formal economy	17 Vehicles breakdown 18 Vehicles maintenance 53 Foreign currency 63 Waste collection vehicles 65 Fuel 66 Fuel cost 67 Distance from disposal site	25 Waste management knowledge 29 Perceptions 50 Planning and monitoring 51 Gender 60 Billed properties 68 Community participation 85 Strategy implementation
Cluster 7 (7)	**Cluster 8** (7)	**Cluster 9** (6)
10 Urbanization 12 Socio-economic class 69 Colonization 70 Travel regulations 74 Racial segregation 77 Waste collection fee 84 Waste transfer to poorer suburbs	22 Waste burying 26 Home ownership 27 Mosquito and rodent manifestation 28 Sewer blockages 31 Environmental pollution 32 Health risk 90 Illegal waste dumping	19 Uncollected waste 71 Illegal settlements 75 Capita city 8 Population 9 Natural population increase 91 Population density
Cluster 10 (6)	**Cluster 11** (5)	**Cluster 12** (5)
20 Crude waste dumping 33 Sanitary landfilling operations 35 Technical capacity 36 No engineered landfills 37 Landfill equipment 83 Sanitary formal solid waste disposal	21 Open waste burning 45 Access control 82 Fights 89 Accidents 92 Dumpsite fires	23 Waste law enforcement 44 Waste policy 48 Weighbridge at dumpsite 49 Waste data 59 Research
Cluster 13 (4)	**Cluster 14** (3)	**Cluster 15** (3)
42 Waste recovery 43 Waste separation at source 58 Private companies 61 Recyclers	38 Donor funding 40Political instability 52 Land reform program	14 Waste collection frequency 15 Harare waste collection policy 16 Suspension of waste collection services

In and out-degree values in Appendix 8.2 identified network drivers and outcomes among Harare's key HSW management issues. The issues with higher in-degree centrality than out-degree centrality were classified as network outcomes, while the vice-versa were classified as network drivers, as shown in Table 4.4 below. Drivers are issues that influence more issues than they are influenced, while outcomes are vice versa. This information is essential in developing strategies because in addressing a driver, the focus is placed on the driver, e.g., to improve financial capacity, solutions are built around making funds available. In contrast, for an outcome like illegal waste dumping, it would require that the factors contributing to this issue, e.g., uncollected waste or street vendors, among others, be identified and addressed. Issues that qualify as both drivers and outcomes have the same in and out-degree centrality values. For example, uncollected waste, strategy development approaches applicable for both outcomes, and drivers need to be applied to address it.

Table 4.4 Classification of key HSW management issues into either drivers or outcomes

	Key HSW management issues	Driver/ outcome
1	Uncollected waste (337.5)	Driver/ outcome
2	Waste collection efficiency (316)	Outcome
3	Illegal waste dumping (300)	Outcome
4	Economy (269)	Outcome
5	Financial capacity (268)	Driver
6	Workforce capacity (253)	Driver
7	Waste data (217)	Outcome
8	Waste volume (210)	Outcome
9	Street vendors (181)	Driver/outcome
10	Planning and monitoring (176)	Driver
11	No engineered landfills (173.5)	Driver/outcome
12	Waste collection pressure (170)	Driver
13	Waste collection frequency (135.5)	Outcome
14	Unemployment rate (126)	Driver
15	Technical capacity (124)	Outcome
16	Waste collection vehicles (117)	Outcome
17	Vehicles maintenance (102)	Outcome
18	Socio-economic class (91.5)	Driver
19	Vehicles breakdown (91)	Driver/outcome
20	Population (90)	Driver/outcome

The potential impact areas of policy change in this study are summarized in Table 4.5 below. The 3Rs concept was applied to the waste management system in Harare while prioritizing the key issues outlined in Table 4.4 above.

Table 4.5 Potential application of the 3Rs policy in Harare's waste management system.

Waste Generation	Waste Collection and Transport	Waste Disposal
Reduce waste volume. - Avoid unnecessary consumption, thus reducing the waste generation rate. - Introduce taxes on all production companies equating to the amount of waste generated by consumers using their products. The taxes will be used to fund initiatives to recover this waste.	**Reduce** the number of waste collection trips. -increase waste collection efficiency by a) improving planning and monitoring, e.g., on issues like vehicle routing efficiency. However, this would entail that a) proper waste data collection methods be employed, b) increase waste collection capacity by improving waste vehicle maintenance and repairs, and c) Increase waste collection frequency by adjusting the city's waste collection policy.	**Reduce** illegal waste dumping. -Work on building a sanitary engineered landfill. -Increase the technical and financial capacity of the local authorities to conduct sanitary waste disposal operations. -Reduce the number of illegal street vendors, which minimizes waste disposal in undesignated areas.
	Reduce the amount of uncollected waste. -Increase waste collection efficiency, e.g., by increasing waste collection capacity. **-** Waste collection capacity can be increased by increasing the number of waste collection vehicles available. This can be done by reducing the number of vehicle breakdowns through offering improved vehicle maintenance and improving the financial capacity of the council to procure more vehicles.	
	Reduce the amount of workforce required. (Instead of working on increasing the workforce which it might not afford to, the local authority can work on reducing it by diverting some responsibilities to external companies thus ensuring efficiency in operations) - This can be done by contracting other private waste collection service providers and vehicle maintenance companies to service the waste management fleet. -	
	Reduce waste collection pressure -This can be done by encouraging waste recovery through **recycling, reuse,** and or composting. This then will reduce the amount of waste the city council needs to collect.	

Generally, although most developing countries are making efforts, most of their municipalities cannot efficiently manage the increasing solid waste volumes (Van de Klundert and Lardinois 1995). With the increase in population, urbanization, and standard of living, among other things, Zimbabwe is no exception. Due to limited funds and expertise, some of the strategies suggested in Table 4.5 above might be better adopted as long-term plans for the city of Harare (Kwenda *et al.* 2021b). For example, increasing waste collection frequency, increasing waste collection capacity, building sanitary engineered landfills, establishing a planning and monitoring department, and increasing technical capacity. Other strategies like taxing companies producing waste-generating products require time to develop and enforce, while decreasing the number of street vendors might prove difficult given the economic crisis in the country. However, reducing waste generation rate, waste recovery, and privatizing some waste management operations are strategies that future studies can assess for adaptation as a short-term response to the household solid waste management crisis. These can potentially reduce waste volume, reduce uncollected waste, reduce the workforce needed, reduce waste collection trips, reduce waste collection pressure, and reduce illegal waste dumping, thus addressing most of the key leverage points within the HSW management system as identified through NA.

4.4 Conclusions

The top 20% key leverage points in Harare's waste management system are uncollected waste, waste collection efficiency, illegal waste dumping, economy, financial capacity, workforce capacity, waste data, waste volume, street vendors, planning and monitoring, no engineered landfills, waste collection pressure, waste collection frequency, unemployment rate, technical capacity, waste collection vehicles, vehicles maintenance, socio-economic class, vehicles breakdown, and population. Application of the 3Rs concept to address these issues would require that the municipality develop strategies to reduce waste volume, waste collection trips, uncollected waste, amount of workforce, collection pressure, and illegal waste dumping. Among other possible strategies suggested in this study for Harare's HSW management system, reducing waste generation rate, waste recovery, and privatizing some waste management operations are potential short-term solutions that future studies can assess for implementation. These are likely to reduce waste volume, reduce uncollected waste, reduce workforce needed, reduce waste collection trips, reduce waste collection pressure, and reduce illegal waste dumping, thus addressing most of the key leverage points within the city's waste management system.

4.5 Future Recommendations

Future research can use the findings of this study to formulate a Causal Loop Diagram and ultimately a system dynamics model that simulates the HSW management system in Harare. The model can then be used for decision-making by the relevant authorities and in waste policy development.

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5. COMMUNITY-BASED MANAGEMENT OF HOUSEHOLD SOLID WASTE FOR HARARE, ZIMBABWE: A SYSTEM DYNAMICS APPROACH

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Abstract

Community-based waste management (CBWM) is a waste decentralization approach that carries the potential to divert about two-thirds of household solid waste (HSW) from landfills. Although many studies have suggested this approach to waste management in the city, assessment studies to quantify its material recovery potential are yet to be conducted. This is the gap this study thus aimed to fill. Due to the complex nature of the HSW management system, the study used Network Analysis (NA) findings to inform the development of a system dynamics model. The model was used to assess household-level composting of food leftovers as well as paper and plastic recycling as strategies towards sustainable and integrated HSW management in Harare. A CBWM strategy implementation chart (CBMW-SIC) that describes four different strategy implementation levels and their potential benefits for Harare if implemented over the next 5-year municipal period (2022-2026) was formulated. According to the author's knowledge, combining NA and SD techniques as done in this study is original.

Hereafter only referred to as Harare, urban Harare currently realizes an average recycling rate of 5.2% (recycled waste as a percentage of the total HSW generated in the city). However, composting all food leftovers and recycling of 50% paper and plastic in the next municipal period of 2022-2026 is likely to increase it to 34.1%, 41.6%, 51.8%, and 63.1% with each level of strategy implementation. On the other hand, uncollected waste will be reduced by 28%, 55.9%, 55.9% and 62.3%, respectively. Illegally dumped waste is potentially reduced from 224 854tons.yr^{-1} to 186 009tons.yr^{-1}, 178 496tons.yr^{-1}, 147 440tons.yr^{-1}, and 112 866tons.yr^{-1}, at each implementation level respectively. Controlled waste treatment in the city will also be increased by up to 38.3%. Generally, composting food leftovers is better prioritized in High-Density (HD) and Medium-Density (MD) suburbs, where food waste comprises 33% of the HSW generated. Since HD suburbs carry most of the city population, recycling paper and plastic is also better prioritized here. Overall, Harare can achieve better recycling rates when mixed strategies are applied.

Keywords: Recycling, composting, household solid waste, Harare, community-based waste management, system dynamics

5.1 Introduction

The prevalence of poor municipal solid waste (MSW) management is a primary global concern (Cervantes *et al*. 2018). While MSW refers to all solid waste produced within a municipality, HSW refers to all waste generated in residential areas. Although mainly consisting of HSW, MSW comprises other waste streams from commercial areas, construction/ demolition sites, and institutions (Hargreaves *et al.* 2008, Sharholy *et al.* 2008).

