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 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 overall performance of the system.

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 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 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.

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 & 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 & 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 & 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 & 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 & 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 & 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 & 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 & 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 & 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. 2019f). 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. 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 & 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 2.1), Literature Selection (described in Section 2.2), as well as Literature Review and Synthesis (described in Section 2.3).

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 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 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.

2.3 Literature Review and Synthesis

Following the literature selection, 27 documents (Muswere & Rodic 2004, Mubaiwa 2006, Mbohwa & Zvigumbu 2007, Chikobvu & Makarati 2011, Chirisa 2012, Tsiko & Togarepi 2012, Mlanda Zvikaramba 2008, Makwara & Magudu 2013, Pawandiwa 2013, Tirivanhu & 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 & Kudzai 2016, Mandevere & 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.

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. 2019g). 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.

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 & Rodic 2004, Mubaiwa 2006, Nemadire et al. 2017, Mandevere & Jerie 2018, Madungwe & Sakuringwa 2007, Kamusoko et al. 2013, Nhubu & 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 & 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 & Togarepi 2012). This increase in population in Harare has contributed to an increase in waste volumes generated (Chikobvu & Makarati 2011, Tsiko & Togarepi 2012, Chirisa 2013, Mada & 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 & Jerie 2018).

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 & 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 & Magudu 2013, Mandevere & 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 0.48kg while in 2017 Nemadire et.al. (2017) stated it was 0.43kg. An estimated 371 697 000kgs and 198 793 000kgs of total MSW and HSW are produced annually in the city, respectively (Nhubu et al. 2019h, Kharlamova et al. 2016). On the other hand, Nhubu & Muzenda (2019) state that the annual MSW generation is 325 266 000kgs while Zamba (2014) estimated HSW volumes produced in the city at about 150 000 000kgs. Others estimate HSW generation to be 233000000 (Nemadire et al. 2017) and 279751000 (Nhubu et al. 2019a). Variations in the annual HSW volumes reported in the literature and those recorded in the HCC records are illustrated in Figure 1 below.

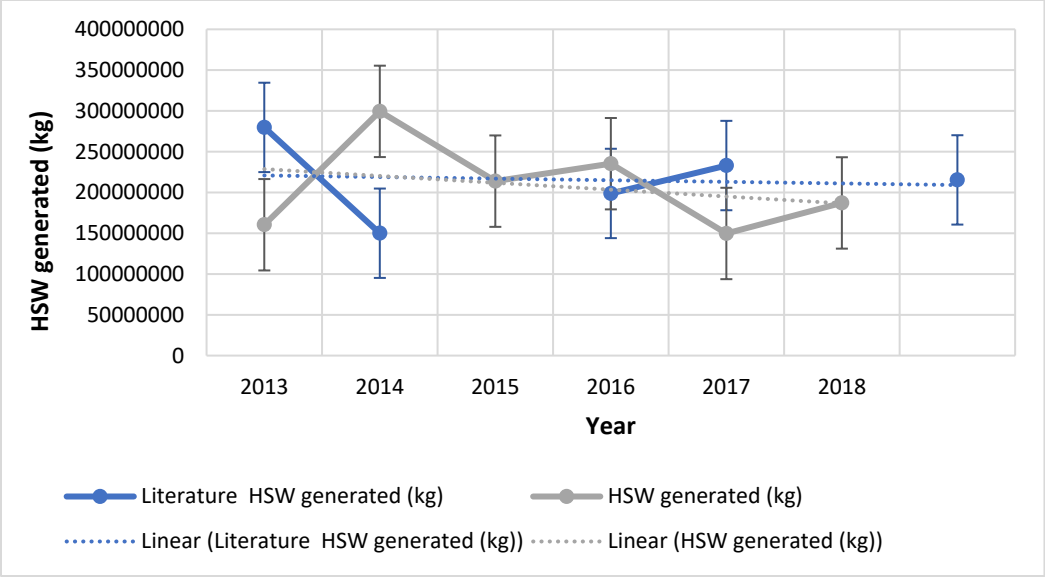

Figure 1 HSW generated annually: literature versus HCC records

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 125 048 119.2kgs was observed for the year 2014 as shown in Figure 1 above.

Figure 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 wrong population figures to estimate its HSW generation.

