DETERMINING SPATIAL AND TEMPORAL CHANGE IN HOUSEHOLD SOLID WASTE COMPOSITION WITHIN STELLENBOSCH LOCAL MUNICIPALITY

CHARLOTTE MARIA NELL

15291642

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SUPERVISOR: Mr Jan de Waal

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DECLARATION

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ABSTRACT

The quantities in which solid waste is generated are continuously increasing throughout the world. If waste is not treated or disposed of in an appropriate manner, the consequences for societies and environments are likely to be extremely adverse, if not catastrophic. Consequently, effective management of household solid waste is crucial to ensuring the maintenance of clean and healthy living environments. As it is incumbent upon local authorities in South Africa to provide solid waste management services, they require accurate information pertaining to their waste streams to guide their waste management practices. It is widely recognised throughout the world that waste characterisation studies represent an optimal means of obtaining detailed data pertaining to waste streams.

This thesis concerns the findings and a comparative analysis of two waste characterisation studies which were conducted in 2012 and 2017 in the Stellenbosch municipal area. The studies were concerned solely with the residual portion of household solid waste which is landfilled. While the fourteen areas were surveyed in the study of 2012 and samples were sorted into seven fractions, twenty-three areas were surveyed in the study of 2017 and some of the fractions which had been used in 2012 were further sub-divided to yield a total of eighteen fractions. Ten of the areas which were surveyed in 2017 were either similar to or overlapped with those which were surveyed in 2012. In each study, waste profiles were determined by both mass and uncompacted volume for each area. The respective findings from 2012 and 2017 were then compared to identify spatio-temporal changes and statistical analyses were performed to determine the significance of each change. Correlations were also determined between relevant socioeconomic parameters and the data which had been obtained pertaining to the waste streams of individual areas.

Organic waste represented the predominant waste fraction by mass in all ten overlapping areas in the two characterisation studies, while the plastic wrap/packaging fraction was the largest by volume in all areas in both studies. The largest and most significant temporal changes from 2012 to 2017 were a very large increase by mass in the case of the plastic wrap/packaging fraction and by volume in that of the hard plastics fraction.

The findings revealed that the high rates at which particular fractions of the waste stream were disposed of in low-income areas were skewed as a consequence of the separation at source programme not being implemented in the areas. Consequently, it is recommended that the implementation of the programme should be extended to all areas which fall under the jurisdiction of the Stellenbosch Local Municipality, in the form of a three-bag separation at source programme. Improved education and awareness concerning the waste crisis with which the municipality is faced at present is also equally crucial.

KEY WORDS

Waste characterisation study, municipal solid waste, household solid waste, waste management, diversion from landfill, waste data

OPSOMMING

Die hoeveelhede vaste afval wat gegenereer word, neem deurlopend wêreldwyd toe. As afval nie op 'n toepaslike manier hanteer of weggegooi word nie, sal die gevolge daarvan vir samelewings en die omgewing waarskynlik uiters nadelig wees, indien nie katastrofies nie. Gevolglik is effektiewe bestuur van vaste huishoudelike afval noodsaaklik om die instandhouding van 'n skoon en gesonde leefomgewing te verseker. Aangesien dit die plaaslike owerhede in Suid-Afrika se verantwoordelikheid is om dienste vir vaste afvalbestuur te lewer, benodig hulle akkurate inligting rakende hul afvalstrome om hul planne te beraam. Wêreldwyd word dit algemeen erken dat afval-ontledingsstudies 'n optimale manier is om gedetailleerde data rakende afvalstrome te bekom.

Hierdie tesis handel oor die bevindings en 'n vergelykende analise van twee afval-ontledingsstudies wat in 2012 en 2017 in die Stellenbosch munisipale gebied uitgevoer is. Die studies het slegs betrekking op die gedeelte van die afvalstroom wat na die stortingsterrein toe gestuur word. Veertien areas was tydens die 2012 studie ondersoek en monsters in sewe fraksies sorteer. Drie-en-twintig areas was in 2017 ondersoek en monsters in dieselfde sewe fraksies sorteer en toe verder verdeel om 'n totaal van agtien fraksies te lewer. Tien van die gebiede wat in 2017 ondersoek is, het oorvleuel met die wat in 2012 ondersoek is. In albei studies is profiele vir elke gebied bepaal deur die massa en die onsaamgepersde volume van daardie area se afvalstroom te bepaal. Die onderskeie bevindings van 2012 en 2017 is daarna vergelyk om tyd-ruimtelike veranderinge te identifiseer en statistiese ontledings is uitgevoer om die belang van elke verandering te bepaal. Korrelasies is ook bepaal tussen relevante sosio-ekonomiese parameters en die gegewens wat verkry is met betrekking tot die afvalstrome van individuele gebiede.

Organiese afval verteenwoordig die oorheersende afvalfraksie volgens massa in al tien oorvleuelende gebiede in albei ontledingsstudies, terwyl die plastiekomhulsel / verpakkingsfraksie die grootste volgens volume in al die gebiede in albei studies was. Die grootste en belangrikste tydelike veranderinge van 2012 tot 2017 was 'n baie groot toename in massa in die geval van die plastiekomhulsel / verpakkingsfraksie en volgens volume in dié van die harde plastiekfraksie.

Die bevindings het aan die lig gebring dat hoë hoeveelhede van sekere fraksies van die afvalstroom was in lae-inkomstegebiede weggegooi. Dit was as gevolg van die herwinningsprogram wat nie in die gebiede geïmplementeer is nie. Gevolglik word dit aanbeveel dat die implementering van die herwinningsprogram uitgebrei moet word na alle gebiede wat onder die jurisdiksie van die Stellenbosch Plaaslike Munisipaliteit val, in die vorm van 'n drie-sak skeiding. Meer klem moet ook geplaas work op bewusmaking rakende die tekort aan lugspasie.

TREFWOORDE

Afval ontledingsstudie, munisipale vaste afval, huishoudelike vaste afval, afvalbestuur, stortingsterrein wegkering, vaste afvaldata

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  - My siblings Hilda-Mari, Rickus and Gareth.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
C&D	Construction and demolition
CSIR	Council for Scientific and Industrial Research
CWDM	Cape Winelands District Municipality
DEA	Department of Environmental Affairs
DEA&DP	Department of Environmental Affairs and Development Planning
DST	Department of Science and Technology
DVLS	Devon Valley Landfill Site
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
EPS	Extruded polystyrene
GW	Garden waste
HDPE	High-density polyethylene
HHHW	Household hazardous waste
HIPS	High-impact polystyrene
HSW	Household solid waste
IW	Industrial waste
IT	Information technology
LDPE	Low-density polyethylene
MRF	Materials Recovery Facility
MSW	Municipal solid waste
NRF	National Research Foundation
Oth	Other
PDP	Professional Driving Permit

PET	Polyethylene terephthalate
PP	Polypropylene
PPE	Personal protective equipment
PS	Polystyrene
PVC	Polyvinyl chloride
RDI	Research, Development and Innovation
SARChI	South African Research Chairs Initiative
SW	Solid waste
UNEP	United Nations Environment Programme
WHO	World Health Organisation

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The creation of waste is a consequence of human activities (Matsunaga & Themelis 2019). Solid waste (SW) is defined by the Environmental Protection Agency (EPA) as any discarded material which results from the activities of communities or industrial, commercial, mining and agricultural operations (United States Environmental Protection Agency 2019). SW can be broadly grouped into industrial waste (IW), municipal solid waste (MSW) and construction and demolition (C&D) materials (United States Environmental Protection Agency 2019). This study is concerned solely with the MSW portion of the waste stream.

The Aarhus Convention[1] refers to 'the right of every person of present and future generations to live in an environment adequate to his or her health and well-being' (Guillerm & Cesarit 2015). At the local level, this notion is reinforced by the Constitution of the Republic of South Africa, which creates a framework for environmental governance by emphasising the right of its citizens to an environment which is not harmful to their health or well-being (South Africa (Republic of) 1996). It also allocates environmental functions to an array of government agencies, directing the provision of basic waste management services to its local authorities (South Africa (Republic of) 2000), a practice which is adhered to by the governments of many other countries throughout the world. Consequently, it is usually incumbent upon local governments to take appropriate measures to ensure that the environments of their districts are not polluted by MSW. In an effort to minimise potential pollution, most developing countries still rely heavily on using MSW as landfill as a preferred method of disposal.

Although the basic method of landfilling MSW implemented since 3000 B.C. (Tammemagi 1999) has remained relatively unchanged until today (South Africa (Republic of) 1998), priorities have shifted away from disposal towards more sustainable treatment methods. In order to effect an appropriate shift in practice, the waste hierarchy concept (Figure 1.1) was formulated, which identifies the disposal of waste as the least favourable means of managing MSW and advocates preventing the creation of waste as its principal objective (Cole, Osmani, Quddus, Wheatley & Kay 2014).

Figure 1.1: The waste hierarchy **Source: European Commission (2008)**

[1] The Aarhus Convention was adopted on 25 June 1998 in the Danish city of Aarhus (Århus) at the Fourth Ministerial Conference as part of the "Environment for Europe" process. It entered into force on 30 October 2001 and establishes a number of rights of the public (individuals and their associations) with regard to the environment.

Adhering to the priorities and objectives of the waste hierarchy by moving from disposal towards prevention represents a time-consuming and costly endeavour, owing to the increasingly complex composition of the modern MSW stream (Gregson, Crang, Laws, Fleetwood & Holmes 2013). The sharp rises in the volumes of MSW which are generated and the changing profile of waste necessitates corresponding increases in the resources which are required to ensure that it is appropriately treated and managed (Ozcan, Guvenc, Guvenc & Demir 2016). Throughout the world, 2.01 billion tons of MSW are generated each year, a figure which is expected to grow to 3.40 billion tons per annum by 2050 (Kaza, Yao, Bhada-Tata & Van Woerden 2018).

1.2 RATIONALE

In South Africa, the war on waste has been prioritised by the national government, under the leadership of the Department of Science and Technology (DST), with the support of the Department of Environmental Affairs (DEA) (DEA 2011). The National Waste Information Baseline Report (DEA 2012) reveals that 59 million tonnes of MSW is generated each year in South Africa and that in 2011, approximately 10% of all of the waste which had been generated in the country had been recycled (DEA 2012), a figure which can be much improved upon when comparing with some developed countries.

In January of 2014, the DST launched the Waste Research, Development and Innovation (RDI) Roadmap and tasked the Council for Scientific and Industrial Research (CSIR) with its implementation (DST 2018; DST 2019). The overarching aim of this 10-year project is to assist the government and the industrial sector to achieve diversion of waste away from landfill and towards more sustainable alternatives (CSIR 2019). According to the 2012 National Waste Information Report (DEA 2012), at the time South Africa was consigning approximately 90% of all of the waste which was generated to landfill, a figure which could be significantly decreased with the successful implementation of the roadmap, through the development of a robust, regional secondary resources economy (DST 2014).

In accordance with the objectives of the roadmap, the first ever research chairs in waste management were launched in 2018 under the auspices of the South African Research Chairs Initiative (SARChI) and under the leadership of the National Research Foundation (NRF) (DST 2018). Two new chair positions were created, one in Waste and Society and one in Waste and Climate (DST 2018). The research upon which this thesis is based was funded by the SARChI Chair in Waste and Society and is intended to contribute to increasing the body of knowledge pertaining to waste management in South Africa.

The roadmap is directly aligned with the Good Green Deeds campaign of the President of the Republic of South Africa, which was launched in September of 2018 with the express aim of cleaning up the country (Cape Times 2019). It also supports the National Waste Management Strategy, which is a legislative requirement of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) (DEA 2011; DST 2019).

The National Waste Management Strategy emphasises that South African local authorities are struggling to keep up with the escalating demand for providing basic waste management services (DEA 2011). Only by continuously upgrading their waste management infrastructure and ensuring that related services such as waste collection are not affected by delays and stoppages are local authorities able to ensure that effective waste management is maintained (Kirkman & Voulvoulis 2017; World Bank Group 2018). By contrast, existing infrastructure is subjected to inordinate strain by exponential increases in the volumes of waste which are generated as a consequence of population growth and urbanisation. As a direct consequence, additional resources are needed to maintain existing levels of service (Kumar & Goel 2009). A lack of reliable waste data at local government level has been cited as being one of the principal causes of overburdened waste management infrastructure, which makes it difficult for decision makers to assess their present circumstances and plan adequately for the future (DEA 2011; Edjabou, Møller & Christensen 2012).