In developing countries, funds to efficiently manage HSW are often insufficient (Sanjeevi and Shahabudeen 2015, Mandevere 2015). As a result, most municipalities in these countries prioritize waste collection and dumping in landfill sites without prior treatment (Sekito *et al.* 2013). Zimbabwe is a developing country in Southern Africa. Poor HSW management is one of the most significant challenges faced (Tsiko and Togarepi 2012). Despite the relevant authority's full acknowledgment of the HSW management issues, the strategies used so far have proven ineffective (Chikobvu and Makarati 2011, Zamba 2014, Mandevere 2015, Nhubu *et al*. 2019a).

Harare is the capital city of Zimbabwe. Located in the Northern part of Zimbabwe, the city covers an area of 961km^2 and carries a population of 1 851 620 (Mandishona and Knight 2019, HCC 2019). Kwenda *et al.* (2021c) recently published an article extensively describing Harare's HSW management system. Residents in Harare are responsible for sourcing receptacles for HSW storage. There are no transfer stations in Harare. Kerbside collection is the primary method used by the municipality to remove HSW waste from residential areas (Kwenda *et al.* 2021c). The average recycling rate in the city is about 5.2%, with most recycling done at the city's formal dumpsite, Pomona. About 220 waste pickers licensed to work at the dumpsite sell their recovered waste to recycling companies around Harare (Kwenda *et al.* 2021b).

Harare's increase in municipal service demand has not supported infrastructure development, mainly due to financial constraints (Rinke *et al*. 2014, Mandevere 2015). Some of the consequences that poor HSW management has posed for the city include environmental pollution, foul odors, vermin infestation, death, and blockage of sewer systems, among other things (Nhapi 2008, Mandevere and Jerie 2018, Nhubu *et al.* 2019b).

Nhubu *et al*. (2019a) identified that little to no research has been done so far using Harare as a case study to assess the city's integrated solid waste management options. Due to Harare municipality's financial limitations, recent studies are looking into the potential benefits of community participation in HSW management (Chikowore, 2021). There have been reports that Harare has taken up about 3 500 anti-litter monitors within its communities who have proven effective in raising waste management awareness (Zambezi *et al.* 2021). Moreso, Kanonhuhwa and Chirisa (2021) suggested food waste recycling at the household level for urban Zimbabwe to reduce waste collection pressure on the already compromised municipalities. Nhubu *et al.* (2021) also explored the various decentralization options for Harare to ensure sustainability among which included backyard composting at household level (i.e composting of HSW) and waste separation at source for material recovery explored in this study. However, Nhubu *et al.* (2021) did not, but rather suggested that assessment studies to quantify material recovery potential, among other things, be conducted at local level. This is the knowledge gap the study intends to fill. This study thus aims to assess the potential impact of a CBWM system on Harare using system dynamics (SD) modelling techniques. A CBWM system uses separation at source and composting to manage HSW within communities. The system saves landfill space, is low-cost, reduces waste collection pressure, is effective, and increases revenue if the compost generated is sold (Sekito *et al.* 2013).

Over the decades, several models have been developed to support decision-making tools (Hung *et al.* 2007). As cities continue to grow, models need to be revised to achieve optimal sustainability (Simatele *et al.* 2017). SD is a 60-year-old methodology based on feedback control theory used to study complex systems like waste management (Towill 1993, Wang *et al*. 2013). This methodology has been widely used in waste management planning (Ahmadvand *et al.* 2014, Eleyan *et al.* 2013, Hao *et al.* 2008). STELLA is a user-friendly system dynamic modelling graphical software that helps local governments achieve optimal planning objectives in MSW, hence its preference in this study (Laganis and Debeljak 2006). For example, the software has been used to develop an SD model for MSW strategy and policy analysis in (Khulna city) Bangladesh, (Tianjin) China, and Pakistan (Kauser and Muhammad 2020, Rafew and Rafizul 2021, Wang and You 2021).

5.2 Methodology

The flow of HSW in Harare's current waste management system compared to the proposed CBWM system is illustrated in Fig. 5.1 below. The performance of the HSW management system in Harare is measured using waste management indicators listed in the Service Level Benchmarking (SLB) chart given in Appendix 8.3. The municipality provided SLB data for the years 2013-2019. The SLB chart uses a set of indicators to assess the annual performance of local authorities. An indicator can act as a descriptive or evaluative function that synthesizes any relevant data to describe complex phenomena or measure the state of a phenomenon over time (Cervantes *et al*. 2018).

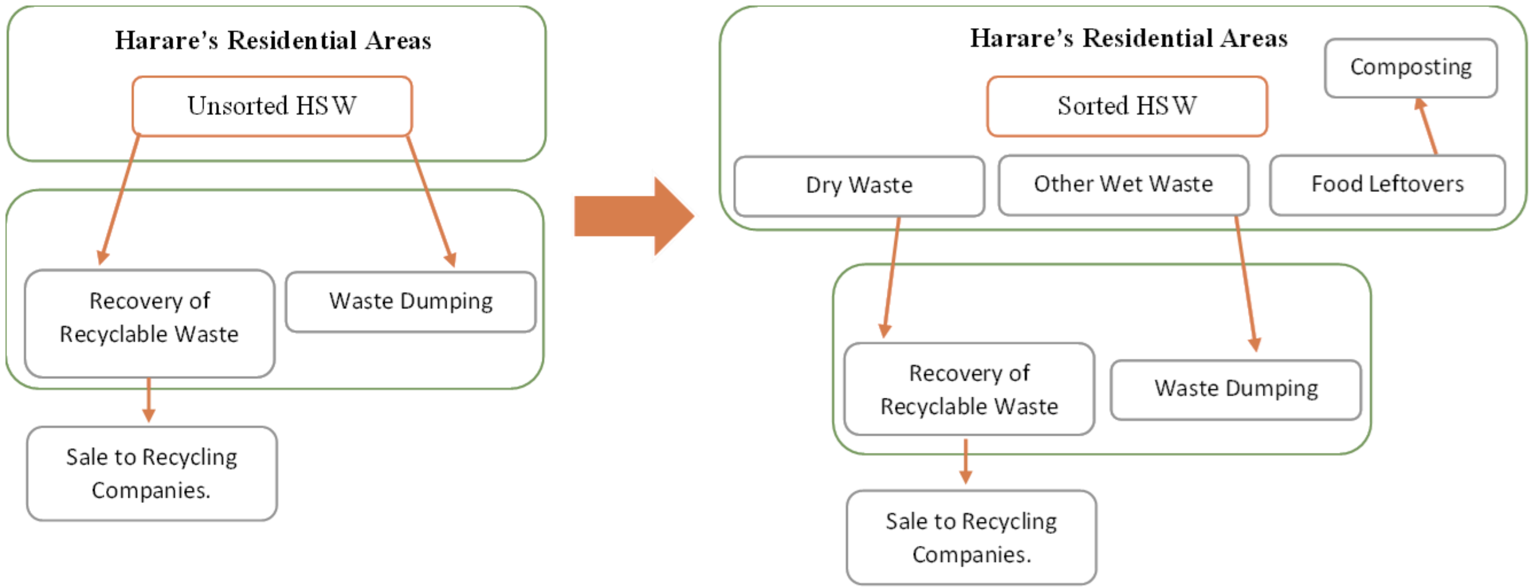

Figure 5.1 Harare's current versus the proposed HSW streamflow.

5.2.1 Model development and training

In 1960, Professor J Forrester developed an information feedback methodology called System Dynamics (SD) (Ding *et al*. 2018). This methodology simulates the dynamic nature of various elements within waste management systems. It allows for studying interactions between variables in a complex system over time (Sukholthaman and Sharp 2016, Chaerul *et al.* 2008). It is ideal for policy impact assessment, e.g., in waste generation, waste processing, and waste management options (Xiao *et al.* 2020). In this study, a modified process of SD modelling according to Sterman (2000) was adopted as illustrated in Figure 5.2. In addition to five phases of SD modeling, this study included an initial and additional Network Analysis (NA) phase as shown in Figure 5.2 b).

Apart from the waste management system elements that facilitates waste generation, collection and disposal, there are other aspects that need to be managed to ensure sustainability. For example, financial, institutional, socio-cultural, environmental, legal or policy aspects as well as the importance of stakeholder cooperation (Khatib, 2011). The addition of the NA phase to the modeling process was thus designed not only to identify the leverage points within Harare's HSW management system but to also understand the parts of the system that can be simulated given the available data. The NA phase of the modeling process is as presented in Chapter 4 of this thesis. According to the author's knowledge, the combination of NA and SD as done in this study is original.

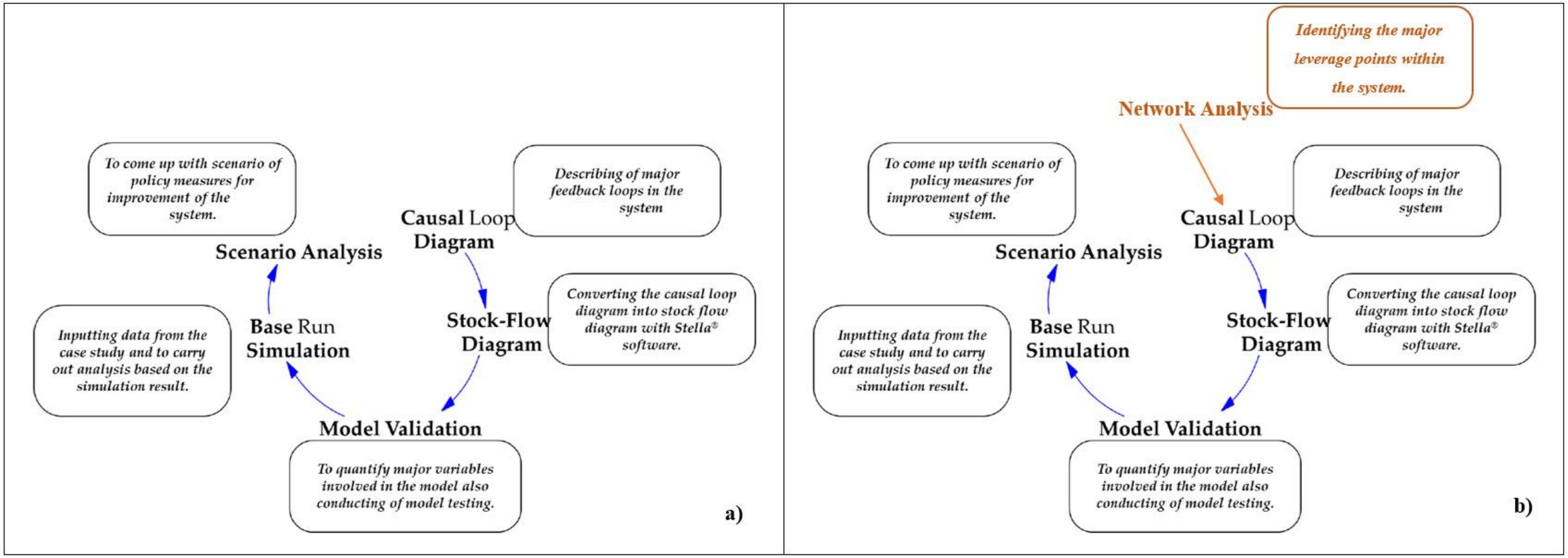

Figure 5.2 The System Dynamics modeling process a) according to Sterman (2000) as illustrated by Babalola (2019) and b) as modified in this study.