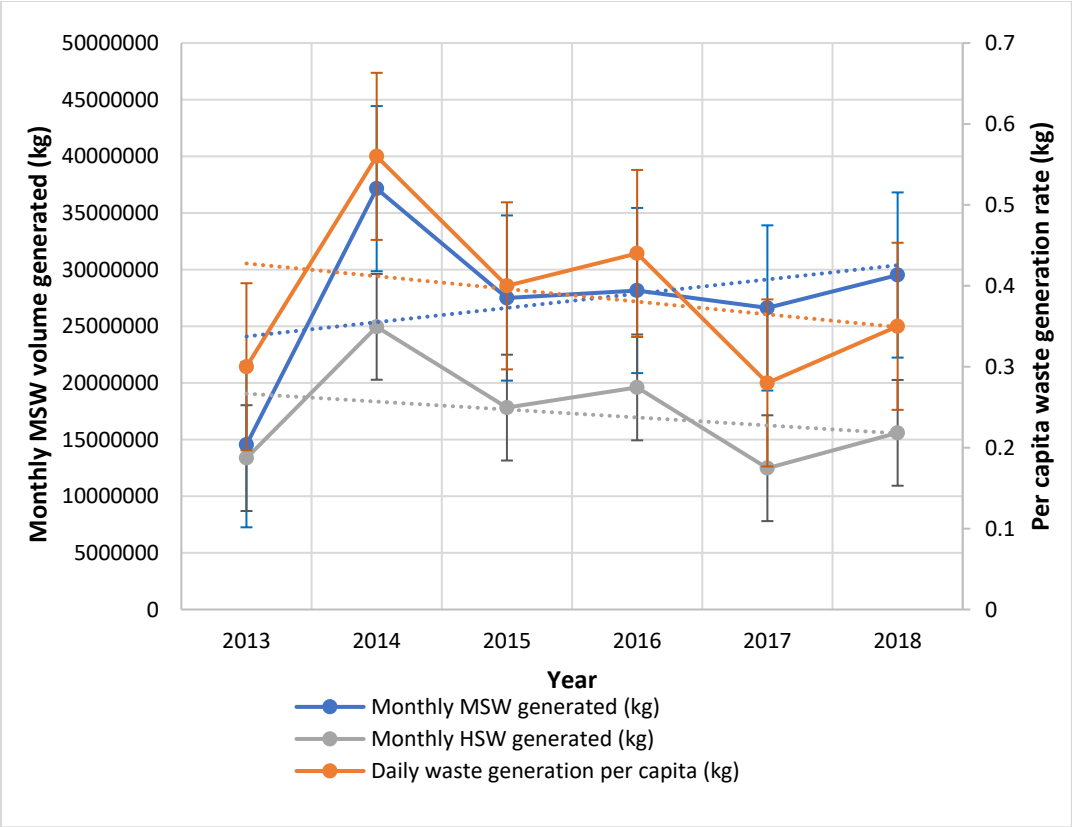

Figure 2 MSW generated, HSW generated, and waste generation rate in Harare (HCC 2019).

Figure 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 as shown in Table 1 below.

Table 1 Waste management indicator values in Harare (HCC,2019)

	Year							
Waste management indicator	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Average**	**Standard Uncertainty**
MSW generated (kg)	174576000	445764000	329952000	337896000	319452000	354312000	326992000	87485219.16
HSW generated (kg)	160404948	299422570	213873264	235260590	149711285	187139106	207635294	56027040
Daily waste generation per capita (kg)	0.3	0.56	0.4	0.44	0.28	0.35	0.3883333	0.1032311
MSW collected (kg)		331692000	251268000	273516000	195456000	246528000	259692000	49359956.81
HSW collected (kg)		214008000	156636000	197328000	145596000	138360000	170385600	33384208.55
MSW collection efficiency (%)		74	76	81	61	70	72.4	7.5033326
HSW collection efficiency (%)		71.47357	73.237766	83.876352	97.251186	73.934306	79.954636	10.814801
MSW recovery (kg)		17268000	23328000	24204000	24336000	28356000	23498400	3988816.967
MSW recovery (%)		5.2	9.3	8.8	12.5	11.5	9.46	2.8289574

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.

1.3 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 & 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 & 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 task 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 & 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 & 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 & 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 collected as well as the efficiency with which it is collected however varies annually as shown in Figure 3 below.