MSW comprises waste which originates from households (which is referred to as household solid waste or HSW) and also waste from commercial and institutional sources (Nezami & Cortes 2017; Kaza et al. 2018). This study concerns only HSW. Dependable data pertaining to HSW is essential to implementing successful waste management strategies and achieving the objectives of the waste hierarchy (Miezah, Obiri-Danso, Kádár, Fei-Baffoe & Mensah 2015). In many developing countries there is a lack of available information pertaining to the composition of HSW and how it is generated (Guerrero, Maas & Hogland 2013). In others, although data is available, it is often unreliable, because either the origin of the information is unknown or the information is based loosely on perceptions or interpretations, rather than on statistics and the findings of relevant studies (Miezah et al. 2015). Godfrey (2008) found that only 69% of South African municipalities collected any form of waste data, of which 62% were uncertain of the reliability of the information which they had at their disposal.

Waste characterisation studies enable relevant data pertaining to HSW to be gathered to assist decision makers to identify constraints and opportunities with respect to the management of their HSW streams (Yenice, Doğruparmak, Durmuşoğlu, Özbay & Öz 2011). Dependable waste characterisation data is crucial to decision-making processes (Gay, Beam & Mar 1993), which can be effectively hamstrung by a lack of data (Edjabou et al. 2012). Optimal methods of collecting and freighting HSW, recovering materials from it and appropriate 'end-of-life' methods are highly reliant upon the characteristics of particular waste streams (Ozcan et al. 2016). The availability of information enables local authorities to increase the accuracy of their predictions concerning remaining landfill airspace, optimise their waste management strategies and comply with budgetary requirements (Haider 2019, pers com). It also assists them to implement appropriate waste management, reuse and minimisation strategies (Hanekom 2019, pers com).

The South African State of Waste Report (DEA 2018) explains the severity of the shortage of landfill airspace by revealing that three of the largest municipalities in the country (by population), namely, the City of Cape Town, City of Johannesburg and City of Tshwane municipalities, have only 6, 8 and 18 years of remaining landfill airspace respectively. Best practice requires cities to have at least 15 years of landfill airspace available at any given time (Hanekom 2019, pers com). Figure 1.2 depicts the estimated landfill lifespan for each local municipality within the province of the Western Cape of South Africa.

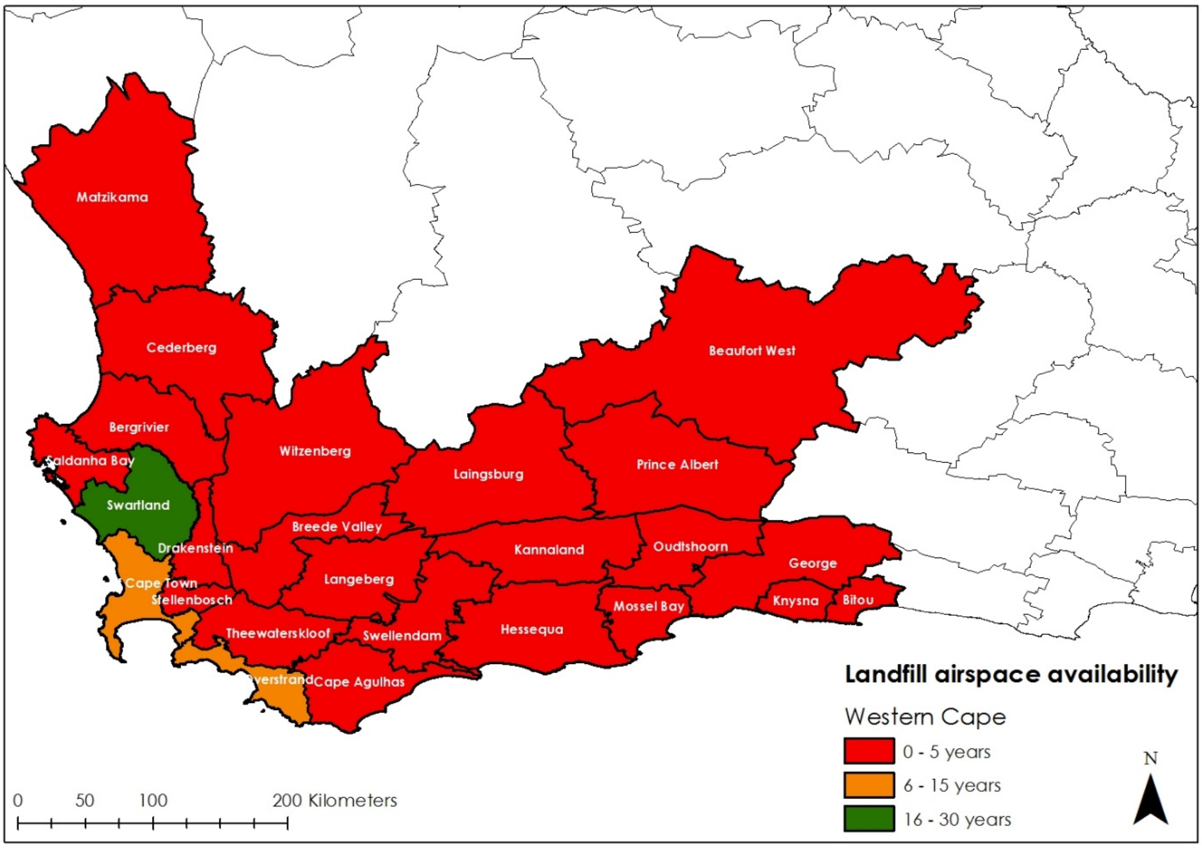


Figure 1.2: Remaining landfill airspace for each local municipality within the province of the Western Cape in South Africa (in years) Adapted from GreenCape (2019)

As it can be seen in Figure 1.2, the Stellenbosch Local Municipality is one of the many local authorities in the Western Cape with less than 5 years of landfill airspace remaining. The reality is even more disturbing, as the only licensed waste disposal facility in the district, the Devon Valley Landfill Site (DVLS), reached capacity in March 2019 (Utter Rubbish 2019a[2]). As the municipality is tasked with providing waste management collection and disposal services to 43 420 households (Municipalities of South Africa 2019), reliable and comprehensive information concerning the composition of waste in the district is crucial to enabling the municipality to plan waste management effectively for the future (DEA 2012). This study is intended to meet this crucial need by providing in-depth information concerning the HSW component of the MSW which falls within the purview of the Stellenbosch Local Municipality.

1.3 RESEARCH PROBLEM

In 2012, the Stellenbosch Local Municipality did not have access to any trustworthy data concerning either the composition or the quantities of waste which were being generated within its area of jurisdiction (Haider 2019, pers com). One of the pressing concerns at the time was the rapidly diminishing airspace at its only disposal site, the DVLS. In 2012 it was estimated that the landfill had only 5 years of remaining airspace left at the prevailing

[2] "Utter Rubbish" is a quarterly newspaper compiled and distributed by Stellenbosch Municipality's Solid Waste Management Department with the aim of providing up to date and reliable information to its citizens regarding the state of waste in its jurisdiction.

rates of disposal and was due to reach capacity in 2017 (Haider 2012, pers com). It needs to be emphasised that the estimate was made without any reliable waste data being available.

As a first step to remedy the lack of relevant information, the municipality commenced its first waste characterisation study in 2012, with the aim of quantifying and classifying the waste which was being generated at the household level (Bradfield 2014). Ten suburbs were sampled and characterised and waste profiles for each were created (Cronjé, Du Plessis & Mearns 2014). The data was then analysed to gain an understanding of the financial, social and environmental viability of changing and improving the overall waste management system (De Beer 2013).

As a second step, the municipality installed a weighbridge and relevant software at the DVLS to capture data pertaining to all incoming loads which were to be disposed of on-site, which provided an accurate assessment of the composition of the entire MSW stream, by capturing the tonnages of garden waste (GW), industrial waste (IW), construction & demolition (C&D) waste and household solid waste (HSW) which were disposed of (Haider 2019, pers com). The findings also served to inform the municipality of the short-, medium- and long-term interventions which would be needed to provide solutions to the looming impasse which it faces with respect to managing its solid waste (Cronjé et al. 2014).

Although the predicament which the steadily diminishing landfill airspace represents persists (Haider 2019, pers com), the municipality has been able to manage the problem to a certain extent. It had been expected that the DVLS would reach capacity by the end of 2017, but through sound landfill management and successful waste minimisation projects which were initiated subsequent to the initial waste characterisation study in 2012 the life expectancy was extended by two years. Consequently, the DVLS reached capacity in 2019, rather than in 2017, the initial deadline which had been anticipated (Haider 2019, pers com; Utter Rubbish 2019a). The operational plans of the municipality for managing waste in the absence of any remaining airspace are covered in section 1.5.

Proper management of the remaining airspace at the DVLS was crucial to extending its lifespan and could be accomplished only through an intimate knowledge of the composition of the waste which was disposed of on-site (Stellenbosch Municipality 2018). As it has been explained, a mixture of GW, IW, C&D waste and HSW has been accepted on-site and as loads which enter the facility are individually recorded on the weighbridge system prior to disposal, the municipality has been able to monitor the quantities of each waste stream which are disposed of (Utter Rubbish 2016a).

Owing to the homogeneity of the materials which comprise the GW and C&D waste streams, the municipality does not need any additional information concerning them (Heckrath 2018, pers com). In addition, the municipality has already introduced and begun to implement waste beneficiation programmes for both streams: GW is chipped on-site and removed for further beneficiation; C&D waste is crushed and screened on-site to predetermined specifications in accordance with tender requirements and made available for resale (Stellenbosch Municipality 2018; Utter Rubbish 2019b).

IW is transported to the facility by private contractors and accepted if it can be classified as 'general solid waste' (Monaila 2017, pers com). This classification implies that it may not be classifiable as a sludge and may not contain any hazardous material (DEA 2009). The content of IW loads is also captured as the waste enters the facility, but as IW is generated at private facilities and removed and transported by private contractors, the Municipality has little operational control over the types and quantities of waste which are generated (Haider 2019, pers com).

By contrast, municipalities are able to exert significant influence with respect to minimising their HSW streams. Since 2010, a separation at source programme has been implemented in some areas of Stellenbosch. Residents are encouraged to separate their recyclable materials from their non-recyclable materials at the point of generation, namely, at their homes (Please see section 1.5) (Sango 2014). The households which participate in the programme generate two types of waste. The first category comprises mainly non-recyclable and organics waste. It is discarded in black bags, landfilled and referred to as residual waste. The second category is collected separately in clear bags, sorted for further beneficiation and comprises mainly recyclable materials (Bradfield 2014). The separation at source programme provides the municipality with a monthly breakdown of the types and quantities of recyclable materials which have been separated by households from residual waste (Utter Rubbish 2017a). Accordingly, the contents and composition of the clear bags are known. Households in areas in which the separation at source programme is not implemented generate waste which is used as landfill only. The waste consists of a mixture of recyclable, non-recyclable and organic waste, which is disposed of in black bags. Consequently, the composition of the waste stream which enters the DVLS of which the municipality is most uncertain is the residual portion of the HSW stream.

An improved understanding of the residual portion of the HSW stream can be obtained by conducting a second waste characterisation study, which is concerned solely with the residual portion of the HSW stream, in order to update the available information concerning waste composition. A second study enables updated (2017) information to be evaluated in relation to the baseline which the data from the study of 2012 provides. In addition, areas which were not characterised in the previous study are included in the second study. This information will once again assist the municipality to obtain an understanding of how diverting waste from being used as landfill can be maximised.

1.4 RESEARCH QUESTIONS

- What is the composition in 2017 of the residual portion of HSW in the Stellenbosch Local Municipality?
- What is the composition in 2017 of the residual portion of HSW in each area from which data was collected?
- What are the types and quantities of materials which are landfilled annually according to the data which is obtained from the study of 2017?
- Are temporal changes observed in waste composition in the overlapping areas in which the study is conducted, by comparison with the findings of the study of 2012?
- Are spatial changes observed in waste composition in the overlapping areas in which the study is conducted, by comparison with the findings of the study of 2012?
- Do economic and demographic parameters, such as household size, household income and the geographical density of households, affect the quantity and composition of waste?

1.5 AIM AND OBJECTIVES OF THE STUDY

The aim of this research project is to carry out a waste characterisation study in the municipal area of Stellenbosch, in order to determine the composition of the residual portion of the HSW stream in 2017, to compare it with that of the 2012 study, to identify spatial and temporal changes. In order to achieve this aim, the following objectives have been formulated:

1.4.1 To determine the composition of the residual portion of HSW in 2017.

1.4.2 To determine the quantities of the fractions of HSW which have been identified which are landfilled each year, according to the data which was obtained in the characterisation study of 2017.

1.4.3 To compare the findings of the 2012 HSW characterisation study with those of this study, to determine the spatial and temporal changes which can be observed in overlapping areas.

1.4.4 To correlate the quantity and composition of waste with relevant economic parameters for households.

1.6 STUDY AREA

The Stellenbosch Local Municipality (WC024) is one of five local municipalities which fall within the boundaries of the Cape Winelands District Municipality (CWDM) of the province of the Western Cape of South Africa.