Despite findings showing the existence of issues around low stakeholder cooperation, existence of ineffective policies, and negative environmental impact of poor HSW management, the NA study summarized in Chapter 4, revealed that the leverage points within Harare's HSW system are uncollected waste, low waste collection efficiency, illegal waste dumping, bad economy, low financial capacity, low workforce capacity, unreliable waste data, high waste volume, increase in street vendors, no planning and monitoring, no engineered landfills, high waste collection pressure, low waste collection frequency, high unemployment rate, low technical capacity, few waste collection vehicles, low vehicles maintenance, difference in socio-economic classes, high rates of vehicles breakdown, and high population. Applying the 3Rs principle while prioritizing these leverage points suggested that the municipality develop strategies to reduce waste volume, waste collection trips, uncollected waste, amount of workforce, collection pressure, and illegal waste dumping. As a result, and given the municipal data available as summarized in Appendix 8.3 for the years 2013-2019, focus was placed on simulating particularly the elements (waste generation, collection, disposal and recycling) of the Harare's HSW management system as well as the factors immediately affecting them. Thus, the Causal Loop Diagram (CLD), shown in Fig. 5.3 was built to guide the development of the HSW SD model. The CLD describes the relationships between system elements as well as the relevant performance indicators used to assess solid waste management in Harare.

The Causal Loop Diagram (CLD) was developed using STELLA. The direction and polarity of the arrows show the influence that one variable has on another or rather describe a cause-and-effect relationship between variables. These were determined based on literature studies described in Chapter 3. Various issues affect the HSW management system in Harare. However, the system's leverage points identified in Chapter 4 and the availability of the relevant data were key determinants in selecting the components of the CLD. The arrows in bold show the relationships of variables considered in this study. In contrast, the dotted arrows indicate the existence of some direct links between these variables and others that could not be explored due to the unavailability of data. Identifying and understanding reliable associations between time-series data can be vital in understanding interactions within a system (Xia *et al.* 2015).

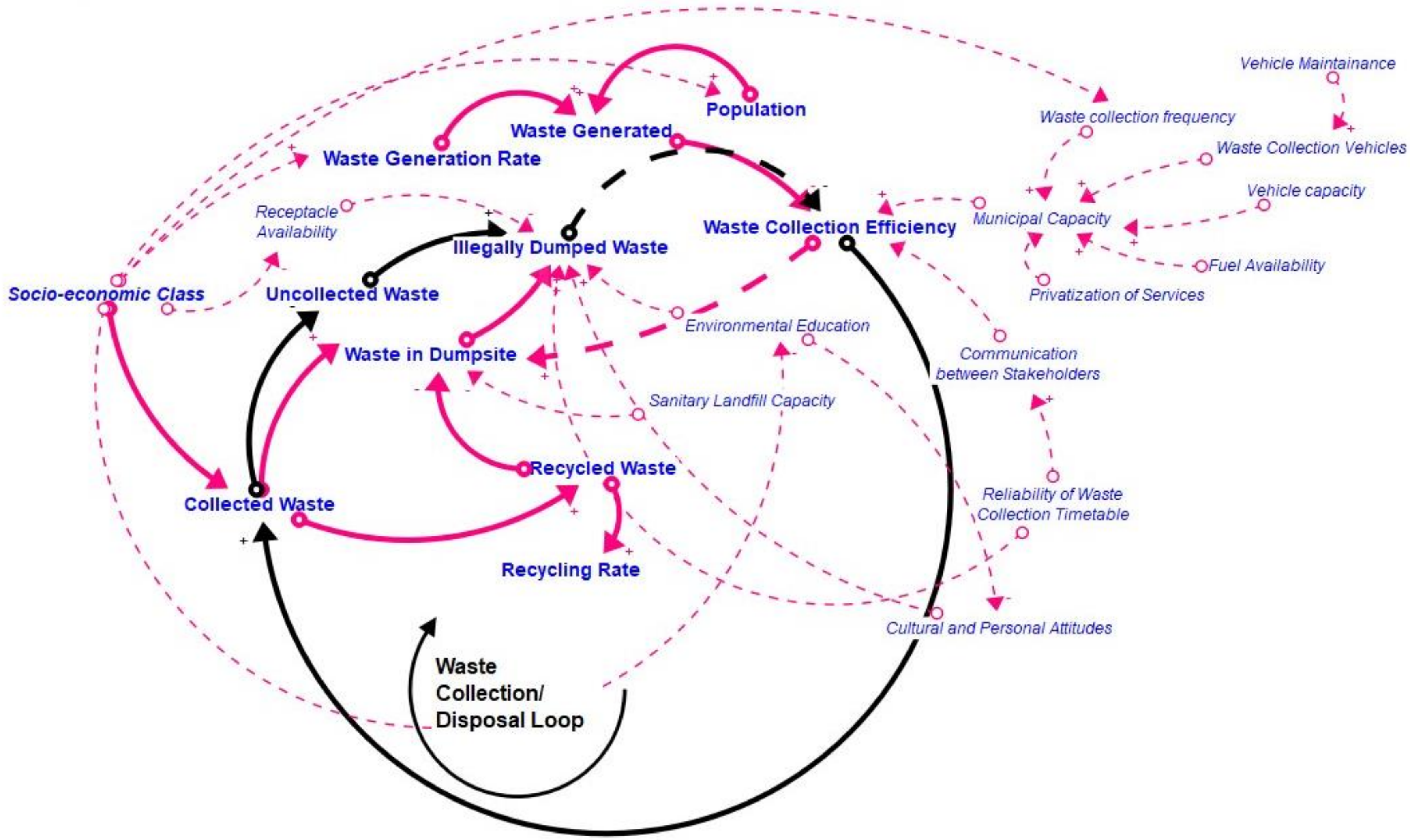

Figure 5.3 Causal loop diagram used to develop the HSW model.

As shown in Fig. 5.3 above, the HSW generated in Harare is directly proportional to population and waste generation rate. The higher the socio-economic class (Low-Density ~10% of the city population, Medium-Density ~30% of the city population, High-Density ~60% of the city population), the higher the population it carries. Waste collection efficiency in Harare depends on the capacity of the municipality to collect the generated waste. In turn, it is determined by factors such as waste collection frequency, the number of waste collection vehicles available, the capacity of the vehicles by weight, the availability of fuel for the waste collection vehicles, and the privatization of part or the entire waste collection service provision. Moreso, issues like poor communication between residents and the municipality concerning waste collection times results in lesser volumes of collected waste. Lower waste collection efficiency thus results in higher amounts of uncollected waste remaining in the suburbs and hence illegal disposal of the waste by residents becomes more prevalent. All collected HSW in Harare ends up in the unsanitary dumpsite, Pomona. As a result, an increase in collected waste means an increase in waste dumped in Pomona hence an increase in the amount of waste illegally dumped. With low waste collection rates, limited environmental education, low reliability of the waste collection timetable, and differences in cultural or personal attitudes, residents resort more to illegal waste dumping before waste collection dates. This contributes to lower waste collection efficiency as there is reduced volumes available for collection per collection area covered. With most recycling done at the Pomona dumpsite, the greater the amount of waste dumped, the higher the waste recycled. Increasing the amount of recycled waste and reducing the amount of waste generated improves recycling rates in Harare.

The Harare municipality provided data used in model development for the years 2013-2019. The HSW model comprises three components: waste generation, collection, and disposal, as shown in Fig. 5.4 below.

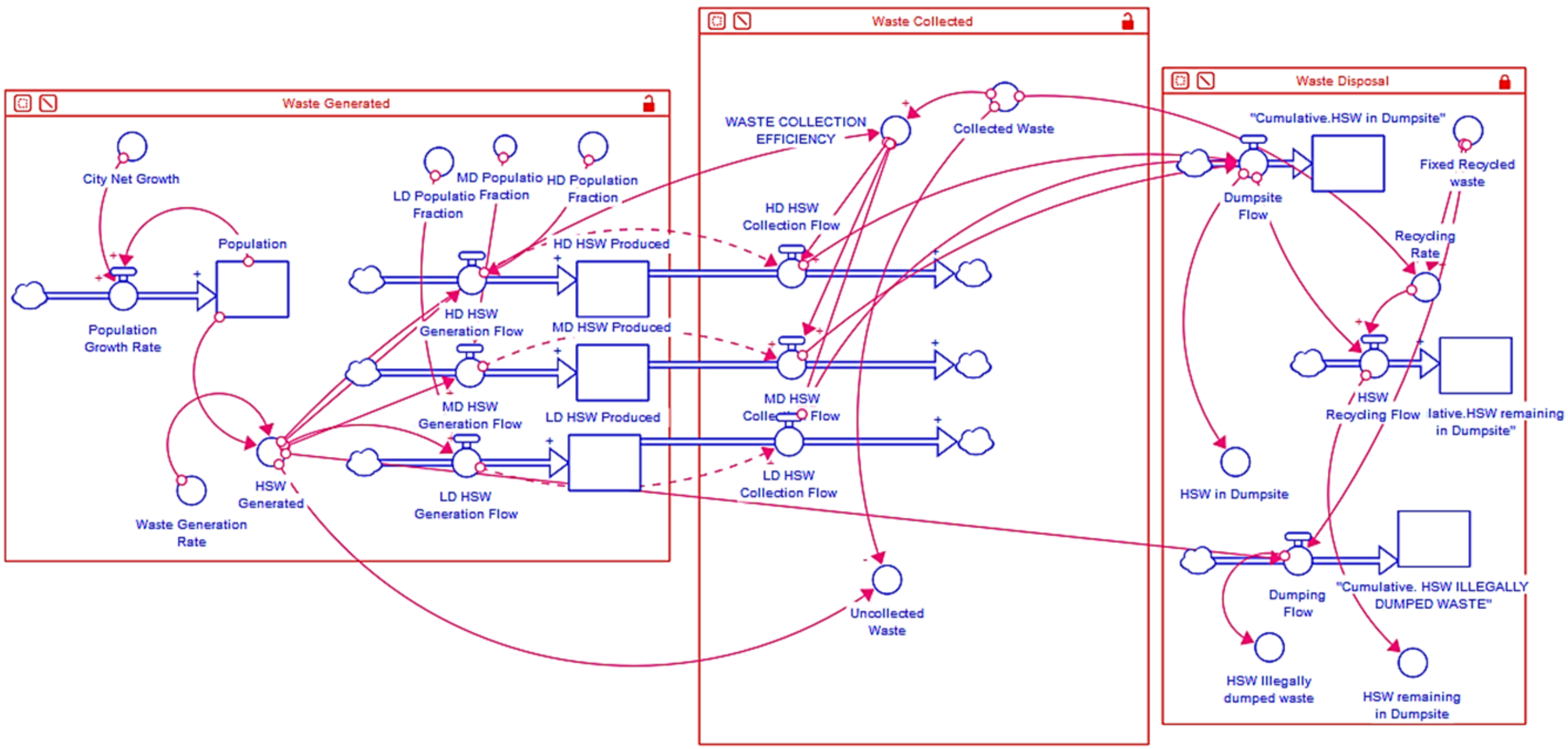

Figure 5.4 The SD model for HSW management in Harare.