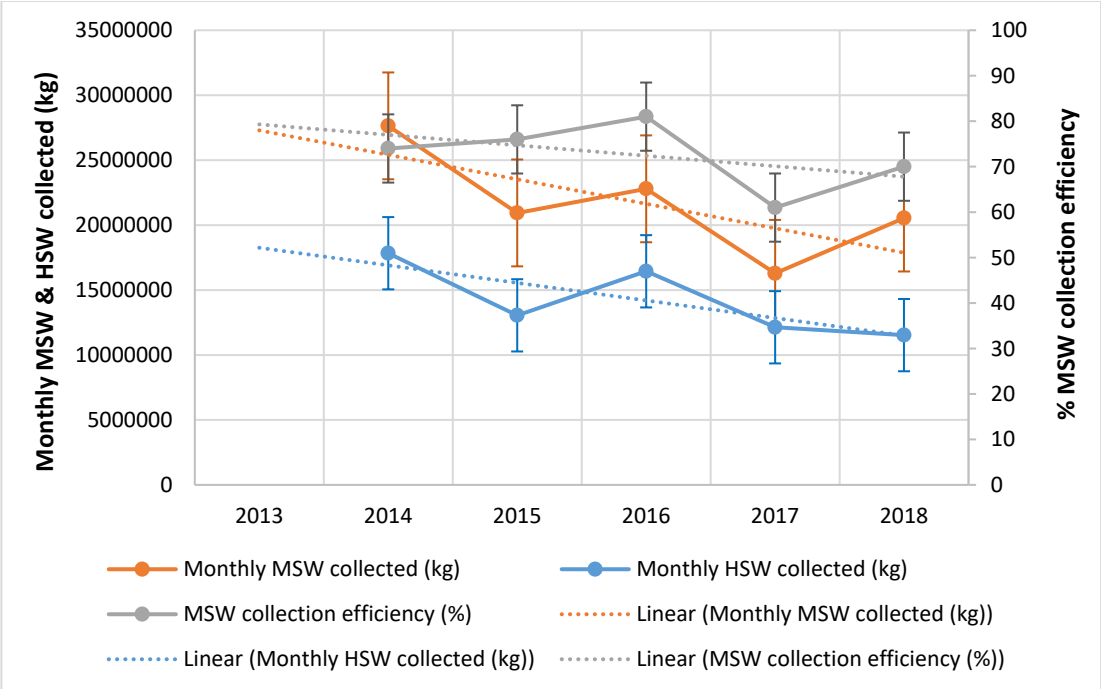

Figure 3 MSW collected, HSW collected, and MSW collection efficiency in Harare (HCC 2019)

All waste collection indicators are shown in Figure 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 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 & Togarepi 2012, Tanyanyiwa 2015). However, in some instances, the HCC reschedules waste collection frequency from once-a-week to once-a-month (Nyatsanza & Kudzai 2016, Mandevere & 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 & 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 & Jerie 2018, Chikobvu & 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 & 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) states that the Council has 40 HCC-owned vehicles that transport waste to the Pomona waste dump each with a carrying capacity of about 10 tonnes 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 & Jerie 2018). In turn, this results in the use of the vehicles until they breakdown and hence are more costly to repair.

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 000kgs and 500 000kgs or about 10 000 000kgs per month (Nemadire et al. 2017, Mandevere 2015). Pomona, which covers an approximate area of 1 000 000m^2, is expected to reach the end of its service life by 2020 (Nhubu & 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. 2019g, 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). Figure 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.

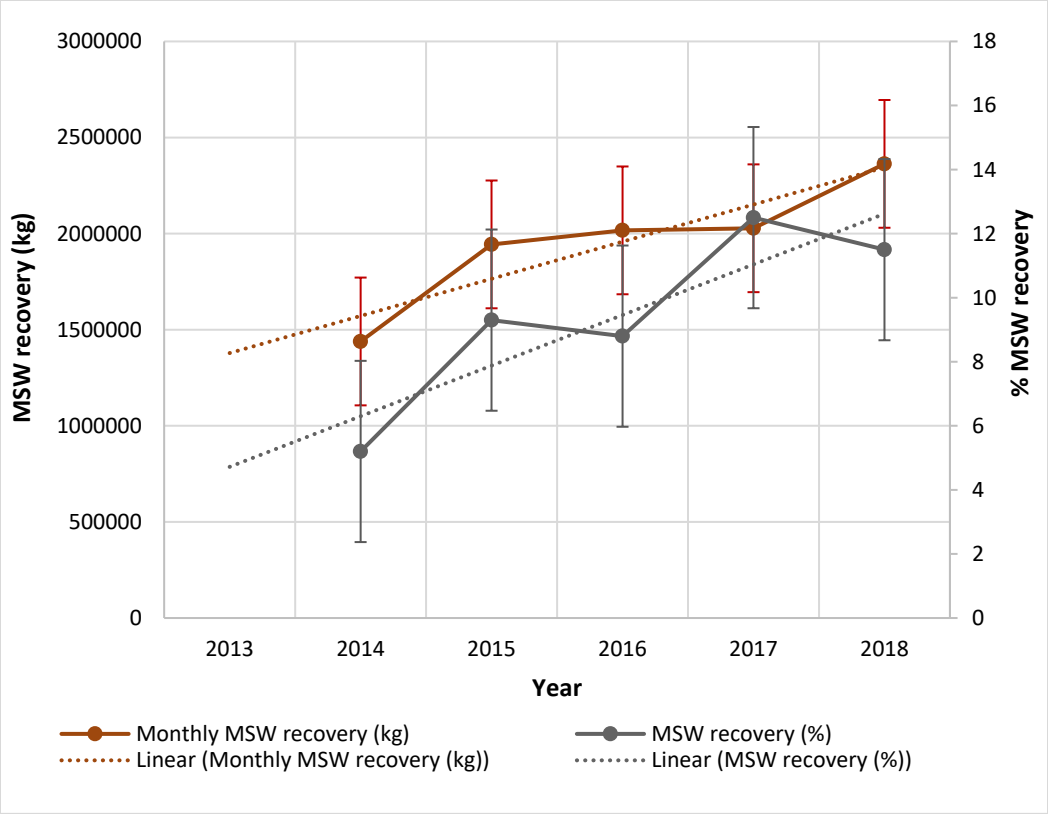

Figure 4 MSW recovery in Harare (HCC, 2019)

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 & Jerie 2018). In 2018, Mandevere & 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.