The CWDM is made up of five local authorities, namely, the municipalities of Witzenberg, Drakenstein, Stellenbosch, Breede Valley and Langeberg (Municipalities of South Africa 2019). To place the Stellenbosch Local Municipality within the context of the CWDM, Table 1.1 summarises some of the key statistics concerning the makeup of each local authority.

Table 1.1: CWDM: Summary of municipal geographic, demographic and service provision statistics

Name of local municipality	MDB code	Size (km^2)	Population	Number of households	People / km^2	Weekly refuse removal
Witzenberg	WC022	10 753	115 946	27 419	10.78	70%
Drakenstein	WC023	1 538	251 262	59 774	163.37	86%
Stellenbosch	WC024	831	155 728	43 420	187.40	87%
Breede Valley	WC025	3 834	166 825	42 527	43.51	75%
Langeberg	WC026	4 518	97 724	25 125	21.63	72%

Source: Municipalities of South Africa (2019)

As it can be seen in the table, the Stellenbosch Local Municipality has jurisdiction over an area of only 831 km^2, with a total population of 155 728 people who reside in 43 420 households (Statistics South Africa 2012; Municipalities of South Africa 2019). It houses 19.78% of the total population of the CWDM on only 3.87% of the total area under its jurisdiction. From these statistics it is evident that the area which falls under the Stellenbosch Local Municipality is the most densely populated in the overall district (186.40 people/km^2), followed by that which falls under the Drakenstein Municipality (163.37 people/km^2). The Stellenbosch Local

Municipality provides a weekly refuse removal service to 87% of the population, the highest collection rate in the district (Municipalities of South Africa 2019). The study area map in Figure 1.3 depicts the location of the areas which are served by the municipality within the context of the province of the Western Cape of South Africa. Figure 1.3 further indicates the various areas studied in 2012, 2017 and both 2012 and 2017 respectively.

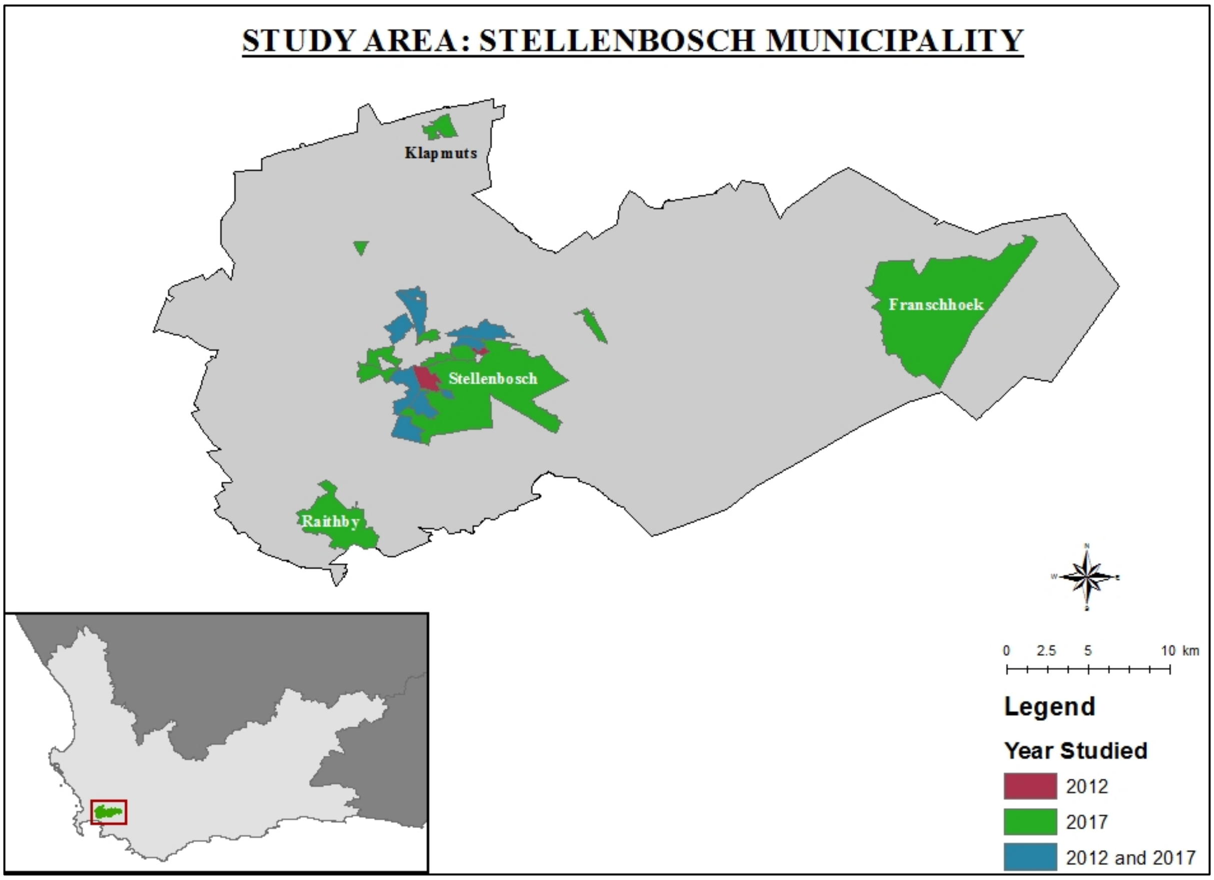


Figure 1.3: Locality map of the Stellenbosch Local Municipality **Source: Author**

The Stellenbosch Local Municipality is responsible for providing services to the towns of Stellenbosch, Klapmuts and Franschhoek and also to the settlements of Groendal, Koelenhof, Kylemore, Johannesdal, Pniel, Jamestown and Raithby.

1.6.1 Disposal of MSW in the areas served by the Stellenbosch Local Municipality

At present the DVLS is the only solid waste disposal facility which serves the Stellenbosch Municipal Region (Haider 2019, pers com). The Stellenbosch Local Municipality is the designated permit holder and at present the facility is operated on the basis of a permit which was issued by the then Department of Water Affairs and Forestry in 1999 (DWAF 1999). The facility has a G:M:B+ classification[3] and three cells (DWAF 1999). A cell refers to a specific area within the larger, permitted, waste disposal facility which is specifically designed, constructed and approved for the disposal of waste (Advanced Disposal 2019).

[3] This classification is based on the 1998 DWAF Minimum requirements for operating a landfill site viz. **G** (General waste type) l **M** (Medium size >150 and <500 tonnes/day) l **B+** (positive water balance, i.e. leachate management required) (Barbour & Van der Merwe 2011).

Cells 1 & 2 are historic cells, which have been operated by the Stellenbosch Local Municipality since approximately 1966 and were initially permitted to expand up to a height of 16 metres above ground level (JPCE 2008). In 2010 permission was granted by the provincial Department of Environmental Affairs and Development Planning (DEA&DP) to extend the height restriction of the facility to 22 metres above ground level (Haider 2012, pers com).

This amendment granted the municipality sufficient time to build a new, engineered landfill cell (Cell 3) with a liner for proper leachate management, at a cost of ZAR18.3million (Haider 2014). Cells 1 & 2 were operational until 2012, when Cell 3 was initiated (Utter Rubbish 2016b). In 2015, ZAR10 million was spent to cut and shape Cells 1 & 2 in accordance with the requirements for proper closure and rehabilitation to a 1:3 slope. This slope was temporarily capped by a layer of clay which was excavated during construction of Cell 3 while the municipality waited for a closure and rehabilitation licence to be issued by DEA&DP (Stellenbosch Municipality 2017). Stellenbosch Municipality received this Closure and Rehabilitation Licence on 13 September 2018 (SAWIC 2019). Cell 3 was planned to have a lifespan of approximately 5 years and to reach capacity in 2017 (Haider 2012, pers com; Haider 2014). The lifespan of the landfill was extended as a result of the implementation of substantial waste minimisation and sorting strategies and reached capacity only in 2019, some 2 years later than the anticipated deadline of 2017 (Haider 2019, pers com). The Municipality was able to continue on-site operations until 30 September 2019, by disposing of waste on the side slope of the facility, changing the slope from 1:3 to 1:2 (Haider 2019, pers com).

In order to compensate for the shortage of landfill airspace, the municipality has applied for permission to construct a new cell between Cells 1 & 2 and Cell 3 (Utter Rubbish 2019a), in effect permitting 'piggybacking' between the existing cells. This initiative will require 3 to 4 years to complete (Utter Rubbish 2019a) and, in the interim, the municipality will divert waste which is generated in Franschhoek and Klapmuts from the DVLS to a disposal facility in Cape Town (Haider 2019, pers com; Utter Rubbish 2019a). Once the new cell has been completed, it will be sufficient to provide 18 to 40 years of landfill airspace (Utter Rubbish 2019a), a figure which is dependent on the degree of success which is achieved in diverting waste from landfill.

1.6.2 Formal areas of the Stellenbosch Local Municipality

High- and medium-income areas which fall under the municipality share similar traits. They are mainly single residential, large (2+ bedroomed) single- or multi-storey houses which are constructed on sizeable erven. Streets and houses are named and numbered and homes generally have well-kept gardens. Streets are tarred and residents receive all available municipal services, which include refuse removal at least once per week, electricity, access to running water and sewerage services.

In the medium-income areas, apart from the single residential units, there are also many apartment blocks or complexes, particularly in the town of Stellenbosch, which are tenanted mainly by small families, young working professionals or students. Stellenbosch is home to one of the most highly-ranked tertiary education facilities in South Africa, namely, Stellenbosch University (URAP 2019). In 2018, 31 765 students enrolled at the university, which is supported by a personnel corps of 3 454 (Stellenbosch University 2018). Although accommodation for students is available in the residences of the university, they are able to accommodate only in the region of 7 500 students in total (Stellenbosch University 2019). Consequently, the majority of students are obliged to rely on private accommodation.

Streets and houses in formal, low-income areas are also named and numbered, but there is a general absence of gardens, a phenomenon which is attributable mainly to a shortage of space. Low-income areas in the municipal area consist mainly of single-storey stand-alone or semi-detached homes. Streets in the low income areas are tarred and generally well maintained by the Municipality. In addition, the households in these areas enjoy the same degree of access to services which are provided to the residents of medium- and high-income areas. In many cases, unused space on low-income erven is rented out to informal dwellers who receive permission from the owners to erect structures in exchange for monthly rentals which are payable to their landlords. In most cases, these 'backyard dwellers' do not have shared access to the services which the tenants or owners who reside in the main dwellings enjoy, which include access to formal refuse removal services.

HSW which is produced in the research area is collected by refuse compactor vehicles. The vehicles are manned by an operator (driver) and five crew members. Houses in all areas are required to place their 240-litre Municipal-issued wheelie bins on the pavement outside their homes on refuse collection days. HSW is collected once a week, from Monday to Friday (Utter Rubbish 2016c). Housing complexes may also request refuse collection three times a week (Mondays, Wednesdays and Fridays), which is offered by the municipality at an increased tariff (Utter Rubbish 2019c).

A separation at source initiative, which is implemented in specific areas within the municipal area, enables residents to place recyclable waste in clear bags next to their wheelie bins on collection days. A different vehicle collects and transports recyclables to small Materials Recovery Facility (MRF) which is located adjacent to the DVLS, where it is sorted manually before it is baled and transported to recyclers.

1.6.3 Informal areas of the Stellenbosch Local Municipality

Informal areas are defined as areas which do not meet all of the requirements of a local municipality to be recognised as formal areas within the boundaries of towns or cities (DoE 2018). Informal settlements are characterised by the Department of Housing (Western Cape Government 2005) as often being located on land which is not properly zoned for residential use or unsuitable for reasons such as conflicts with respect to the ownership of land, environmental considerations or hazards in relation to health and safety. Informal areas proliferate in South Africa as a consequence of the rate of urbanisation increasing at a faster pace than the ability of local authorities to provide adequate housing and related infrastructure (Western Cape Government 2005). There are a number of informal areas within the municipal boundaries, the largest being Langrug in Franschhoek, Mandela City in Klapmuts, Enkanini in Stellenbosch as well as a certain area within Kayamandi in Stellenbosch.

Dwellings in the informal areas of this study area are mostly single-storey, one-roomed structures which are constructed from discarded materials such as corrugated iron, wood and chipboard off-cuts or cardboard. These homes do not have access to any municipal services or infrastructure. In some cases, depending on the location, shared ablution facilities which consist of pit toilets and wash basins with running water are available. In the absence of adequate sewerage services, residents are mainly obliged to make use of bucket toilets, whose undesirable consequence is the discarding of blackwater and greywater in the streets outside of their homes. No door-to-door or kerbside solid waste collection is available and in many cases, illegal connections are made to connect homes to the electrical grid.