5.2.1.1 Waste generation sub-model

The waste generation sub-model captures waste generation in Harare using the indicators waste generation rate and population. According to the last census report for Zimbabwe in 2012, net population growth and population in Harare is 3.2% and 1 485 231, respectively (Zimstat 2012). Population in the model was calculated using Eq. 2, derived from Eq. 1. An assumption made in this calculation is that the net population growth estimated for Harare in the 2012 census remained the same over the years.

$$\frac{dP_u(t)}{dt} = P_u(t) * P_g \quad \textbf{(1)}$$

$$P_u(t) = P_i e^{P_g * t} \quad \textbf{(2)}$$

Where: $\boldsymbol{P_i}$ is the initial Harare population of 1 485 231,

$\boldsymbol{P_g}$ is the population net growth of value 3.2%, and

$\boldsymbol{P_u}$ is the Harare population at a given time $\boldsymbol{t}$.

Waste generated ($\boldsymbol{W_t}$) was calculated using Eq. 3.

$$\boldsymbol{W_t = P_u * W_g} \quad \textbf{(3)}$$

Where: $\boldsymbol{W_g}$ is the waste generation rate with a value of 0.1407 tons.capita^{-1}.year^{-1}. This is the average waste generation rate calculated from the municipal data, and

$\boldsymbol{P_u}$ is the Harare population at a given time $\boldsymbol{t}$.

This value also agrees with literature that identifies that $\boldsymbol{W_g}$ in developing countries ranges from 0.073-0.292 tons.capita^{-1}.year^{-1} (Jadoon *et al.* 2014, Kumar and Samadder 2017, Sujauddin *et al.* 2008).

5.2.1.2 Waste collection sub-model

When formulating waste management strategies in developing countries, it is critical to consider socio-economic status (Chikowore 2021). There is no waste generation per capita data for each of the different socio-economic classes in Harare. As a result, the total waste generated in Harare ($\boldsymbol{W_t}$) was separated into that produced in the different socio-economic classes HD, MD, and LD using Eq. 4.

$$\boldsymbol{W_s = P_f * W_t} \quad \textbf{(4)}$$

Where: $\boldsymbol{W_s}$ is waste generated in socio-economic class *s*, and

$\boldsymbol{P_f}$ is the population fraction of the socio-economic class. It was calculated using Eqn. 5.

Municipal data show that the estimated population fractions for HD, MD, and LD suburbs are 0.6, 0.3, and 0.1, respectively (HCC, 2019).

$$\boldsymbol{P_s = P_f * P_u} \tag{5}$$

Where: $\boldsymbol{P_s}$ is the population in the socio-economic class,

$\boldsymbol{P_f}$ is the population fraction, and

$\boldsymbol{P_u}$ is the population at time $\boldsymbol{t}$.

The waste collection efficiency ($\boldsymbol{E}$) was calculated using Eq. 6.

$$\boldsymbol{E = C_t/W_t} \tag{6}$$

Where: $\boldsymbol{C_t}$ is the waste collected of 157 486 tons.year^{-1}. This value is the average waste collected value calculated from the municipal data.

5.2.1.3 Waste disposal sub-model

The waste disposal sub-model captures the primary disposal methods used in Harare, i.e., waste dumping and recycling. The waste management indicators, namely recycling rate and recycled waste, were simulated in this model. All HSW collected by the local authorities ends up in the city's official dumpsite, Pomona, where most recycling happens. Eq. 7 was used to calculate the amount of waste dumped ($\boldsymbol{D}$) in Pomona.

$$\boldsymbol{D = \sum_{s=1}^{3} C_s} \tag{7}$$

Where: $\boldsymbol{C_s}$ is the amount of waste collected from different socio-economic classes (tons) and $\boldsymbol{C_1, C_2, C_3}$ represents the amount of waste collected from LD, MD, and HD suburbs, respectively.

To calculate waste recycling rate ($\boldsymbol{R_r}$) in the model, Eq. 8 was used.

$$\boldsymbol{R_r = R/W_t} \tag{8}$$

Where: $\boldsymbol{R}$ is the amount of recycled waste estimated at 15 434.266 tons.yr^{-1}. This value is the average recycled waste calculated from municipal data available. and

$\boldsymbol{W_t}$ is the total waste generated in Harare at time $\boldsymbol{t}$.

To then calculate the total amount of waste that is illegally dumped in the city (***I***), Eq. 9 was used. All waste collected from Harare suburbs is disposed of in an un-engineered and unsanitary dumpsite, Pomona. As a result, this waste is counted as illegally dumped waste as well.

$$\boldsymbol{I} = \boldsymbol{D} + \boldsymbol{U} \qquad \textbf{(9)}$$

Where: ***U*** is the amount of uncollected waste in the city.

5.2.2 Model testing

Sensitivity Analysis (SA) was used to test the competency of the HSW model. It is a method of uncertainty analysis used to quantitatively assess the effect of varying specific parameters on model output (Xing *et al*. 2017). SA verifies the consistency of model behavior for model calibration or assesses uncertainty (Pianosi *et al*. 2016). The study used an inbuilt function in STELLA to perform Mathematical SA. While other variables were kept constant, each input variable was varied ±100% of the initial value as shown in Fig. 5.5 below. Changes in the outputs listed in Fig. 5.5 were analyzed each time.

SA Run 1	**Varied Input 1:** City Net Growth	**Test range:** 0-0.064 **Model set value:** 0.032
SA Run 2	**Varied Input 2:** Waste Generation Rate	**Test range:** 0.00001*-0.2847 tons.capita^{-1}.year^{-1} **Model set value:** 0.1407 tons.capita^{-1}.year^{-1}
SA Run 3	**Varied Input 3:** Collected Waste	**Test range:** 0.00001*-314 972 tons **Model set value:** 157 486 tons.year^{-1}
SA Run 4	**Varied Input 4:** Recycled Waste	**Test range:** 0-30868.266 tons. year^{-1} **Model set value:** 15 434.266 tons. year^{-1}

Outputs Assessed
HSW Generated
HSW in Dumpsite
HSW Remaining in Dumpsite
Illegally Dumped Waste

*a non-zero value had to be set to be able to run the analysis

Figure 5.5 Mathematical SA runs and outputs assessed in STELLA.

The sensitivity parameters were set to follow an incremental distribution, the Sobol sequence sampling option selected and five runs made each time. This was done to visually assess change in model outputs with changes in specific parameters.

SPSS software was used for statistical SA. The study ran linear regression analysis on waste management indicator variables and correlation values (**R** and $\mathbf{R}^2$ values) calculated. As described in Eq. 10, 11, and 12, regression coefficient values were calculated (Narkuniene *et al.* 2019, Pianosi *et al*. 2016, Tian 2013).

$$\boldsymbol{S_i} = \boldsymbol{Correlation}\ (\boldsymbol{x_i}, \boldsymbol{y_i}) \quad \textbf{(10)}$$

Where: $\boldsymbol{S_I}$ is the sensitivity measure of variable $\boldsymbol{i}$

$\boldsymbol{x_i}$ is the independent variable, and

$\boldsymbol{y_i}$ is the dependent variable.

For variables following a linear relationship as described in Eq. 11, the unstandardized regression coefficient ($\boldsymbol{b}$) was used when all input variables had the same units. When variables had different units, the Standardized Regression Coefficient (SRC) was used as the sensitivity measure calculated in Eq. 12.

$$\boldsymbol{y}_i = a + b\boldsymbol{x}_i \quad \textbf{(11)}$$

$$\boldsymbol{S_i} = b\frac{SD(\boldsymbol{x_i})}{SD(\boldsymbol{y_i})} \quad \textbf{(12)}$$

Where: $SD(\boldsymbol{x_i})$ is the standard deviation of $\boldsymbol{x_i}$, and

$SD(\boldsymbol{y_i})$ is the standard deviation of $\boldsymbol{y_i}$

5.3 Scenario Analysis

In most developing countries, the primary purpose of waste management systems is to increase waste collection coverage and thus reduce illegal waste dumping (Cervantes *et al*. 2018). This study assesses how introducing a CBWM system (i.e., implementing composting and/ paper and plastic recycling) can potentially impact HSW management in Harare. The study initially ran nine scenarios showing different levels of implementation of the two strategies over the historical period 2015-2019. The level of implementation is measured as the extent of strategy execution in Harare's suburbs, i.e., HD, MD, and LD. Future projections (2022-2026) of the HSW management system used the scenarios yielding the best results at each level of implementation.

5.3.1 Scenario 1: Harare's current HSW management system

This scenario represents the baseline. It shows the current state of the HSW management system in Harare. In scenario 1, it is assumed that the system's current state is maintained in the city.