1.5 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 in 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 & Makarati 2011, Muswere & Rodic 2004, Mandevere & 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 & Jerie 2018, Chikobvu & Makarati 2011). Moreso, in preparation for the development of the National Integrated Solid Waste Management Plan (NIWMP), a baseline study was successful conducted in 2011. Although the NIWMP 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 & Jerie 2018, Nhubu et al. 2019b).

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 Integrated Solid Waste Management (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 & Jerie 2018, Lavagnolo & Grossule 2018). However, presently, the country's HSW management strategies do not seem to be prioritizing sanitation and creating a subsistence economy.

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 & Makarati 2011). Despite this, due to financial constraints, residents sometimes even fail to pay these fees (Mandevere, 2015, Mandevere & 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 are 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 & 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 Figure 2 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 Figures 2 above. The increase in population, consumption patterns, and waste generation rates in the city are contributors to the increase in waste volumes (Chikobvu & Makarati 2011, Zamba 2014, Kharlamova et al. 2016, Nyatsanza & Kudzai 2016, Nhubu et al. 2017, 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 & 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 & 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 & 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).

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 & 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 collection are fully covered.

Generally, the HCC has failed to provide efficient waste collection services to its residents (Chikobvu & Makarati 2011, Jerie 2018, Mafume et al. 2016, Makarichi et al. 2018, Mandevere & Jerie 2018, Mandevere 2015, Mlanda Zvikaramba 2008, Rinke et al. 2014, Tanyanyiwa 2015, Tsiko & 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 Figure 3 above. This is also despite that the 2015 MSW generated was 9 674 000kgs lower than that recorded in 2014 as shown in Figure 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 Figure 2 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 Figure 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 Figure 2 above) and HSW collected graphs (shown in Figure 3 above) signifying that larger monthly volumes of HSW of up to about 7 692 000kgs and 5 036 000kgs were being left uncollected in Harare's residential areas in the years 2017 and 2018, respectively. This contrasts with the up to 4 077 000kgs 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 Figure 2 above) also saw a 13.7% increase in waste collection efficiency (shown in Figure 3 above) as well as a 26% increase in the volume of municipal solid waste collected by the HCC.

Overall, as also discussed in Section 4.1, 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. 2019g). 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 & Jerie 2018). Communal composting can be considered where household-level compost pitting is not feasible.

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. 2019g).

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 & Kudzai 2016, Nemadire et al. 2017, Mandevere & 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 & 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 & 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 modeling techniques, it is rather cumbersome and inefficient to holistically consider the entire waste management system and its interconnectivity during planning.

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.

6 Recommendations

Generally, future studies can look into using SD modeling 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 & Chang 2005, Sufian & Bala 2007, Chi 2012, Escalante 2012, Wager & Hilty 2012, Lin 2012, Inghels & Dullaert 2011, Popli et al. 2017). The methodology is used to study or manage systems with complex feedbacks (Dyson & Chang 2005, Ahmad & Simonovic 2000, Minegishi & Thiel 2000, Homer & Hirsch 2006). Table 1 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 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 ~ 0.35kgs • 325 000 000- 400 000 000kgs of MSW produced annually • 150 000 000- 200 000 000kgs of HSW produced annually • Population estimated at 1.5-3 million as of 2012 • 6-8% population growth annually (including urbanization and natural increase • Increase in population causes an increase in waste volumes • Responsibility of 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 & 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 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 inconsistent and inaccurate • 40-47 municipality owned waste collection vehicles each with a carrying capacity of about 10 tonnes • ~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 to 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 & Vassanadumrongdee 2012, Meng et al. 2019). -Establish waste transfer stations across the city's residential areas (Nhubu et al. 2019c, Chatzouridis & Komilis 2012, Yadav et al. 2016, Kirca & Erkip 1988). -Strategically position waste collection bins. Use modeling 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. 2019g). - Reduces the amount of waste to be collected by the municipality, reduces waste collection costs, and potentially increase 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 & 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 000kgs and about 10 000 000kgs 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 Systems. -Establishment of waste to energy recovery systems (Mbohwa & Zvigumbu 2007; Makarichi et al. 2018, Nhubu & 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 & Zvigumbu 2007).

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