HSW is collected from informal areas by removing 6 m^3 skips up to five times a week. The use of skips is preferred by the municipality in these areas because access to homes is often hindered by low-hanging electrical cabling and a lack of formal roads (Heckrath 2018, pers com). Consequently, the locations of skips are usually determined by the ease with which refuse removal vehicles are able to reach them and not necessarily by other equally significant factors such as the distances between the skips and residents (Hendricks 2018, pers com).

To encourage the responsible management of waste in the informal areas, black bags are regularly distributed by the municipality to each dwelling (Dyidi 2017, pers com). A Swop Shop initiative has also been piloted in two lower-income areas, Klapmuts and Kayamandi (Utter Rubbish 2017b). In these areas, residents are encouraged to bring recyclable materials such as glass, paper, cardboard, tins and plastic to the Swop Shop once a week to exchange for items to meet basic needs, such as coffee, milk, sugar, stationery, clothes and personal hygiene products.

1.7 OVERVIEW OF THE RESEARCH METHODOLOGY

The initial study of 2012 was carried out in accordance with the draft guidelines which were compiled by the United Nations Environment Programme (UNEP) (2007) to guide the procedures which were followed to characterise the waste. The guidelines for the study of 2017 were provided by the document 'Waste Characterisation Guideline for Municipalities' (DEA&DP 2017), which was published by the DEA&DP of the Western Cape.

Figure 1.4 provides a schematic depiction of the sequence of procedures which the researcher developed to enable the study to be carried out in a logical and efficient manner.

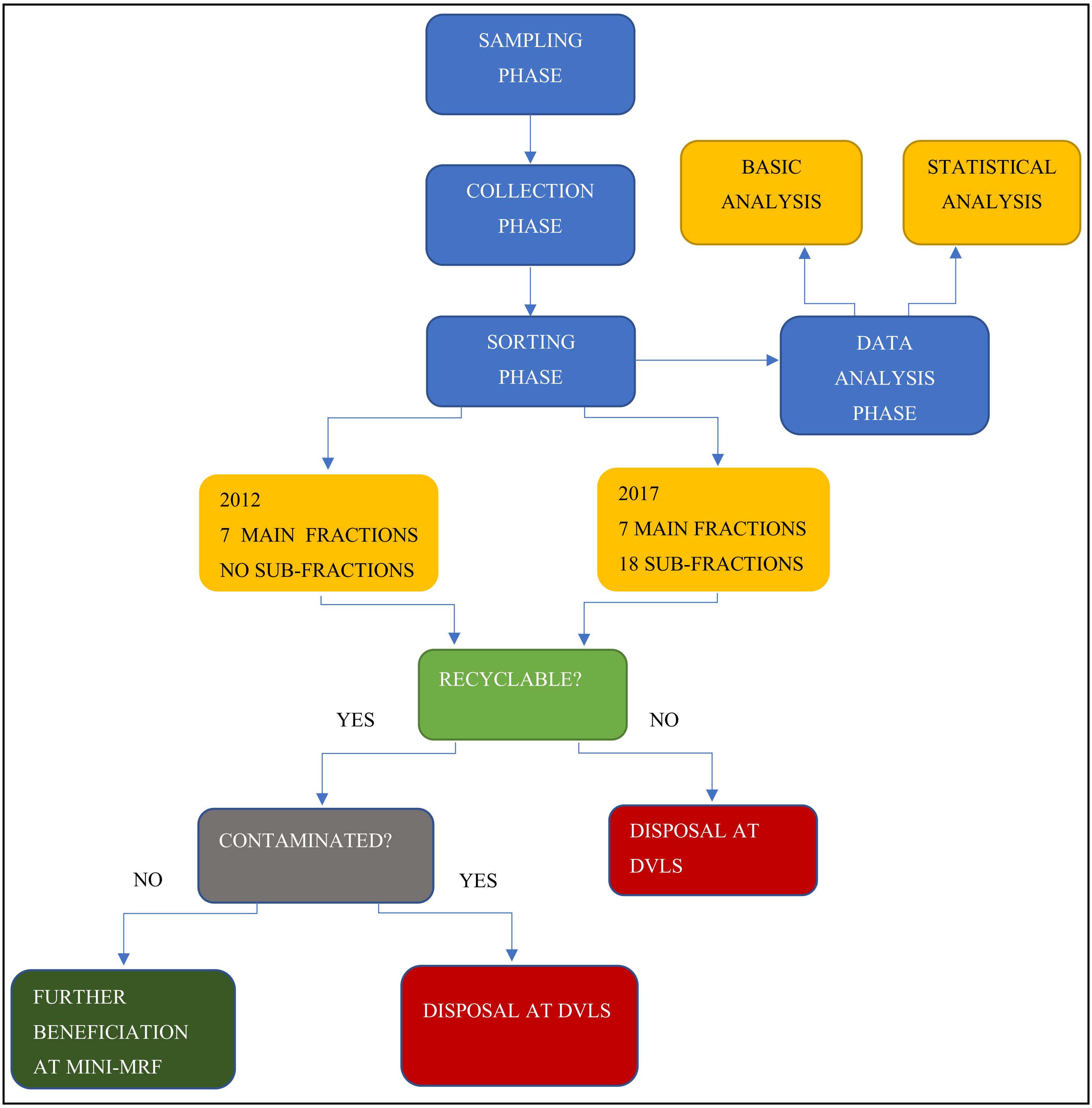


Figure 1.4: Overview of the research methodology

1.8 ASSUMPTIONS AND LIMITATIONS

The scope of the second waste characterisation is broader than that of the study which was completed in 2012. Not only were all ten areas which were characterised in 2012 re-characterised, but an additional thirteen areas were also included, which had been excluded in the earlier study, owing to a lack of funds and capacity.

This study is concerned solely with the residual portion of the HSW stream. Only black bags which contained materials which were destined for landfill were sampled and sorted. Areas in which a separation at source programme is implemented generate additional waste which is not accounted for in the findings of this study. Although this omission does not affect the findings which are published in this thesis, it does preclude the calculation of a per capita waste generation rate.

The researcher made use of statistics pertaining to parameters such as population, household size, household density and household income during the conducting of the study, to compare the respective findings with respect to waste characterisation. The most recent official South African statistics were used for this purpose, which were obtained from the Census 2011 database. As no follow-up to Census 2011 was conducted during the period from 2012 to 2017, the statistics remain unchanged, which presents a limitation for any endeavour which is intended to identify changing patterns.

Potential seasonal fluctuations were not taken into account during the conducting of this study. The researcher made the decision on the basis of the findings which emerged from the experiments which the Stellenbosch Local Municipality conducted in 2012 to determine whether seasons influenced the overall compositions of waste streams. The findings revealed that although the size of the garden waste fraction was most affected by seasonal changes, the generation and disposal of other waste fractions were mainly unchanged, with a few exceptions, such as those which occurred as a consequence of spikes in waste generation at times such as public holidays (Haider 2019, pers com). In addition, the researcher made use of a technique which was based on one which Emery, Griffiths and Williams (2003) had developed to determine whether seasonal fluctuations represented a factor which needed to be taken into account (please refer to section 2.3.5.1), but the results were negative and seasonal fluctuations have consequently been excluded from this study.

1.9 CONCLUSION AND STRUCTURE OF THE THESIS

The introduction chapter will be concluded with a structure of the thesis. The first chapter of the thesis provides an introduction to the study, mainly highlighting the need for the study in the rationale and the research problem. In this chapter, the research questions, aim and objectives are also clearly defined. The study area is described to the reader and a short overview on the research methodology to be expected given, as well as the study's assumptions and limitations.

The second chapters covers the literature review which covers firstly contextual literature about the management of solid waste in general, thereafter a more detailed discussion on the methodologies followed by other researchers when conducting waste characterisation studies, and lastly the various waste fractions are discussed. Results obtained through waste characterisation studies are also critically analysed and used for comparative purposes.

The third chapter describes the research methodology utilised specifically during the course of this study. The methodology makes use of quantitative data collection methods. Chapter four presents the study's findings which are, in turn, interpreted in the fifth chapter. The sixth chapter summarises the core findings and the thesis concludes with recommendations, contained in the last chapter, chapter seven.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is devoted to an in-depth review of the relevant available literature pertaining to the research topic. The literature is reviewed under three specific headings:

2.1 Contextual literature

2.2 Literature pertaining to the characterisation of waste

2.3 Literature pertaining to the composition of HSW streams

2.2 CONTEXTUAL LITERATURE

The need for MSW to be properly handled and treated is not a modern concept. In Babylon in ancient Mesopotamia, the disposal of waste on streets was common practice (McMahon 2015). The daily repetition of the practice resulted in a continuous increase in relative street levels over time, to the point that homeowners were compelled to alter the designs of the entrances to their homes to ensure continued access (Donn & Donn 2007). The first documented waste legislation was enforced during the period of the Minoan civilisation, which flourished in Crete from 3 000 to 1 000 B.C. (Tammemagi 1999). In the Minoan capital of Knossos, waste was placed in large pits and covered with layers of earth at regular intervals (Tammemagi 1999) – a technique which is still in use to this day, but now better known as the practice of sanitary landfilling. In Athens, the capital of ancient Greece, the haphazard disposal of waste on the streets had been prohibited by 500 B.C. (Steyl 1996), an initiative which culminated in the development of the first recorded municipal dumpsite, approximately 1.6 kilometres outside of the city walls (Columbus 2006).

Health concerns and nuisances, which emanated from the inadequate management of MSW, were the principal motivators for the development of more systematic waste management systems in ancient times (McMahon 2015) and remain so today (Obi, Orga, & Ogadimma 2018; Yenice et al. 2011). Adverse environmental consequences can also result from the incorrect handling of waste (Gomez, Meneses, Ballinas & Castells 2008). Kaza et al. (2018, 1) articulate the range of distressing consequences of improper management of waste for the environment, animals and human beings, alike, as follows:

> *'Poorly managed waste is contaminating the world's oceans, clogging drains and causing flooding, transmitting diseases via breeding of vectors, increasing respiratory problems through airborne particles from burning of waste, harming animals that consume waste unknowingly, and affecting economic development such as through diminished tourism.'*

The first two words of this quotation, namely, 'poorly managed' are possibly the most crucial. Although it is inevitable that human beings produce vast quantities of waste, the phenomenon has adverse implications only if it cannot be adequately managed. Conversely, it becomes increasingly difficult to manage waste as the quantities which are generated continue to rise exponentially (Kumar & Goel 2009; De Beer 2013). Two of the most prominent factors which have been identified as being responsible for accelerating the generation of waste are population growth and urbanisation (UNEP 2018).

It is projected that the population of the world will increase to 8.6 billion by 2030, an increase of 11.68% from 7.7 billion in 2019 (United Nations Department of Economic and Social Affairs, Population Division 2017). During this time the populations of developed countries are projected to grow by only 2.9%, six times more slowly than the projected growth of 18.5% for developing countries (Krys & Fuest 2017; Roser & Ortiz-Ospina 2017). These projections are based primarily on the future levels of fertility in the largest high-fertility countries of the world today (Raftery, Li, Ševčíková, Gerland & Heilig 2012). Among the ranks of high-fertility countries are India, Nigeria and Pakistan, where 30% of the total worldwide population growth is expected to occur between now and 2030 (The World Bank 2018). As the quantities of MSW which is generated are directly influenced by this population growth (Gomez et al. 2008), it is logical to expect exponential increases in the waste which is generated in developing countries. A relevant quote from Sir David Attenborough concisely encapsulates the nature of the problem with which the world is faced: '*All our environmental problems become easier to solve with fewer people, and harder - and ultimately impossible - to solve with ever more people*' (Population Matters 2019). The grim prognosis is further underscored by the numerous crises which have ultimately stemmed from improper waste management.

At the present rates of disposal, it is estimated that there is a mean generation of 0.74 kg MSW per capita per day, with the figure fluctuating between 0.11 kg to 4.54 kg per capita per day, depending on income brackets and rates of urbanisation (Kaza et al. 2018). By 2050, this figure is projected to increase respectively by 19% in high- and 40% in middle- and low-income nations (Kaza et al. 2018).

With respect to sub-Saharan Africa, it is projected that any decrease in the generation of waste in other parts of the world will be dwarfed by the amount of waste which is generated on the African continent over the coming decades, as a consequence of impending economic and social transformation (UNEP 2018). To illustrate this projection, it can be seen in Figure 2.1 that the amount of MSW which is generated within sub-Saharan Africa is set to increase effectively by two thirds by 2030 and then double during the period from 2030 to 2050 – from 269 million tons per annum (mtpa) to 516 mtpa (Kaza et al. 2018).