5.3.2 Scenario 2: Scenario 1 + Compulsory household level composting of food leftovers

In scenario 2, it is assumed that composting of food leftovers at the household level is introduced in the city. Not only is HD the largest carrier of the population in Harare, but it is also the largest producer of food leftovers, as highlighted in Table 5.1 below. It is thus essential that composting be a strategy mostly emphasized in these suburbs. Composting of food leftovers in scenario 2 was theoretically assessed as follows:

Implementation Level I. All HD food leftovers (i.e., 53% of the HD HSW produced) is composted,

Implementation Level II. All HD and MD food leftovers (i.e., 53% of the HD HSW produced and 25% of the MD HSW produced) is composted, and

Implementation Level III. All HD, MD, and LD food leftovers (i.e., 53% of the HD HSW produced + 25% of the MD HSW produced + 17% of the LD HSW produced) are composted.

Table 5.1 Household solid waste composition data from nine suburbs in different socio-economic classes (Mandevere 2015, Tsiko and Togarepi 2012).

	Low Density			Medium Density			High Density		
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
% Food leftovers	15	18	17	25	26	23	54	49	55
% Papers	35	32	33	30	31	29	10	14	13
% Wood	9	8	8	10	8	7	9	9	9
% Yard waste	1	2	2.5	7	6	9	2	1	2
% Organic waste	60	60	60.5	72	71	68	75	73	79
% Glass	4	5	4	6	2	4	1	2	3
% Metals	3	4	3	5	2	3	5	4	3
% Electronic	4	5	5	2	2	2	7	6	4
% Plastics	18	16	16.5	22	21	20	9	10	8
% Miscellaneous	11	10	11	3	2	3	3	6	3
% Inorganic waste	40	40	39.5	38	29	32	25	28	21

Besides the economic benefits it provides, composting is an environmentally superior waste management strategy compared to landfilling. Over 200 000 tons of organic waste per year is produced in Harare, most of which is thrown in landfills (Jingura and Matengaifa 2009). Harare shortly ran a composting plant that was not successful due to the high running costs (Jerie and Tevera 2014). Introducing household-level composting will potentially encourage the community's involvement in waste management, reduce the amount of waste collection pressure exerted on the municipality, and eliminate direct composting running costs on the city.

5.3.3 Scenario 3: Scenario 1 + Increase in paper and plastic recycling

In scenario 3, it is assumed that the municipality focuses on recycling more paper and plastic HSW. Worldwide, Germany is one of the most accomplished countries in waste recycling achieving municipal waste recycling rates of about 87% (Žmak and Hartmann 2017). Over the years, paper recycling in the country increased to approximately 82% in 2014 from about 40% in 1990 (Nellesa *et al.* 2016, Žmak and Hartmann 2017). This study thus assumed a 50% recycling rate for paper and plastic in all scenarios as an initial target for Harare.

As highlighted in Table 5.1 above, more paper and plastics are generated in LD and MD suburbs than in HD suburbs. The city can thus prioritize the launch of a recycling strategy in these socio-economic classes as these are likely to yield a more significant change to the HSW management system. The strategy will be assessed in the model as follows:

Implementation Level I. Half of LD and MD paper (i.e., 16.5% of the total LD waste produced and 15% of the MD waste produced) is recycled,

Implementation Level II. Half of LD and MD paper (i.e., 16.5% of the LD waste produced and 15% of the MD waste produced) and plastic (i.e., 8.5% of the LD waste produced and 10.5% of the MD waste produced) is recycled, and

Implementation Level III. Half of all paper and plastic produced in Harare is recycled.

This scenario also assumes that wet and dry waste separation at the source is made mandatory in Harare's suburbs. This way, the municipality collects already separated waste and thus potentially increases waste recovery at the dumpsite. In Implementation Level I, only 50% of paper recycling in the highest producing suburbs was assumed, while in Implementation Level II both paper and plastic recycling was considered. Implementation Level III assesses 50% paper and plastic recycling in all suburbs. Another assumption is that some paper and plastics generated are spoiled, non-recyclable or that residents are noncompliant to waste separation at source. As a result, 50% of the total recyclable waste was deemed reasonable for simulations (Tsiko and Togarepi 2012).

5.3.4 Scenario 4: Scenario 2 + Scenario 3

This scenario assumes that each implementation stage of Scenarios 2 and 3 is combined, i.e., food leftover composting and paper and plastic recycling.

5.4 Results and Discussions

Results from model testing are as described in Section 4.1. Scenario analysis findings and future HSW management system recommendations are as given in Section 4.2.

5.4.1 Model testing

5.4.1.1 Sensitivity analysis

For all variables in the significant Eq. 3, 6, and 8 used in model calculations, the R values show that the independent variables can explain more than 98% of the total variation in the dependent variables. Moreso, the level of significance expressed as the probability value (p-values) from the ANOVA tests, shows how well the regression equations generated can predict the dependent variables. A p-value of less than 0.05 indicates strong evidence that a relationship exists between variables. For all variables used in Eq. 3, 6, and 9, p-values were less than 0.05. This validates the suitability of their use in simulations.

According to this study, the more influential variables in Harare's HSW management system are HSW collected in Harare ($\boldsymbol{C_t}$), HSW generation rate ($\boldsymbol{W_g}$), and Recycled waste ($\boldsymbol{R}$). This is because a positive regression coefficient value means that the dependent variable increases when the independent variable increases while a negative value signifies vice-versa. When all other variables are held constant, the size of the coefficient value shows the magnitude of change that occurs to the mean of the dependent variable value per unit change of the independent variable. A low percentage error between simulated and actual average data of annual HSW generated (W_t), HSW collection efficiency (E), and recycling rate (R_r) is 1.63%, -4.91%, and 3.60%, respectively was calculated.

5.4.1.2 Mathematical sensitivity analysis

As shown in Table 5.2 below, while varying city net growth ($\boldsymbol{P_n}$) between 0.016, 0.032, and 0.064, a uniform average HSW in dumpsite ($\boldsymbol{D}$) of 157 486tons.yr^{-1} was obtained. This is because, during the simulation, all other variables except city net growth are held constant. HSW collected ($\boldsymbol{C_t}$) in the model has a constant value of 157 486tons.$^{-1}$ which was calculated by finding the average HSW collected waste in Harare over the years 2015-2019 using the historical data obtained from the municipality. In Harare, Pomona dumpsite is the official HSW dumpsite, so all collected waste ends up there. If the HSW collected ($\boldsymbol{C_t}$) does not change, the amount of waste that ends up in the dumpsite does not change. This explanation is also applicable for the uniform average HSW remaining in the dumpsite of 142 052tons.yr^{-1} obtained in the simulation. In the model, a constant value of recycled waste of 15 434.266tons.yr^{-1} is retained. This value is the average amount of recycled waste in the city calculated from historical data.

Table 5.2 Mathematical sensitivity analysis results for the years.

Outputs Assessed	**Original city net growth (P_n) = 0.032**	**1X lower city net growth (P_n) = 0.016**	**2X greater city net growth (P_n) = 0.064**	**Original waste generation rate (W_g) = 0.14235tons**	**1X lower waste generation rate (W_g) = 0.071175 tons**	**2X greater waste generation rate (W_g) = 0.2847 tons**	**Original av. collected waste (C_t) = 157 486 tons**	**1X lower collected waste (C_t) = 78 743 tons**	**2X greater collected waste (C_t) = 314 972 tons**	**Original av. recycled waste (R) = 15 434.133 tons**	**1X lower recycled waste (R) = 7 717.0665 tons**	**2X greater recycled waste (R) = 30 868.266 tons**
Average HSW Generated (W_t) (tons.yr^{-1})	240 288	225 395	273 058	240 288	120 145	480 576	240 288	240 288	240 288	240 288	240 288	240 288
Average HSW in Dumpsite (D) (tons.yr^{-1})	157 486	157 486	157 486	157 486	120 145	157 486	157 486	78 743	240 228	157 486	157 486	157 486
Average HSW remaining in Dumpsite (D_r) (tons.yr^{-1})	142 052	142 052	142 052	142 052	108 370	142 052	142 052	63 309	228 513	142 052	149 769	126 618
Average HSW illegally Dumped (I) (tons.yr^{-1})	224 854	209 961	257 624	224 854	108 370	465 141	224 854	224 854	224 854	224 854	232 571	209 419

Since the HSW collected ($\boldsymbol{C_t}$) and so the HSW in dumpsite ($\boldsymbol{D}$) are the same despite variations in city net growth ($\boldsymbol{P_n}$), the amount of HSW remaining in dumpsite ($\boldsymbol{D_r}$) will be the same since the same Recycled waste ($\boldsymbol{R}$) remains constant.

However, the original city net growth ($\boldsymbol{P_n}$), 1X $\boldsymbol{P_n}$, and 2X $\boldsymbol{P_n}$ of 0.032, 0.016, and 0.064 yielded an average of the HSW Generated ($\boldsymbol{W_t}$) of 240 288tons.yr^{-1}, 225 395tons.yr^{-1} , and 273 058 tons.yr^{-1} , respectively. The bigger the city net growth ($\boldsymbol{P_n}$), the higher the population *($\boldsymbol{P_t}$)* and so the greater the amount of waste generated. Literature supports this finding by identifying that waste generation is proportional to population (Mandevere, 2015). This explanation is also true for the HSW illegally dumped ($\boldsymbol{I}$). This is because a non-engineered and non-sanitary dumpsite is the city's primary disposal site. Apart from the recycled waste, whether HSW is collected or not, it is still disposed of illegally. The higher the waste generated, the higher the HSW illegally dumped, as evidenced in Table 5.2 above.

On the contrary, varying annual waste generation rate per capita ($\boldsymbol{W_g}$) between 0.14235 tons, 0.071175 (1X lower), and 0.14235 (2X higher) yielded HSW in dumpsite ($\boldsymbol{D}$) of 157 486 tons.yr^{-1}, 120 145tons.yr^{-1}, and 157 486tons.yr^{-1} while an output of 142 052tons.yr^{-1}, 108 370tons.yr^{-1}, and 142 052tons.yr^{-1} was generated for HSW remaining in dumpsite ($\boldsymbol{D_r}$). The difference between HSW in dumpsite ($\boldsymbol{D}$) and HSW remaining in dumpsite ($\boldsymbol{D_r}$) can be explained by the fact that $\boldsymbol{W_t}$ < 157 486tons.yr^{-1} which is the HSW collected ($\boldsymbol{C_t}$) constant value set in the model. As a result, less waste was available for collection and disposal to the dumpsite. However, generally for HSW Generated ($\boldsymbol{W_t}$) and HSW illegally dumped ($\boldsymbol{I}$), simulated average values increase as the waste generation rate per capita ($\boldsymbol{W_g}$) increases as also illustrated in Table 5.2 above.

Even when HSW collected ($\boldsymbol{C_t}$) is varied between 157 486tons.yr^{-1}, 78 743tons.yr^{-1}, and 314 972tons.yr^{-1}, the SA run yields average HSW Generated ($\boldsymbol{W_t}$) and HSW illegally dumped ($\boldsymbol{I}$) values of 240 288tons.yr^{-1} and 224 854tons.yr^{-1}, respectively. This is because, in the simulations, only HSW collected ($\boldsymbol{C_t}$) values are varied while the rest are held constant. The HSW in dumpsite ($\boldsymbol{D}$) and HSW remaining in dumpsite ($\boldsymbol{D_r}$) are higher with higher values of collected waste. However, the latter continues to increase until it reaches a constant value which marks the set value for collected waste, as shown in Table 5.2 above. This is because, initially, the waste collection capacity of the city is greater than the waste available for collection. As waste production increases annually, it reaches a point where waste collection is higher than the collection capacity, hence the constant value.

When Recycled waste ($\boldsymbol{R}$) is varied between 15 434.1330tons.yr^{-1}, 7 717.0665tons.yr^{-1}, and 30 868.2660tons.yr^{-1}, average HSW Generated ($\boldsymbol{W_t}$) and HSW in dumpsite ($\boldsymbol{D}$) retain the values of 240 288tons.yr^{-1} and 157 486tons.yr^{-1}, respectively. However, the HSW remaining in dumpsite ($\boldsymbol{D_r}$) and HSW illegally dumped ($\boldsymbol{I}$) decrease with an increase in the amount of Recycled waste ($\boldsymbol{R}$) diverted from the dumpsite as shown in Table 5.2 above.

5.4.2 Scenario analysis

Results from the preliminary simulations are presented in Section 4.2.1, while the future recommendations for Harare are as shown in Section 4.2.2.

5.4.2.1 Preliminary scenario simulations

Scenario 2 assessed what composting of all food leftovers in each household would have achieved for Harare over the historical 5-year period of 2015-2019. The simulation results show that diverting all food leftovers produced in HD suburbs to composting would have likely increased the recycling rate in the city from 5.2% to 27.0%, as illustrated in Fig. 5.6 below. Introducing composting in MD and LD suburbs would have yielded an increase in the recycling rate by 7.5% and 1.7%, respectively.

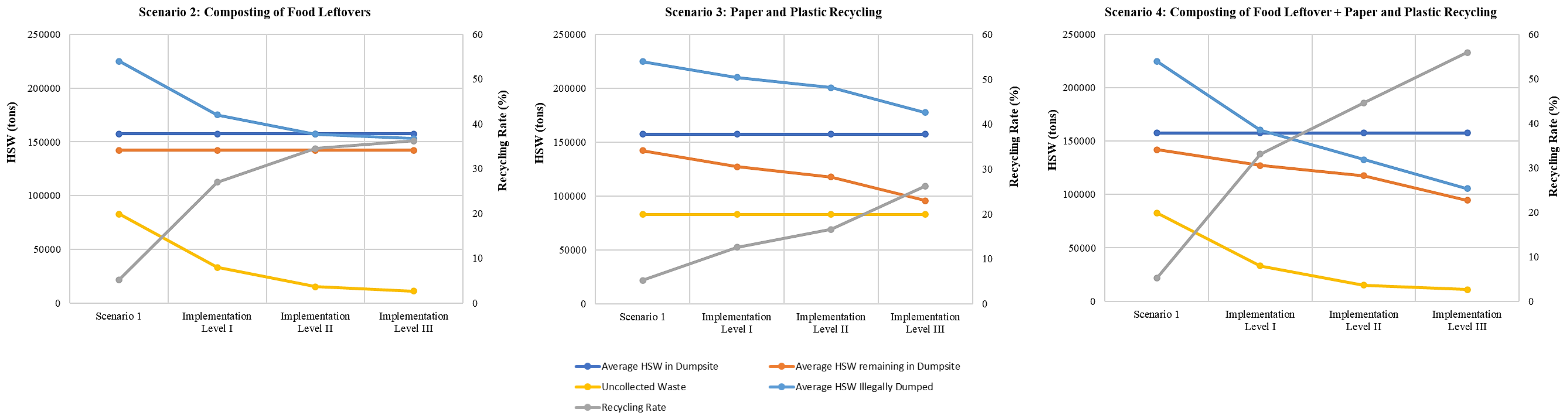

Figure 5.6 Potential changes in waste management indicator values over the historical period 2013-2019 at different levels of implementation.

If waste collection capacity remained at an average of 157 486tons.yr^{-1} over the simulated years, introducing this strategy in Harare would not have changed the amount of waste dumped in Pomona (i.e., all collected waste), and neither would it have changed the average 15 434tons.yr^{-1} HSW recycled at the dumpsite. However, it would have improved the amount of waste treated from 0 to about 71 788tons.yr^{-1}. It would also reduce the amount of HSW left uncollected in communities from 82 802 to 11 014tons.yr^{-1} and the illegally dumped HSW from 224 854 to 153 066tons.yr^{-1}.

In Scenario 3, the study assesses the benefits that paper and plastic recycling would have likely achieved for Harare's HSW management system over the period 2015-2019. Implementation Level III yields the most significant benefits for the city with a 26.2% increase in recycling rate and a 21.1% decrease in the amount of HSW illegally dumped, as illustrated in Fig. 5.6 above. Although HSW produced in MD and LD suburbs carry higher plastic and paper waste compositions than that generated in HD suburbs, HD suburbs have higher volumes of HSW as they carry about 60% of the city's population. This explains the highest 9.6% increase in recycling rate in Implementation Level III. Although this strategy would not have addressed the issue of the uncollected waste remaining in Harare's suburbs, it would have potentially reduced the amount of waste remaining in Pomona dumpsite by about 32.7%.

The results of Scenario 4 show how combining composting and paper and plastic recycling strategies would have affected Harare's HSW management system over the year range 2015-2019. This combination of strategies would have brought no change in HSW taken to the dumpsite. However, it would have likely increased the recycling rate up to 55.9% from the current 5.2%, as shown in Fig. 5.5 above. It would also have reduced the amount of waste left uncollected in communities by up to 86.7% and decreased the amount of illegally dumped waste in the city by 53.0%.

5.4.2.2 Future recommendations to improve Harare's HSW management systems

This section of the study used the results in Section 5.4.2.1 to develop a CBWM strategy implementation chart (CBWM-SIC) for the municipal period of 2022-2026. It summarizes the performance of the best scenarios at each level of implementation, as shown in Fig. 5.7 below.

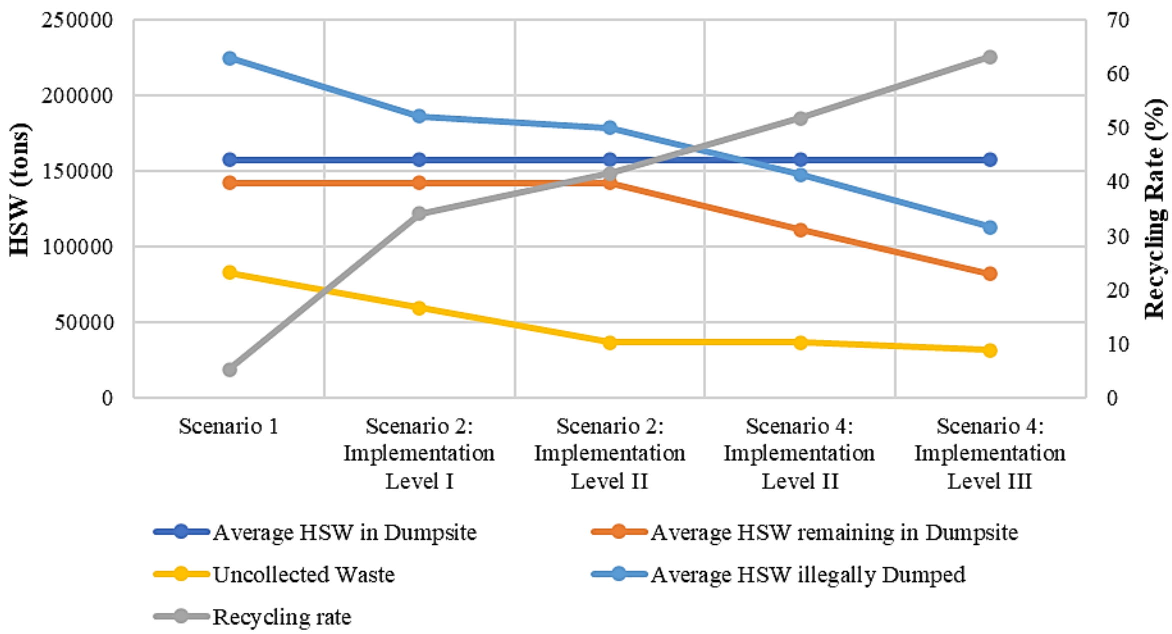

Figure 5.7 CBWM Strategy implementation chart (CBWM-SIC) for Harare city.

Composting (Scenario 2: Implementation Levels I and II) will likely dramatically impacts the HSW management system. It will potentially increase the recycling rate in Harare to 34.1% and 41.6%, respectively. It will probably also reduce uncollected waste by up to 28.0% and 55.9%, respectively. On the other hand, combining composting with paper and plastic recycling (Scenario 4: Implementation Level II and III) will likely increase recycling rates in the city to 51.8% and 63.1%, respectively. Uncollected waste potentially reduces by 55.9% and 62.3%, respectively. The amount of illegally dumped waste can reduce from 224 854tons.yr^{-1} to 186 009, 178 496, 147 440, and 112 866tons.yr^{-1}, respectively.

5.5 Conclusions

Reducing the per capita waste generated and increasing the amount of waste recycled or treated in Harare can help reduce the amount of waste in Pomona dumpsite. To reduce the amount of illegally dumped waste in Harare, increasing the amount of waste collected will not be effective since all collected HSW waste ends up in an unsanitary and non-engineered dumpsite. However, a potentially effective strategy can be to increase the amount of waste diverted from the dumpsite through recycling.