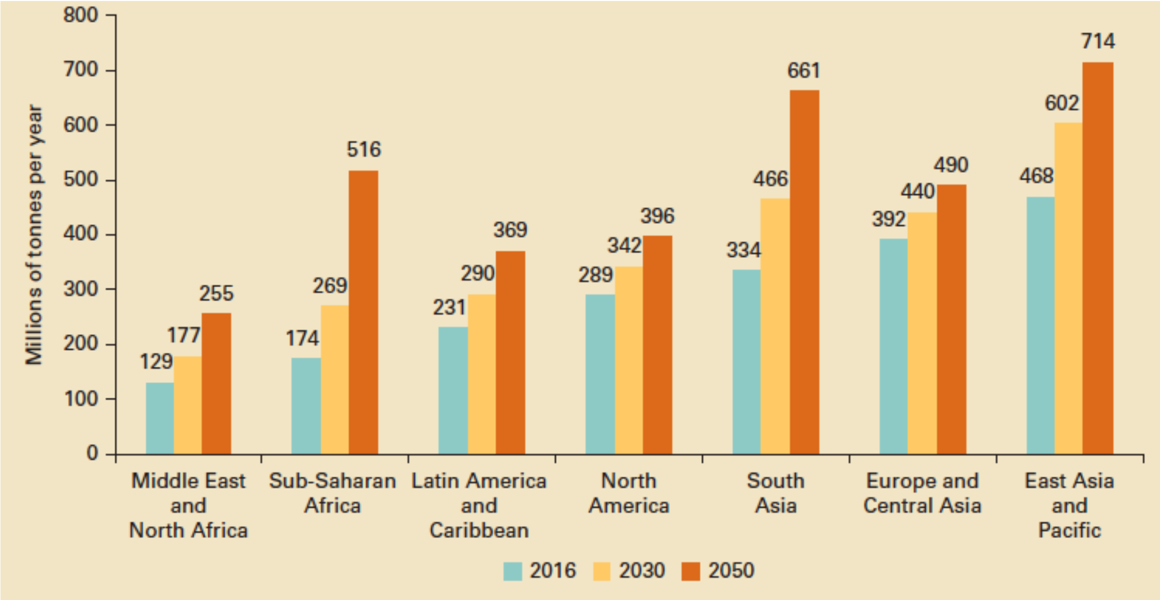


Figure 2.1: **Total global projected waste generation** **Source: Kaza et al. (2018, 28)**

By 2050, Sub-Saharan Africa is set to produce 196.55% more waste than it did in 2016, followed by South Asia with a 97.9% and the Middle East and North Africa with a 97.68% increase (Figure 2.1).

2.3 LITERATURE PERTAINING TO THE CHARACTERISATION OF WASTE

It becomes evident from a study of previous research pertaining to the characterisation of HSW that most studies have specific traits in common and when they are synthesised into a singular approach, the common traits make it possible to enumerate the defining features of a typical HSW characterisation process. Accordingly, a HSW characterisation study can be defined as the sampling, collection, sorting and analysis of HSW, with the aim of determining its overall composition, the relative contribution of each component, such as glass, metal, paper or plastics, to it and also the per capita rate of HSW generation within a specified geographical area (CSIR 2017).

HSW is defined as the waste which is generated within residential areas, which includes waste which is generated by the activities of families in their homes and also that which is generated by home-based businesses (Suthar & Singh 2014). It is considered to be acceptable to include waste which is generated by businesses in a study of HSW because the aim is to determine the overall composition and quantity of waste which is generated by residential areas, rather than to make comparisons between the composition and quantities of household and commercial waste (Parizeau, Maclaren & Chanthy 2006). Home-based businesses typically include home-based offices, hairdressers, day-care centres and nursing homes (Vorley & Rodgers 2012), each of which affects overall compositions of waste differently.

A vast number of HSW characterisation studies have been carried out in diverse geographical, environmental and political settings and climates throughout the world (Emery, Griffiths & Williams 2003; Gomez et al. 2008; Dangi, Urynowicz & Belbase 2013; Ezeudu, Ozoegwu & Madu 2019). A comprehensive review of the research which has been conducted reveals that the single factor which exerts the most influence on waste characterisation studies and their findings is the methodology utilised. To date, no single or specific research method or set of research methods has been accorded the status of an internationally standardised approach to conducting HSW characterisations (Al-Khatib, Monou, Zahra, Shaheen & Kassinos 2010). Conversely, numerous methods which are generally accepted are to be found in the relevant available literature. Each has been developed with honourable intentions in the absence of a single recognised approach and each has been employed in an endeavour to remedy the same obstacle, namely, a lack of data concerning the composition of HSW (Gay, Beam & Mar 1993; Bernache-Pérez, Sánchez-Colón, Garmendia, Dávila-Villarreal, & Sánchez-Salazar 2001; Edjabou et al. 2012; Kaartinen, Sormunen & Rintala 2013; Miezah et al. 2015).

The structure of this section of the literature review has been based upon the four phases of the waste characterisation process. Each phase is discussed individually by reviewing the approaches which were adopted to carry out the same phases in previous studies. A discussion of the two factors which have been identified as having an influence on patterns of waste generation, namely, economic factors and seasonal effects, follows and the chapter concludes with a comparative survey of the overall waste compositions which were identified in previous studies.

2.3.1 The sampling phase

The sampling phase of a HSW characterisation study has two distinct steps: first, the sample size is determined and second, the sampling methodology which is to be used is identified (Bartlett, Kotrlik & Higgins 2001; Gomez et al. 2008). It is useful when researchers specify the numbers of samples which they have chosen and the numbers of households or the sizes of the populations within their study areas, as doing so enables readers to obtain an in-depth understanding of the samples which they have used in their studies.

Bernache-Pérez et al. (2001) used a two-stage stratified sampling design, which had been developed by Rathje & McCarthy (1985). Their sample size to characterise HSW, which was generated in Guadalajara in Mexico, consisted of 300 households, which were visited three times each, to provide a sample size of 900 bags of waste. It would be difficult for subsequent researchers to determine how representative their sample was with respect to their target population, as the total number of households within the study area is not mentioned. Monavari, Omrani, Karbassi & Raof (2012) also used this technique. A sample size of 400 for Ahvaz in Iran was deemed to be sufficient for a population of 1 115 113. As it was determined, during the conducting of the study, that the mean household size was 4.95 persons, it can be assumed that the study area comprised approximately 225 275 households. Monavari et al. (2012) indicated that the number of samples which were collected in their study had been proportional to the number of households in their study area.

Two Turkish projects, which were carried out by Yenice et al. (2011) and Ozcan et al. (2016) in the city of Kocaeli and the Kartal district of Istanbul respectively, made use of the guidelines of the American Society for Testing and Materials (ASTM) D5231-92 (2008) to determine appropriate sample sizes. Although the methodologies which were employed to conduct the two studies were described in the two articles which the studies generated, actual sample sizes selected were not indicated in either article.

Ezeudu, Ozoegwu and Madu (2019) used a simple sample size formula for ±10% precision to ascertain the number of samples which would be required for a HSW characterisation study for the Awka municipality in Nigeria. The sample size determination was crucial to the success of their project, as their sample size needed to justify an assumption of normality, which is the foundation of the regression analysis which they used to analyse their data.

By means of the simple sample size formula, they were able to determine that collecting samples from 100 households would be sufficient to justify the assumption of normality. The eventual sample comprised 82 of a total of 52 817 households in Awka, with 10 samples being collected from each for a total of 820 samples.

Gomez et al. (2008) made use of the central limit theorem (Abu Qdais, Hamoda & Newham 1997), with a 99% confidence level and 10% standard error. Ten samples were collected from fifty-six households. Consequently, 560 samples were used to determine the HSW composition of waste from 194 561 households in Chihauhau in Mexico. A similar method which was developed by Cochran (1977) was used to carry out a HSW characterisation in Ghana, with 5% precision (Miezah et al. 2015). A total of 11 675 samples were collected to represent the population of 3 530 722 (number of households unknown).

Al-Khatib et al. (2010) based their sample size on methods which had been employed by Sharma and McBean (2007), who maintain that a sample size of thirty is sufficient for any HSW characterisation study. Accordingly, they collected and characterised the composition of 30 samples of HSW as being representative of the population of the district of Nablus in the Palestinian enclave of the West Bank, whose inhabitants number 336 380 (number of households unknown).

Dangi, Urynowicz and Belbase (2013) used cluster sampling techniques to select the research sample for the study which they conducted in Tulsipur in Nepal. They characterised a sample of 84 bags to obtain relevant information concerning the composition of waste which could be considered to be representative of 7 056 households.

Nordtest (1995) recommends collecting from 100 to 200 samples for each sub-area within a particular study site. Edjabou et al. (2015) adopted the strategy for a project to analyse the HSW which was generated by three Danish municipalities, namely, Aabenraa, Haderslev and Sønderborg. Although they collected a total of 1 442 samples, they did not disclose the numbers of households in each of the three municipalities.

It is possible to make meaningful comparisons between the sample sizes of individual studies only if figures are supplied for both the numbers of households within the study areas and the numbers of sample which are studied. Of the ten studies which have been covered in this section, only three provided details concerning both the numbers of households and those of the samples which were studied (Ezeudu et al. 2019; Gomez et al. 2008; Dangi et al. 2013) and one other study made it possible to deduce the number of households, as figures were provided for both the total population and the average household size (Monavari et al. 2012). Table 2.1 provides a comparative summary of the sample sizes which were used in these four studies, by enumerating the relationships between the numbers of samples and the numbers of households.

Table 2.1: Summary of ratios for samples to households from the highest to the lowest

Author	Samples	Households	Ratio samples : households
Monavari et al. (2012)	400	225 275 (deduced)	1:563
Gomez et al. (2008)	560	194 561	1:347

Dangi, et al. (2013)	84	7056	1:84
Ezeudu et al. (2019)	820	52 817	1:64

The ratio for samples to households was the highest in the study of Monavari et al. (2012), in which one bag was sampled for every 563 households in the research population. Conversely, the ratio was the lowest in the study which Ezeudu et al. (2019) conducted, in which they sampled one bag for every sixty-four households (Table 2.1).

2.3.2 The collection phase

The phase of a HSW characterisation study during which samples are collected is crucial to its success and can influence the reliability of the findings which the study generates (Bartlett, Kotrlik & Higgins 2001; Thanh, Matsui & Fujiwara 2010; Bernache-Pérez et al. 2001). Relevant factors which need to be considered include whether samples were compacted or uncompacted during collection, how regularly collections were carried out and the methods which were used to select households to participate in studies (Dhokhikaha, Trihadiningruma & Sunaryob 2015).

In a study conducted by Emery, Griffiths & Williams (2003) in Southern Wales, samples were collected once a week from 162 households, chosen out of a total of 98 000 within the study area, by a small refuse collection vehicle with no compaction equipment and transported to a facility where sorting took place. This was repeated for a period of three weeks for all 486 samples, totalling 3 338 kg. In Siem Reap, Cambodia, Parizeau, Maclaren & Chanthy (2006) collected samples daily from 49 homes, chosen out of a total of 1 000 households, for a period of 7 days. The means of sample transportation was not noted but from context it is presumed it was collected on foot. The average daily weight of the 49 samples is cited 97 kg per day and therefore it can be presumed that the 343 samples weighed a total of 679 kg. Neither study disclosed the methodology that the collection method was based on.

Ojeda-Benítez, Armijo-de Vega & Marquez-Montenegro (2008) spent five days collecting waste from 125 households. Although the total population of Mexicali, Mexico (the study area) is noted as 855 962, the number of households within the study area is not mentioned. This omission is particularly strange given that this study makes use of a "family socioeconomic profile" (e.g. a household) as unit of analysis and the number of households within the study area should therefore be a critical factor. As with the Cambodian study, the authors do not address the means utilised to collect the samples. In total 682 samples were collected weighing 2 674 kg.

For the 2009 portion of a study done in the Czech Republic, comparing two waste characterisations done in 1999 and 2009, the usual refuse collection routine was followed, and the regular refuse truck was used to collect samples (Doležalová, Benešová & Závodská 2013). This was done over a 12-month period where one truckload was collected every month for each of three household types identified in an area with 5 757 residents (number of households unknown). For the 2009 study a total of 36 samples were collected totalling 228 310 kg. A subsample of 100 – 200 kg was then obtained from each main sample using the quartation method and through this process a total of 7 107 kg was identified to be further sorted.

Collection of samples from 100 households took place during two seasons in the Mekong Delta City, Vietnam; for a month in the dry season and for two weeks during the wet season. Although the total population is noted as 1 154 900, the number of households within the study area is not mentioned. Households were provided with two types of coloured transparent plastic bags and were requested to do an initial separation – biodegradable and non-biodegradable waste. Biodegradable samples were collected daily and non-biodegradable collected weekly during the dry season but both types of samples collected daily in the wet season. The final number of samples and weight thereof, as well as the means by which it was collected and transported to the sorting area is unknown (Thanh, Matsui & Fujiwara 2011).