This study developed scenarios on how composting HSW food leftovers and recycling 50% of HSW paper and plastic can potentially impact the HSW management system. Material recovery potential assessment studies of waste management approaches like CBWM in Harare is the gap in knowledge this study aimed to fill. Running the scenarios on historical data for 2015-2019 showed that composting food leftovers in Harare's HD, MD, and LD suburbs would have potentially resulted in a 21.8%, 7.5%, and 1.7% increase in recycling rate. A decrease in illegally dumped waste of 22.1%, 10.3%, and 2.6%, respectively, would have been realized. HD suburbs are the highest producers of food leftovers and would have likely realized the most significant increase in recycled waste. On the other hand, implementing 50% recycling of paper and plastic waste alone would possibly have achieved up to 7.4%, 4.0%, and 9.6% increase in recycling rate as well as a 6.6%, 4.6%, and 11.5% decrease in illegally dumped waste, respectively. Adopting Scenario 4: Implementation Level III, which harnesses both composting as well as paper and plastic recycling in HD, MD, and LD suburbs, would have yielded the most significant positive impact on Harare's HSW management system by increasing the recycling rate by 27.9%, 11.5%, and 11.3% as well as reduce illegally dumped waste by 28.7%, 17.2%, and 20.45%, respectively. Should the city of Harare adopt this latter scenario in the next five-year period from 2022-2026, the recycling rate is likely to increase to 63.1%, while illegally dumped waste reduced by about 49.8%, respectively. However, implementing the complete strategy can prove difficult for the local government. As a result, the city can gradually upgrade its HSW management system until this scenario is achieved by following the CBWM Priority Strategy Implementation Chart (CBWM-PSIC) developed and proposed in this study, as shown in Fig. 5.7 above. The Chart can help the city improve the recycling rate from 5.2% to 34.1%, 41.6%, 51.8%, and 63.1% with each level of strategy implementation. It can also increase controlled waste treatment and reduce uncollected waste by 38.3% and 62.3%, respectively.

Finally, model validation is a continuous process. Future recommendations for this study include obtaining expert and stakeholder input for model improvement and the model's simulation of annual variability in waste management indicators improved. A social survey to understand city residents' approval of these community-based waste management strategies before implementation is also crucial. Moreso, inorder to generally gather more insight into integrated waste management, future studies can look into other management frameworks like Integrated Water Management, Integrated Coastal Management or Integrated Port Development and Management.

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6. SYNTHESIS AND CONCLUSIONS

Household solid waste (HSW) management in Harare is a system that requires the immediate attention of the relevant authorities to safeguard the health of city residents. Being complex, the system is multifaceted meaning its components interact to give a collective behaviour which can otherwise not be explained by a single component. As a result, this study used the exploratory sequential research methodological approach. This entails combining qualitative and quantitative research methods, which were divided into Phase 1 and Phase 2 in this study, respectively. Phase 1 used the Case Study research techniques to understand the HSW management system in Harare and identify the issues affecting it. Subsequently, Phase 2 used the Network Analysis (NA) and System Dynamics (SD) research techniques. According to the researcher's knowledge, the combination of NA to identify the leverage points within the HSW management system and subsequently using SD techniques to assess the performance of different community-based waste management scenarios is original work.

Harare is a city in the northern part of Zimbabwe, Southern Africa. Although quite debated in literature, it carries a population of between 1.5-3 million. The city has a rather closed approach to managing its waste that does not realize much diversion from the dumpsite. The elements of the HSW management system thus primarily includes waste generation, waste collection, and waste disposal. The city has a daily waste generation per capita of about 0.38±0.1kg while annually producing about 207 635 294±56 027 040kg of HSW. The estimated volume of HSW collected in the city is on average 170 385 600±33 384 209kg, while the recovery efficiency at the dumpsite is around 9.5±2.8%.

Although many factors are crippling the HSW management system in the city, NA revealed that the potential leverage points for significant system improvement are uncollected waste reduction, waste collection efficiency increase, reduction of illegal waste dumping, stability of the economy, and the increase in municipal financial capacity, among others. Addressing the issues identified in the study as key would generally call for the municipality to develop strategies to reduce waste volume, waste collection trips, uncollected waste, amount of workforce, collection pressure, and illegal waste dumping. However, addressing issues like municipal financial capacity and the country's economic instability are not short-term solutions to the urgent waste crisis given the country's political instability, lack of adequate donor funding among other things. It is thus imperative that HSW management solutions be tailor-made for Harare to ensure the feasibility and sustainability of the system.

This study proposed and assessed a community-based waste management approach that combines organic (through mandatory food waste compost pitting at household level) and inorganic (through paper and plastic recovery) waste recycling for Harare. Over the historical or last municipal period of 2013-2019, should the municipality have independently implemented organic waste recycling or inorganic waste recycling, the city would have potentially achieved an increase in recycling rates from 5.2% to 36.2% and

26.2%, respectively, while a combination of both strategies would have increased it up to 55.9%. However, future projections of the waste management system if both strategies are implemented over the next five-year period from 2022-2026, a probable increase in controlled waste treatment in the city from 0% to 38.3%, an increase in recycling rate to 63.1%, and a reduction in the amount of illegally dumped waste by about 49.8% can be realized.

To improve the finding of this study, expert and stakeholder inputs are required to verify or supplement the literature review findings, NA results, and the SD model developed for Harare. In-person interviews and focus group discussions with municipal personnel and city residents are vital data sources to be considered. A social survey to understand city residents' approval of the CBMW system should be done before implementing strategies. Simulation of the annual variability of waste management indicators should also be improved. To enhance performance, future studies can also include other relationships between variables like that of socio-economic class with waste generation rate and waste collection efficiency in the model. Other key variables like the number of available waste collection vehicles, vehicles maintenance efficiency, vehicles breakdown frequency, municipal capacity (financial, technical, and human resources), unemployment rate, and number of vendors can be explored in the model as well.

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8. APPENDIX

Appendix 8.1 Harare's waste management issues identified from a literature review conducted by Kwenda et al. (2021a)

Issue	Description	Issue	Description
1 "Poverty"	The lack of financial resources of the of people to afford a basic standard of living.	49 "Waste data"	The availability of data that describes waste management in Harare e.g waste generation rate, waste collection rate etc.
2 "Urban agriculture"	Farming practices in urban areas.	50 "Planning and monitoring"	The availability of a planning and monitoring services within the waste management department.
3 "Operation Murambatsvina"	Also known as the 'Operation Restore Order', is a government initiative conducted in 2005 where slum areas/ illegal structures were forcibly removed across the country (Bratton and Masunungure 2007).	51 "Gender"	The sex of the city resident i.e. male or female.
4 "Festive season"	The period leading up to the Christmas and New year holidays.	52 "Land reform program"	The redistribution of land that occurred in Zimbabwe in the year 2000 (Palmer 1990).
5 "Waste volume"	The quantity of waste produced in Harare.	53 "Foreign currency"	The available of foreign currency.
6 "Waste collection pressure"	The demand for waste collection services from the local authorities by the city residents.	54 "Hyperinflation"	The excessive general increase in prices in Harare.
7 "Consumption"	The extent of use of resources by the city residents.	55 "Unemployment rate"	The increase in the fraction of unemployed people in Harare.
8 "Population"	The amount of people who live in Harare city.	56 "Municipal capacity"	The ability of the local authorities to handle generated waste.
9 "Natural population increase"	The natural positive change in population in Harare which occurs when live births are higher than deaths recorded in a given period.	57 "Multicurrency"	The simultaneous use of different currencies in the economy.
10 "Urbanization"	Population shift from rural to urban areas (Berry 2008).	58 "Private companies"	Privately owned companies.
11 "Changes in waste consumption patterns"	-	59 "Research"	Conducted studies.
12 "Socio-economic class"	Social standing which is measured by place of residence and income.	60 "Billed properties"	The number of properties that are recognised by the local authorities and hence should pay for municipal services offered.
13 "Waste collection efficiency"	The efficiency with which the local authorities collect waste.	61 "Recyclers"	The number of people who collect waste for reuse or sale.
14 "Waste collection frequency"	The frequency (i.e number of waste collection days) with which the local authorities collect waste.	62 "Loans"	Money borrowed by the local authorities inorder to fund waste management operations.
15 "Harare waste collection policy"	The stipulated waste collection frequency by the local authorities.	63 "Waste collection vehicles"	The number of vehicles available for waste collection.
16 "Suspension of waste collection services"	-	64 "Workforce capacity"	The number of workers available for waste management as compared to the number of workers needed.
17 "Vehicles breakdowns"	How often waste collection vehicles break down.	65 "Fuel"	The availability of fuel for waste collection.
18 "Vehicles maintainance"	The efficiency and frequency with which waste collection vehicles are maintained.	66 "Fuel cost"	The cost of fuel.
19 "Uncollected waste"	The amount of waste that remains uncollected.	67 "Distance from disposal site"	The distance waste collection vehicles must travel inorder to collect and dispose of waste.
20 "Crude waste dumping"	Waste dumped by unsanitary means at the official Harare dumpsite.	68 "Community participation"	Involvement of communities in waste management.
21 "Open waste burning"	The waste disposal method where waste is set on fire in open spaces.	69 "Colonization"	The effect of Zimbabwe's colonization period of 1988-1980.
22 "Waste burying"	The waste disposal method where pits are dug, waste emptied in them and covered in soil.	70 "Travel regulations"	The restriction of entry of black people in urban areas that was set during the colonial period (Barnes 1997).
23 "Waste law enforcement"	The efficiency with which waste laws are enforced.	71 "Illegal settlements"	Non-registered settlements in Harare.
24 "Receptacle availability"	The availability of waste receptacles.	72 "Black access to goods and services"	During the colonial period.
25 "Waste management knowledge"	Residents' knowledge on how to manage waste.	73 "Processed products"	Packaged goods.
26 "Home tenureship"	The number of people that own the houses they reside in.	74 "Racial segregation"	During the colonial period.
27 "Mosquito and rodent manifestation"	The extent to which vermin is prevalent.	75 "Capital city"	Harare is the capital city of Zimbabwe.
28 "Sewer blockages"	Blockage of sewer pipes which can cause sewer overflows.	76 "Corruption"	Fraudulent conduct by authorities in the city council.
29 "Perceptions"	How the city residence view or awareness on waste management issues.	77 "Waste collection fee"	The waste management service charges for households.
30 "Street vendors"	The number of people illegally selling products in the city streets.	78 "Communication"	Communication between waste management stakeholders.
31 "Environmental pollution"	The extent of land, water and air pollution.	79 "Worker strikes"	Strikes by waste management workers.
32 "Health risk"	Exposure of people to the possibility of health endangerment.	80 "PPE"	Workers' personal protective equipment.
33 "Sanitary landfilling operations"	Waste disposal procedures that follows the environmental, social and public health safety guidelines.	81 "Salaries"	The amounts of salaries workers receive.
34 "Financial capacity"	The ability of the local government to fund operations.	82 "Fights"	Conflicts between people.
35 "Technical capacity"	The ability of the local government to offer technical resources needed for waste management operations.	83 "Sanitary formal solid waste disposal"	Waste disposal that follows the environmental, social and public health safety guidelines.
36 "No engineered landfills"	-	84 "Waste transfer to poorer suburbs"	-
37 "Landfill equipment"	Equipment required to ensure sanitary landfilling operations.	85 "Strategy implementation"	Implementation of waste management strategies.
38 "Donor funding"	The amount of external funding received by the local authorities towards waste management in Harare.	86 "Changes in waste composition patterns"	-
39 "Economy"	National output which determines the goods and services received by the residents.	87 "HIV/AIDS epidemic"	The effects of the HIV/AIDS epidemic.
40 "Political instability"	Conflicts and competitions between political parties.	88 "Cost of service provision"	The cost of providing waste management services.
41 "Municipal expansion"	Positive change in the capacity of the local authorities to manage waste.	89 "Accidents"	-
42 "Waste recovery"	Reuse of waste either through composting or recycling.	90 "Illegal waste dumping"	Waste dumped in unsanitary means.
43 "Waste seperation at source"	Amount of waste is separated at source.	91 "Population density"	The number of people per unit area.
44 "Waste policy"	The policies that govern waste management in Harare.	92 "Dumpsite fires"	-
45 "Access control"	The control measures set by the local authorities in accessing the official dumpsite.	93 "National informal economy"	Economic activities and workers that are not registered with the government.
46 "Waste generation rate"	The amount of waste generated per capita per day.	94 "National formal economy"	Economic activities and workers that are registered with the government.
47 "Disposable income"	The average amount of money available to spend for a family or individual after deduction of taxes.	95 "Weather"	Rainfall received.
48 "Weighbridge at dumpsite"	The availability of a weighbridge at the official dumpsite.		

Appendix 8.2 Degree and betweenness centrality of nodes in the network.

Node	Degree Centrality: Degree	In-degree	Out-degree	Betweenness Centrality	Node	Degree Centrality: Degree	In-degree	Out-degree	Betweenness Centrality
1 "Poverty"	4	1	3	20	49 "Waste data"	4	3	1	217
2 "Urban agriculture"	3	2	1	19.5	50 "Planning and monitoring"	5	2	3	176
3 "Operation Murambatsvina"	1	0	1	0	51 "Gender"	1	0	1	0
4 "Festive season"	1	0	1	0	52 "Land reform program"	1	0	1	0
5 "Waste volume"	9	7	2	210	53 "Foreign currency"	2	0	2	0
6 "Waste collection pressure"	3	1	2	170	54 "Hyperinflation"	2	0	2	0
7 "Consumption"	5	2	3	58.7	55 "Unemployment rate"	3	1	2	126
8 "Population"	6	3	3	90	56 "Municipal capacity"	4	4	0	0
9 "Natural population increase"	1	0	1	0	57 "Multicurrency"	1	0	1	0
10 "Urbanization"	2	1	1	29	58 "Private companies"	1	0	1	0
11 "Changes in waste consumption patterns"	3	1	2	6.7	59 "Research"	3	1	2	67
12 "Socio-economic class"	7	1	6	91.5	60 "Billed properties"	2	0	2	0
13 "Waste collection efficiency"	]5	4	1	316	61 "Recyclers"	1	0	1	0
14 "Waste collection frequency"	5	4	1	135.5	62 "Loans"	1	0	1	0
15 "Harare waste collection policy"	1	0	1	0	63 "Waste collection vehicles"	3	2	1	117
16 "Suspension of waste collection services"	1	0	1	0	64 "Workforce capacity"	6	2	4	253
17 "Vehicles breakdowns"	2	1	1	91	65 "Fuel"	3	2	1	28
18 "Vehicles maintenance"	3	2	1	102	66 "Fuel cost"	1	0	1	0
19 "Uncollected waste"	4	2	2	337.5	67 "Distance from disposal site"	1	0	1	0
20 "Crude waste dumping"	3	2	1	72.5	68 "Community participation"	1	1	0	0
21 "Open waste burning"	2	0	2	0	69 "Colonization"	3	0	3	0
22 "Waste burying"	1	0	1	0	70 "Travel regulations"	2	1	1	8
23 "Waste law enforcement"	2	1	1	10	71 "Illegal settlements"	2	1	1	56.5
24 "Receptacle availability"	4	3	1	42.5	72 "Black access to goods and services"	3	2	1	4.8
25 "Waste management knowledge"	4	1	3	28	73 "Processed products"	2	1	1	1.8
26 "Home tenureship"	1	0	1	0	74 "Racial segregation"	2	1	1	43.5
27 "Mosquito and rodent manifestation"	2	1	1	0	75 "Capital city"	1	0	1	0
28 "Sewer blockages"	3	1	2	0	76 "Corruption"	1	0	1	0
29 "Perceptions"	5	2	3	32	77 "Waste collection fee"	2	1	1	67
30 "Street vendors"	6	3	3	181	78 "Communication"	1	0	1	0
31 "Environmental pollution"	2	2	0	0	79 "Worker strikes"	4	3	1	92
32 "Health risk"	3	3	0	0	80 "PPE"	1	0	1	0
33 "Sanitary landfilling operations"	3	2	1	17.5	81 "Salaries"	2	1	1	51
34 "Financial capacity"	13	5	8	268	82 "Fights"	1	1	0	0
35 "Technical capacity"	5	3	2	124	83 "Sanitary formal solid waste disposal"	3	2	1	68
36 "No engineered landfills"	4	2	2	173.5	84 "Waste transfer to poorer suburbs"	1	1	0	0
37 "Landfill equipment"	2	0	2	0	85 "Strategy implementation"	2	2	0	0
38 "Donor funding"	2	1	1	47	86 "Changes in waste composition patterns"	4	4	0	0
39 "Economy"	9	6	3	269	87 "HIV/AIDS epidemic"	1	0	1	0
40 "Political instability"	3	1	2	44	88 "Cost of service provision"	4	4	0	0
41 "Municipal expansion"	2	1	1	0	89 "Accidents"	1	1	0	0
42 "Waste recovery"	5	4	1	60.5	90 "Illegal waste dumping"	14	10	4	300
43 "Waste separation at source"	1	0	1	0	91 "Population density"	1	1	0	0
44 "Waste policy"	2	1	1	17	92 "Dumpsite fires"	2	2	0	0
45 "Access control"	4	1	3	84	93 "National informal economy"	2	1	1	73
46 "Waste generation rate"	2	1	1	0	94 "National formal economy"	1	0	1	0
47 "Disposable income"	4	1	3	18.5	95 "Weather"	1	0	1	0
48 "Weighbridge at dumpsite"	1	0	1	0					

Appendix 8.3 Service Level Bench-marking (SLB) indicator set used for waste management assessment in Harare (HCC, 2019)

3.1	**Coverage of SWM services through door to door collection of waste.**	
	Definition: Percentage of occupied properties and establishments that are covered by doorstep collection system at least once a week.	
3.1.1	a. Total number of occupied properties and establishments in the service area	The total number of occupied properties and establishments (not properties) in the service area should be established. The service area refers to either the ward or the council boundary
3.1.2	b. Total number of properties with doorstep collection at least once a week	Include doorstep collection by the council itself or council-approved service providers. This includes door-to-door collection systems operated by vendors, etc.
	Coverage = [(b/a)*100]	
	Additional information	
3.1.3	c. Properties with collection daily	
3.1.4	d. Properties with collection once a week	
3.1.5	Properties with collection twice a week	
3.1.6	e. Properties with collection once in more than a week	
3.1.7	f. Total number of properties with some form of collection	
3.1.8	g. Properties with no collection at all	
3.2	**Efficiency of collection of municipal solid waste**	
	Definition: The total waste collected by the council and authorized service providers versus the total waste generated within the council area, excluding recycling or processing at the generation point. (Typically, some amount of waste generated is either recycled or reused by the citizens themselves. This quantity is excluded from the total quantity generated, as reliable estimates will not be available for these.)	
3.2.1	a. Total waste that is generated and which needs to be collected	
3.2.2	b. Total quantum of waste that is collected by the council or authorized service providers	The total waste collected from households, establishments, and common collection points. This should be based on actual weighing of the collected waste. Daily generation should be aggregated to calculate the total monthly quantum. This should exclude any special drives for waste collection, and waste generated from one-off activities such as demolitions, desilting canals, etc.
	Collection efficiency = [(b/a)*100]	
	Additional information	
3.2.3	a. Waste generation per capita for the city or town	
3.2.4	b. Weight of loads collected from domestic areas	
3.2.5	c. Weight of loads collected from industrial areas	
3.2.6	d. Weight of loads collected from commercial areas	
3.2.7	e. Weight of loads collected from institutional areas	
3.2.8	f. Weight of loads collected from other areas	
3.2.9	g. Total weight of loads collected by the council	Total figure should be same as figure given in 3.2.2 so checking figure should be zero
3.3	**Extent of recovery of municipal solid waste collected**	
	Definition: This is an indication of the quantum of waste collected, which is either recycled or processed. This is expressed in terms of percentage of waste collected.	
3.3.1	a. Amount of waste that is processed or recycled	
3.3.2	b. Total quantum of waste that is collected by the council or authorized service providers	The total waste collected from households, establishments and common collection points. This should be based on actual weighing of the collected waste. This should exclude any special drives for waste collection, and waste generated from one-off activities such as demolitions, desilting canals, etc. (This corresponds to the quantity of (b), as measured for the indicator on collection efficiency). Should be same as 3.2.2
	Extent of recovery of municipal solid waste collected = [(a/b)*100	
3.4	**Extent of scientific disposal of waste at landfill sites**	
	Definition: The amount of waste that is disposed in landfills that have been designed, built, operated and maintained as per standards laid down by EMA/SAZ. This extent of compliance should be expressed as a percentage of the total quantum of waste disposed at landfills sites, including open dump sites.	
3.4.1	a. Total waste disposed in 'compliant' landfills every month.	
3.4.2	b. Total waste disposed in all landfills and dumpsites every month	The total waste disposed after collection and recovery (if any) at landfills (including compliant landfills, open dumpsites and undesignated sites). This quantity should be based on actual measurement at weighbridges preferably located at the entrance to such sites. The monthly total should be the sum of daily totals in a month. Should be same as 3.2.2
	Extent of scientific disposal of waste at landfill sites = [a/b]*100	