72 samples were collected in plastic bags in Erbil, Iraq, a city with a population of 700 770 (Aziz, Aziz, Bashir & Yusoff 2011). The number of households in the study area are unknown as well as the means utilised to collect and transport the samples. Although the weight of each of the 72 collected samples is given in a Table (in grams), it is not totalled. One would therefore need to do a manual calculation to know how much waste was collected in total.

In Kétao, Togo, waste bins were handed out to 48 homes, out of a total of 20 000 households, a day before door-to-door collection started. The article states that over a total period of 22 days, waste was collected and transported to the sorting area by handcart every second day (Edjabou, Møller & Christensen 2012). Unfortunately, neither the final number of samples, nor the total weight collected was reported on. Gu et al. (2015) conducted a study in Suzhou, China and collected samples for a week from 240 households four times per year. The total number of households in this study area, as well as the final total of samples collected, was not noted but it was stated that a total of 4 649 kg was collected. The transportation method was not divulged.

2.3.3 The sorting phase

The sorting phase of a HSW characterisation study entails the physical separation of the waste materials which samples contain into specific predetermined fractions (Parizeau, Maclaren & Chanthy 2006). The number of fractions which are chosen is usually influenced primarily by the availability of resources, in the form of time, budgets and human resources and also the purpose of individual studies, with respect to their aims, objectives and research questions (Ozcan, Guvenc, Guvenc & Demir 2016). The waste management practices which are implemented in particular study areas at the time of carrying out characterisation studies could also influence the fractions which are selected or anticipated or determine whether residual waste or entire waste streams are characterised. Consequently, it is imperative to make an adequate appraisal of the resources which are available and also to have determined the precise purpose of the study which is to be carried out during the formulation of the sampling design, to mitigate the risks of overcommitting resources or generating unusable data.

The review of literature which is relevant to the research topic includes an assessment of the sorting nomenclature which was used in nineteen different HSW studies which were conducted from 2001 to 2019. These studies have been selected for inclusion in the literature review because their research methodologies were similar in essential respects to that which was developed in order to conduct this study. To enable comparisons to be made between these studies, the twelve most frequently used categories were identified, namely: plastics (Pl), metals (M), paper (P), organic waste (OW), glass (G), other (O), textiles (T), garden waste (GW), household hazardous waste (HHHW), cardboard (CB), electronic waste (EW) and sanitary waste (SW).

Table 2.2 lists the studies in accordance with the numbers of fractions by means of which HSW was characterised in them, in ascending order. The first entry in the list is the study of Ezeudu et al. (2019), in which HSW was characterised by means of 5 fractions, while the last is the study of Gu et al. (2015), who sorted HSW into 167 fractions, which consisted of both main and sub-fractions. The individual fractions are also listed in separate columns in Table 2.2, in descending order, from left to right, with respect to their use in the studies.

Table 2.2: Sorting nomenclature – HSW characterisation

Author	Fractions	Pl	M	Pa	OW	G	O	T	GW	HHHW	CB	EW	SW
Ezeudu, Ozoegwu & Madu 2019	5	✓	✓	✓	✓	×	✓	×	×	×	×	×	×
Aziz, Aziz, Bashir & Yusoff 2011	6	✓	✓	✓	✓	✓	×	✓	×	×	×	×	×
Kumar & Goel 2009	7	✓	✓	✓	✓	✓	×	×	×	×	×	×	×
Al-Khatib et al. 2010	8	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×
Edjabou, Møller & Christensen 2012	9	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	×
Dangi et al. 2013	10	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×
Monavari et al. 2012	10	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×
Doležalová, Benešová & Závodská 2013	10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Parizeau, Maclaren & Chanthy 2006	12	✓	✓	✓	✓	✓	×	✓	✓	×	×	×	✓
Gomez et al. 2008	15	✓	✓	✓	✓	✓	✓	×	×	✓	✓	×	×
Yenice et al. 2011	16 / 17	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	×
Ozcan et al. 2016	16 / 17	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	×
Miezah et al. 2015	23	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×
Emery, Griffiths & Williams 2003	30	✓	✓	✓	✓	✓	✓	✓	✓	×	×	✓	✓
Ojeda-Benítez, Armijo-de Vega & Marquez-Montenegro 2008	37	✓	✓	✓	✓	✓	×	✓	✓	×	✓	×	✓
Bernache-Pérez et al. 2001	53	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Edjabou et al. 2015	56	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Thanh, Matsui & Fujiwara 2011	83	✓	✓	✓	✓	✓	×	✓	✓	×	×	×	×
Gu et al. 2015	167	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		100%	100%	100%	100%	95%	74%	74%	68%	47%	47%	37%	37%

Pl = Plastics **M** = Metals **Pa** = Paper **OW** = Organic waste **G** = Glass **O** = Other **T** = Textiles
GW = Garden waste **HHHW** = Household hazardous waste **CB** = Cardboard **EW** = E-waste **SW** = Sanitary Waste

The fractions which are designated plastics, metals, paper and organic waste were used in all nineteen of the studies which have been reviewed (100%). Glass was treated as a separate fraction in 95% of the studies. Other and textiles were classified as separate waste streams in 74%, garden waste in 68%, while household hazardous waste, cardboard, electronic waste and sanitary waste had their own categories in less than 50% of the studies.

The capturing of data in a characterisation study is carried out during the sampling phase. It needs to be determined during the development of a sampling design how the materials which have been sorted will be quantified. In most studies, waste fractions are quantified in terms of mass (in kilograms), some by volume (converted to m^3) and some by both weight and volume. Table 2.3 expands upon Table 2.2 to provide additional data to evaluate the same group of studies. Column (1) reflects the references and column (2) the geographical locations of the study areas. Column (3) indicates whether data was captured during the sorting phase with respect to mass (M), volume (V) or mass and volume (M&V). Column (4.1) indicates the numbers of samples which were sorted and Column (4.2) the total mass of the sorted samples. Column (5) indicates whether sufficient data was captured during the sorting phase to enable the overall waste composition to be determined, while column (6) indicates whether the rates of waste generation could be determined in terms of kg/capita/day.

Table 2.3: Summary of the data yielded by the sorting phases of the studies

(1) Author	(2) Location	(3) M/V/M&V[1]	(4) Samples		(5) Overall waste composition	(6) Waste generation per capita (kg/c/d[2])
			(4.1) Number	(4.2) Mass (kg)		
Ezeudu, Ozoegwu & Madu 2019	Awka Municipality, Nigeria	M&V	82 hh[3] x 10 = 820	N.S.[4]	Yes	Yes. 0.42
Aziz et al. 2011	Erbil, Iraq	M&V	72	N.S.	Yes	Yes. 0.65
Kumar & Goel 2009	Kharagpur, West Bengal, India	M	4 cb[5] x 5 = 20	500	Yes	N.S.
Al-Khatib et al. 2010	Nablus District, Palestine	M&V	30	N.S.	Yes	Yes. 0.82
Edjabou, Møller & Christensen 2012	Kétao, Togo	M	48 hh x 10 = 480	N.S.	Yes	Yes. 0.34
Dangi, Urynowicz & Belbase 2013	Tulsipur, Nepal	M	84 hh x 1 = 84	N.S.	Yes	Yes. 0.33
Monavari et al. 2012	Ahvaz, Iran	M	400	N.S.	Yes	N.S.

Doležalová, Benešová & Závodská 2013	Czech Republic	M&V	N.S.	228 310	Yes	Yes. 0.43-0.54
Parizeau, Maclaren & Chanthy 2006	Siem Reap, Cambodia	M&V	49 hh x 7 = 343	679	Yes	Yes. 0.34
Gomez et al. 2008	Chihuahua, Mexico	M	80 hh x 7 = 560	1 517	Yes	Yes. 0.67
Yenice et al. 2011	Kocaeli, Turkey	M	N.S.	N.S.	Yes	N.S.
Ozcan, Guvenc, Guvenc & Demir 2016	Kartal District, Istanbul	M	N.S.	1 940	Yes	Yes. 0.98
Miezah et al. 2015	Ghana	M	11 675	82 101	Yes	Yes. 0.47
Emery, Griffiths & Williams 2003	Rhondda Cynon Taf, South Wales	M&V	162 hh x 3 = 486	3 338	Yes	N.S.
Ojeda-Benítez, Armijo-de Vega & Marquez-Montenegro 2008	Mexicali, Mexico	M	125 hh x 5 = 625	2 674	Yes	Yes. 0.98
Bernache-Pérez et al. 2001	Guadalajara, Mexico	M	300 hh x 3 = 900	N.S.	Yes	Yes. 0.51
Edjabou et al. 2015	Denmark	M	1 442	16 800	Yes	No
Thanh, Matsui & Fujiwara 2011	Mekong Delta City, Vietnam	M	100 hh x 44 = 4 400	N.S.	Yes	Yes. 0.26
Gu et al. 2015	Suzhou, China	M	240 hh x 4 = 960	4 649	Yes	Yes. 0.28

1: M = mass; V = volume; M&V = mass & volume
2: kg/c/d = kilograms per capita per day
3: hh = households
4: N.S. = Not stated
5: cb = communal bins

In their study in the area which fell under the municipality of Akwa in Nigeria, Ezeudu et al. (2019) sorted 820 samples into 5 categories, namely, plastics, metals, paper, organic waste and other and measured both the mass and loose volume of the waste. The waste was then re-mixed and manually compacted to measure its compacted volume. By contrast, Aziz et al. (2011) sorted seventy-two samples of waste which had been generated in Erbil in Iraq into six categories (plastics, metals, paper, organic waste, glass and textiles) and captured data pertaining to its mass and volume and also the density of each waste fraction. Kumar & Goel (2009), as well as Doležalová, Benešová and Závodská (2013) not only physically characterised the waste according to their composition, but also chemically by conducting various laboratory tests.

Al-Khatib et al. (2010) made use of a method which was developed by the World Health Organisation (WHO) to sort their 30 samples in accordance with a 'potential use' categorisation, rather than according to categories for individual types of materials (WHO 1988). They used eight 80-litre bins to sort waste into the following fractions: plastics, metals, paper and cardboard, glass, compostable waste in the form of organic and food waste, textiles, other and waste smaller than 10 mm in size. Parizeau, Maclaren and Chanthy (2006) also made use of the potential use categorisation, on the basis of the studies which had been conducted by Bernache-Pérez (2001), Fehr, De Castro and Calcado (2000) and Ojeda-Benitaz et al. (2003). They divided their samples, which had a total mass of 679 kg, into twelve fractions. Both mass and volume were measured in all of the studies. Although Gomez et al. (2008) used the same approach and sorted their samples into six main categories, with fifteen subdivisions, they measured mass only.

The sorting methodology which was proposed in the D5231-92 guidelines of the ASTM (2008) was used by several of the researchers whose studies are reviewed in this chapter. In Mexico, Bernache-Pérez et al. (2001) sorted 900 samples into 53 categories. In Turkey, Yenice et al. (2011) and Ozcan et al. (2016) sorted unknown numbers of samples into sixteen categories in summer and seventeen in winter, while Miezah et al. (2015) in Ghana sorted 11 675 samples into twenty-three fractions.

Edjabou et al. (2015) studied residual portions of waste after source separation in Denmark. Their sorting methodology was based on those of Riber, Petersen and Christensen (2009); Dixon and Langer (2006) and the Danish EPA (2014). After consulting these sources, they developed three levels for sorting through 16 800 kg waste. Level 1 comprised ten primary fractions, level 2 thirty-six sub-fractions and level 3 fifty-six sub-fractions. Gu et al. 2015 sorted 960 samples according to the physical characteristics of waste in the manner which was suggested by the International Panel on Climate Change (IPCC, 2006), Qu et al. (2009) and Ojeda-Benitaz et al. (2003). They used a total of eleven primary fractions and 167 sub-fractions. They also identified compostable and recyclable materials. The latter category was further subdivided into marketable recyclable materials, in the sense of being readily saleable or potential recyclable materials, which could be marketable in the relatively near future.

2.3.4 The analysis phase

The most crucial research question which researchers endeavour to answer by conducting waste characterisation studies concerns the overall composition of their waste samples, which is usually determined mainly through simple multiplication and interpolation (Edjabou et al. 2012). Correlation and regression analyses are popular techniques for performing further analyses of data which is obtained from waste characterisation studies (Thanh, Matsui & Fujiwara 2011; Monavari et al. 2012; Miezah et al. 2015, Gu et al. 2015; Nezami & Cortes 2017; Ezeudu et al. 2019). In statistical modelling, regression analysis is often used by researchers to determine which factors have measurable effects on their results and which factors can be disregarded (Gallo 2015). To determine the relevant relationships, a dependent variable is identified and tested against one or more independent variables (Corporate Finance Institute 2019). For waste characterisation data, regression analysis is used mainly to determine the strength of predictors and to forecast effects or trends (Statistics Solutions 2013). The strength of predictors is predicated upon the answers to questions such as 'What is the strength of the relationship between waste composition and household size?'. Conversely, forecasting an effect or trend requires researchers to ask questions such as 'Is there a relationship between income levels and the amounts of waste which are generated?' or 'How much additional waste is likely to be produced within the study area in 10 years' time?'.

Among the statistical techniques which have been used in other studies to analyse data is the analysis of variance (ANOVA), which is used to determine whether variances with respect to the compositions of waste could be attributed to the geographical origins of particular samples (Al-Khatib et al. 2010). Guerrero et al., (2013) analysed their initial data by performing a Kolmogorov-Smirov test, which was followed by a non-standard parametric test in the subsequent statistical analysis (citing Field 2009), because the data was not normally distributed. Ezeudu et al. (2019) based the analysis of their data on zero-intercept first-order polynomial regression, because they found that the procedure improved the reliability of results with respect to composition by comparison with using the averaging technique which has been used in many other studies. Their results revealed that 73.2% of the waste in their samples consisted of organic materials, which they explained by maintaining that households in their study area typically consumed 'home-prepared, traditional foods'.

In their study, Ozcan et al. (2016) determined not only the composition of the waste stream, but also the calorific value of the waste by means of the ISO 19285 method and using a LECO AC500 bomb calorimeter. They then analysed the moisture content in accordance with the TS10459 standard.

2.3.5 Factors which affect waste characterisation results

Two sets of factors which can potentially influence waste characterisation results are seasonal effects and fluctuations and socioeconomic factors such as household size and income.

2.3.5.1 Seasonal fluctuations

Seasonal fluctuations can have a pronounced effect upon the composition of waste and rates of disposal (Emery et al. 2003; Ozcan et al. 2016). The food waste fraction is the fraction which is influenced most by seasonal dynamics, as the findings of waste characterisation studies, which were carried out during both summer and winter months in the district of Kartal in Istanbul in Turkey, reveal (Ozcan et al. 2016). In addition, seasonal variations in weather conditions can significantly affect the moisture content of waste streams during dry and rainy seasons (Edjabou et al. 2012).

2.2.5.2 Economic factors

In the light of the strong correlations between income levels and standards of living and the consumption of goods and services, it would be logical to assume that there would also be a correspondingly strong positive correlation between household incomes and the amounts of waste which households generate. There is also ample evidence from relevant research to suggest that the rates at which waste is generated in city environments are generally significantly higher than those which are found in rural areas, as a consequence of both higher living standards and higher levels of economic activity. An unusual example of disparities of this type was provided by a study which was conducted in both an urban setting and a refugee camp in Palestine, which yielded similar findings (Al-Khatib et al. 2010).

In addition, not only do the volumes of waste which are generated differ among income groups in particular settings, but the relative contributions of the different fractions to overall waste streams also differ significantly. Relatively little organic waste is generated by low-income segments of communities by comparison with their medium- and high-income counterparts (Edjabou et al. 2012; Ozcan et al. 2016). Owing to their economic circumstances, members of low-income households are likely to consume most of the organic materials which they either grow or purchase for consumption and to discard relatively little, while more affluent households are significantly less likely to do so. Other fractions, such as waste in the form of paper and cardboard, are also generated at considerably higher rates in high- and medium-income areas than low-income areas, as a consequence of greater purchasing power, higher levels of consumption of pre-packaged foods and other products and significantly higher levels of participation in activities which entail the use and consumption of paper. By contrast, the findings of other studies have revealed no significant correlations between amounts of landfill waste which are generated and household income (Nezami & Cortes 2017; Monavari et al. 2012). These findings suggest that income may not be the only determinant of levels of daily consumption and that higher incomes may be invested or spent in manners which do not influence the rates at which waste is generated.

2.4 THE COMPOSITIONS OF HSW STREAMS

As it has been explained in section 2.3.3, the fractions into which researchers divide HSW streams are determined by the specific aims and objectives of their particular research studies. This section is devoted to an in-depth discussion of the typical composition of the twelve principal waste fractions which were identified in Section 2.3.3 in relation to the categories of waste which are typically produced by households.

2.4.1 Plastics

Plastics can be divided into the seven different categories which are summarised in Table 2.4.

Table 2.4: Categories of plastics

Polymer code	Name	Abbreviation	Popular packaging applications
#1	Polyethylene terephthalate	PET	Bottles for containing liquids Food jars Blister packets Trays
#2	High-density polyethylene	HDPE	Bottles for containing liquids Bottles for containing chemicals and oils Various films
#3	Polyvinyl chloride	PVC	Pipes Cable insulation Tamper-evident seals
#4	Low-density polyethylene	LDPE	Shrink film Stretch film Food packaging Consumer bags
#5	Polypropylene	PP	Biscuit packaging Adhesive tape Bottle labels Flower sleeves
#6	Crystal and High-impact polystyrene	PS / HIPS	Yoghurt tubs Clamshell food containers Cake domes Photograph frames Stationery items (e.g. pens and rulers)
#6	Extruded polystyrene (e.g. Foamalite)	EPS	Food trays Protective product packaging
#7	Other	Oth	Combinations of two or more materials, e.g. polycarbonates, nylon or acrylics

Source: Adapted from PlasticsSA 2019

2.4.2 Metals

Metal waste which is produced by households typically consists of ferrous and non-ferrous post-consumer waste, scrap metal, such as steel offcuts, screws or nails and aerosol cans (Kroschwitz & Howe-Grant 2001).

2.4.3 Paper

The paper waste which households generate typically comprises office paper, newspapers, magazines, telephone directories, books and booklets, advertising material, tissue paper, photographic paper, paper plates and cups, cards, envelopes, receipts, wrapping paper, paper packaging and badly soiled paper which cannot be recycled (RecyclePaperZA 2019).

2.4.4 Organic waste

The organic waste which is generated by households usually consists of discarded edible and inedible portions of food (Dahlen & Anders 2008; Gu et al. 2015; Filimonau & De Coteau 2019). Depending on the number of waste fractions which are used in individual studies, garden waste can also be included in this waste fraction, although it is less easily degradable than food waste (Greben & Oelofse 2009). Consequently, it is necessary to characterise food and garden waste separately in endeavours to ascertain the feasibility of biogas-related projects.

2.4.5 Glass

Glass waste which is produced by households typically consists of glass bottles, such as bottles of several different colours which have contained alcoholic beverages, soft drink bottles and bottles which have contained foods or sauces, non-ceramic table and kitchenware and also glass for specialised uses, such as windowpanes (Kroschwitz & Howe-Grant 2001; Bragg 2012; Bragg 2017).

2.4.6 Other

Although the items which are sorted into the fraction which is designated ‘Other’ differ considerably among individual studies, the wide ranges typically include items such as broken crockery or ceramic ware, discarded inner bags from vacuum cleaners, cat litter and pet excrement, bars of soap, costume jewellery, cigarette butts, discarded cleaning equipment such as sponges, sandpaper, fines (<5mm in size, including ash) and soil) (Parizeau et al. 2006; Al-Khatib et al. 2010; Edjabou et al. 2012; Monavari et al. 2012; Dangi et al. 2013; Doležalová et al. 2013).

2.4.7 Textiles

The types of textile waste which households generate typically consists of discarded clothes, shoes and textile offcuts (Redress 2014).

2.4.8 Garden waste

The garden waste which households discard is usually comprised of grass clippings, hedge cuttings, portions of plants which have been pruned, leaves, wood and wilted flower bouquets (Boldrin & Christensen 2010).

2.4.9 Household hazardous waste

Hazardous waste which households generate is toxic, corrosive, flammable or reactive or possesses any permutations of these characteristics (Wessel 2004). Examples of hazardous HSW include solvents, fluorescent and incandescent lamps, pesticides, batteries, expired or unused pharmaceuticals, sharps waste and oil-based paints (Inglezakis & Moustakas 2015; Heckrath 2018, pers com; Haider 2018, pers com).

2.4.10 Cardboard

Households typically generate cardboard waste in forms such as dry food boxes, medicine and cosmetic boxes, roll cores and corrugated and non-corrugated packing cartons (RecyclePaperZA 2019).

2.4.11 Electronic waste

The types of electronic waste which households typically generate include items such as discarded mobile telephones, computers and various handheld devices, large and small household appliances, IT and telecommunications equipment, electric and electronic tools, electrical and battery-operated toys, medical devices such as monitoring equipment, monitoring and control instruments such as thermometers or conductivity meters and automatic dispensers such as hand sanitisers (Lubick 2012; Bhaskar & Kumar 2019).

2.4.12 Sanitary waste

The sanitary waste which households generate typically takes the form of hygiene waste such as disposable diapers, condoms, sanitary items, tissues, wet wipes, colostomy bags and earbuds (Ashley et al. 2005).

2.5 CONCLUSION

The literature review provided the researcher with a wide variety of tried and tested approaches on how to conduct a waste characterisation study. It also enabled the researcher to understand how complex the household solid waste stream really can be. This research was utilised for the next step, to determine the research methodology to be implemented for the study which is discussed, in detail, in the next chapter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter provides a detailed account of the research methodologies which were used to conduct both the 2012 and 2017 HSW characterisation studies. The discussion is structured in accordance with the four distinct phases which HSW characterisation studies entail, which were covered extensively in the literature review. Accordingly, it covers the methodologies which were employed to carry out the sampling, collection, sorting and analysis phases of both studies.

The methodologies which were employed to carry out the collection phases of the two studies were essentially similar. As an in-depth comparison of the methods which were used to conduct the studies would confirm, the most significant methodological differences are to be found in the sampling, sorting and analysis phases. The principal differences in the approaches which were adopted to the carrying out of the sampling, sorting and analysis phases of the two studies stem from the significantly increased availability of financial and human resources for conducting the second study. Consequently, a larger sample size could be used and the scope of the study could be expanded to include areas which had not been surveyed in the previous study. The number of sorting fractions was also increased. These differences are discussed in greater detail in the respective sections which follow.

3.2 METHODOLOGIES EMPLOYED TO CARRY OUT THE SAMPLING PHASES

A representative sample can be defined as a scaled-down version of an entire target population, whose members possess all of the characteristics of the population in which particular researchers are interested in the purposes of their research studies (Grafström & Schelin 2014). In an area as large as Stellenbosch, it would be impossible to collect and analyse all of the waste which is generated within it. As vast volumes are generated each day, it becomes necessary to endeavour to obtain samples which are truly representative of the population as a whole (Acharya, Prakash, Saxena & Nigam 2013). As it is widely acknowledged that HSW is not a homogenous material, the higher the sampling rate, the more accurate the results of a study are likely to be. The comprehensive literature review revealed that there is no single universally acknowledged optimal method to determine sample sizes for waste characterisation studies (Al-Khatib et al. 2010). As a wide range of techniques and sample sizes have been used in a great many studies, it is necessary to evaluate those which have been used most successfully.

Confidence levels for data which is collected for studies which entail the characterisation of solid waste are usually set at from 80% to 90% (UNEP 2007). It has been suggested that thirty samples are sufficient for determining the composition of HSW in a given study area (Al-Khatib et al. 2010). It is also possible to triangulate the findings of characterisation studies which are obtained from thirty samples of HSW by quantitatively and qualitatively analysing waste by taking random samples from 0.5-cubic metre waste receptacles which have been shaken three times (Al-Khatib et al. 2010, citing the WHO 1988).

By contrast, a formula which was developed by Cochran (1977) and further developed by Bartlett, Kotrlik & Higgins (2001), has been successfully used by a number of researchers to calculate sample sizes for more recent waste characterisation studies (Gallardo, Bovea, Colomer & Prades 2012; Miezah et al. 2015). It can be used when studies need to be conducted of large populations with unknown degrees of variability:

$$n_o = \frac{z^2pq}{e^2}$$ Equation 1

where n_o is the sample size;

z is the selected critical value of the desired confidence level;

p is the estimated proportion of an attribute which is present in the population;

q is 1− p; and

e is the desired level of precision.

When the population is finite, the following correction formula can be used to ensure that the sample size does not exceed 5% of the population:

$$n = \frac{n_o}{1+\frac{(n_0-1)}{N}}$$ Equation 2

where n_o is the sample size derived from the first equation; and

N is the population size.

A survey of relevant studies reveals that both sample sizes and confidence levels vary significantly from study to study. In a study which they conducted to analyse sorted household waste which had been collected by collection systems in Spain, Gallardo et al. (2012) set the confidence level at 95% with a precision level of ±5%. Using Cochran's formula (Equation 1), they arrived at an initial sample size of 57, which they subsequently amended to 279 by using Equation 2. Although Miezah et al. (2015) did not specify the confidence level which they used to conduct their study of the composition of household waste in Ghana, they did indicate that they had set the precision level at ±5% and calculated a sample size of 11 675 by means of Cochran's formula.

In their study to characterise HSW in Chihuahua in Mexico, Gomez et al. (2008) used a formula similar to that of Cochran (1977). They calculated a sample size of 560 by setting the confidence level at 99% and the level of precision ±10%. Ozcan et al. (2016) determined their sample size on the basis of volume rather than that of mass. They sorted waste into two representative 1-cubic metre samples for each of the income levels which they had identified in their target population in the Kartal district of Istanbul in Turkey in January, during the winter, which yielded a total of eight 1-cubic metre samples, which, in turn, had a total mass of 1 056 kilograms. They repeated the procedure in July, during the summer, in order to determine seasonal fluctuations, sampling a total of 884 kilograms of waste from an unknown number of individual samples.

3.2.1 Sampling procedure for the characterisation study of 2012

As it has been explained, the earlier characterisation study was guided by the document 'Solid Waste: Guidelines for Data Collection and Analysis', the draft guidelines which were compiled by the UNEP (2007). The guidelines indicate that 580 samples of HSW would be adequate to set the confidence level at 90% with a precision of ±10%.

The maximum possible number of bags were sampled during the 2-week characterisation study in May 2012. The resources which were available permitted a total of 554 bags of HSW to be sampled, which had a combined mass of 2 724.93 kilograms. As it can be seen in Table 3.1, the bags were collected in different numbers from fourteen different areas.

Table 3.1: Breakdown of samples collected in the waste characterisation study of 2012

Name of area: 2012	Numbers of households*	Planned sampling: Confidence Level: 90%; Precision: ±10%	Actual samples
1. Cloetesville	3 329	60	52
2. Jamestown	602	50	46
3. Uniepark	138	20	19
4. Kayamandi	8 568	35	32
5. Idas Valley	2 126	50	49
6. Die Boord	1 085	55	53
7. Welgevonden	1 071	55	53
8. Paradyskloof	594	60	60
9. Brandwacht	91	10	9
10. Simonswyk	138	30	29
11. Rozendal	223	25	21
12. Universiteitsoord	266	35	36
13. Dalsig	436	35	33
14. Enkanini	2 000**	60	62
TOTAL	20 667	580	554

* Statistics South Africa (2012)

** Van Breda (2016)

As it can also be seen in Table 3.1, although it had been planned to collect a total of 580 samples, 554 were actually collected during the conducting of the study.

3.2.2 Sampling procedure for the characterisation study of 2017

In March of 2017, the DEA&DP of the Western Cape published a document which was titled 'Waste Characterisation Guideline for Municipalities' (DEA&DP 2017). Its purpose was to ensure the standardisation of waste characterisation studies which were conducted in the Western Cape, in the interests of obtaining reliable and comparable results. As the Stellenbosch Local Municipality is a local authority which falls under the provincial jurisdiction of the DEA&DP, the guideline was studied and assessed during the planning of the sampling of the 2017 characterisation study to ensure the standardisation of the sampling procedures and compliance. The document could be used to guide the conducting of the study of 2017 only, as it was unavailable in 2012.

The methodology for selecting a representative sample is explained in Section 2.1.1.1 of the guideline and is based on the 'Municipal Waste Characterisation Guidelines' which were compiled by the EPA (please refer to EPA 1996). Figure 3.1 depicts the graph which the guideline prescribes for determining a representative sample size of any area which comprises less than 4 000 households in total.

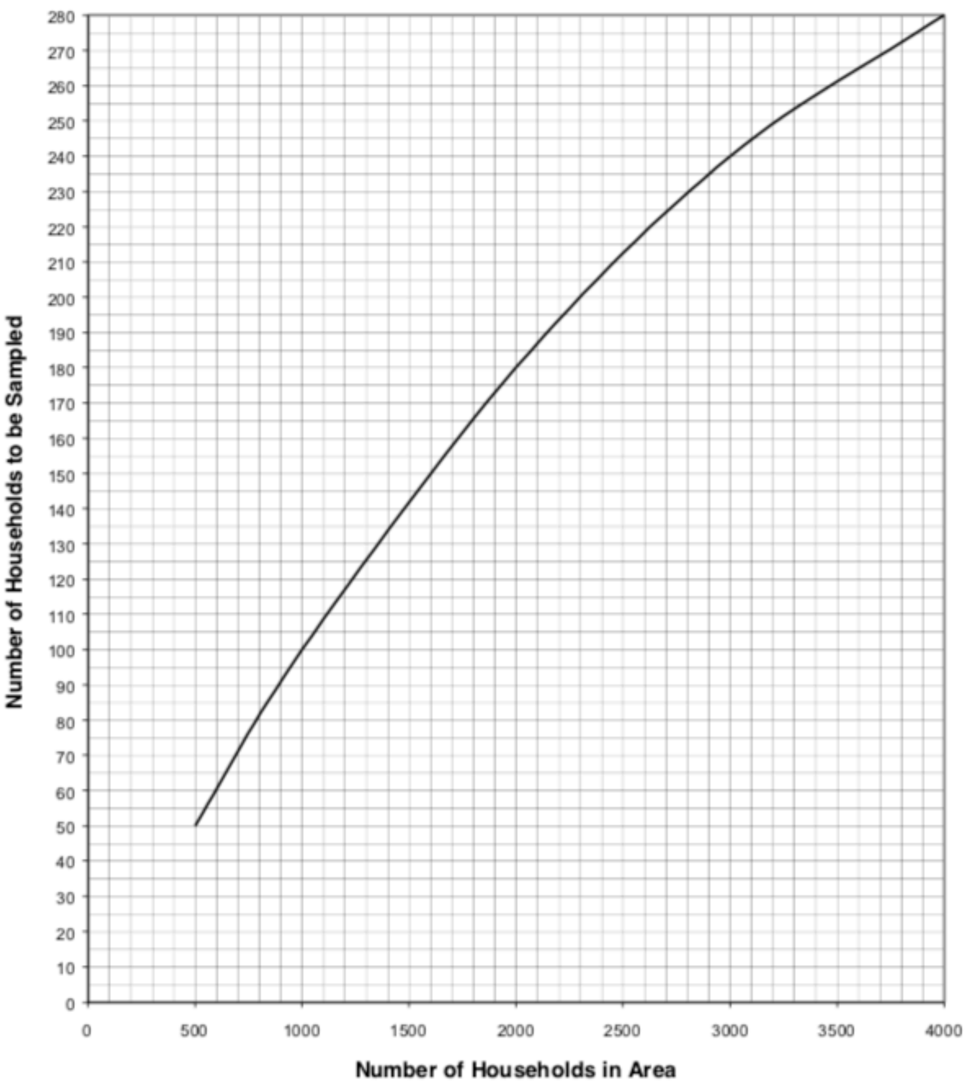


Figure 3.1: Graph for estimating sample sizes for areas which comprise less than 4 000 households EPA (1996)

To determine the sample size for the study of 2017, Cochran's formula (Equation 1) and the graph which is prescribed in the guideline of the DEA&DP (Figure 3.1) were combined. Cochran's formula was used to determine the sample sizes with ±5%, ±7% and ±10% levels of precision at both the 95% and 99% confidence levels. The calculations appear under items 4, 5 and 6 of item 1 and items 7, 8 and 9 of item 2 in Table 3.2. The sample sizes which were calculated in accordance with the graph in Figure 3.1 are tabulated under items 3 and 10. Calculating sample sizes at different confidence levels and levels of precision enables researchers to gauge the most practicable sample sizes with respect to the resources which are available.

After using Cochran's formula to calculate sample sizes at two different confidence levels and three different levels of precision and also using the graph in Figure 3.1 to calculate sample sizes in accordance with the recommendations of the DEA&DP, items 1 to 3 could be averaged to determine a mean confidence level of 95% and items 4 to 10 could be averaged to yield a mean level of precision of ±8%.

Table 3.2: Breakdown of samples collected in the waste characterisation study of 2017

Area	Number of households, N*	(1) Sample size, *n* at the 95% confidence level:			(2) Sample size, *n* at the 99% confidence level:			(3) Sample size, *n* at the 80-90% confidence level:	Mean (1) – (3), *n* at the 95% confidence level:	(11) Actual samples
		(4) ±5%	(5) ±7%	(6) ±10%	(7) ±5%	(8) ±7%	(9) ±10%	(10) ±10%	Mean (4)-(10) ±8%	
1. Cloetesville	3 327	344	185	93	555	308	159	200	263	113
2. Jamestown	601	235	148	83	316	217	130	70	171	207
3. Uniepark	138	102	81	57	114	98	76	30	80	190
4. Kayamandi	8 564	368	192	95	618	327	163	400	309	384
5. Idas Vallei	2 128	326	180	92	507	293	154	170	246	166
6. Die Boord	1 089	284	166	88	413	259	144	80	205	80
7. Kylemore and Farms	994	273	162	87	391	250	142	80	198	172
8. Welgevonden	1 070	283	166	88	411	258	144	80	204	62
9. Mostertsdrift	406	198	132	78	252	185	118	45	144	196
10. Paradyskloof	593	233	147	83	314	216	130	55	168	122

11. Raithby	217	139	103	67	164	133	94	15	102	122
12. Pniel	496	217	141	81	284	202	125	50	157	111
13. Brandwacht	182	124	95	63	143	119	87	35	95	119
14. Jonkershoek	57	50	44	36	53	49	43	10	41	81
15. Simonswyk	138	102	81	57	114	98	76	30	80	100
16. La Collline	579	231	147	82	310	214	129	60	168	75
17. Klapmuts	1 669	312	175	91	476	282	151	150	234	79
18. Onder Papegaaiberg	483	214	140	80	280	200	124	50	155	63
19. CBD	1 281	296	170	89	438	269	147	80	213	411
20. Franschhoek	593	233	147	83	314	216	130	60	169	272
21. Devon Valley	37	34	31	27	35	33	30	10	29	96
22. Krigeville	298	168	118	73	206	159	107	30	123	81
23. Koelenhof	69	59	51	40	63	57	49	15	48	117
TOTALS	**25 009**	**4 824**	**3 004**	**1 714**	**6 772**	**4 443**	**2 654**	**1 790**	**3 601**	**3 419**
	$n_o =$	384	196	96	666	340	166	N/A	N/A	
	p =	0.5	0.5	0.5	0.5	0.5	0.5	N/A	N/A	
	z =	1.96	1.96	1.96	2.58	2.58	2.58	N/A	N/A	

q =	0.5	0.5	0.5	0.5	0.5	0.5	N/A	N/A
e =	0.05	0.07	0.1	0.05	0.07	0.1	N/A	N/A

* Statistics South Africa (2012)

Consequently, the confidence level for the conducting of the study was set at 95% and the level of precision at ±8%. Table 3.2 summarises the calculations in detail and the actual numbers of samples which were collected from each area are listed under item 11. It can be seen that in some areas fewer bags filled with HSW could be collected than had been planned, while in others the numbers which had been planned were exceeded. In total, 3 419 samples of a planned 3 601 were collected.

3.3 METHODOLOGIES EMPLOYED TO CARRY OUT THE COLLECTION PHASES

The wide range of ways in which waste is transported in developing countries includes by rickshaw, animal traction, wheelbarrow, tractor, truck, compactor, tricycle, motorcycle and hand trolley (Guerrero et al. 2013). All of these means have also been used to collect samples during waste characterisation studies throughout the world (Edjabou, Jensen, Götze, Pivnenko, Petersen, Scheutz & Astrup 2015; Gu et al. 2015; Miezah et al. 2015; Ezeudu et al. 2019). During the study which Ozcan et al. carried out in 2016, compactor trucks were replaced with caged vehicles to collect samples, in order to minimise damage to the waste materials before the characterisation was performed. They also ensured that the waste which had been collected from each area was kept separate, in order to ensure that the origin of all of the materials was known. Uncompacted samples were also collected for both of the characterisation studies which were conducted in Stellenbosch in 2012 and 2017, as the method was most suited to the resources and budget which were available. The samples were collected by means of several different vehicles, which included a 5 m^3 caged vehicle and a 2.0 litre light pickup truck with a trailer. The crews which collected the samples consisted of a driver, who was required to hold a valid driver’s license and a Professional Driving Permit (PDP), and from two to four general workers, whose numbers depended on the availability of workers on the days on which samples were collected. Each member of the crews was issued with adequate personal protective equipment (PPE), which included safety bibs for increased visibility, gloves and masks.

The procedure for collecting samples started with the identification of areas from which samples were to be collected each day. Each pre-identified area was assigned a unique coloured sticker for the day. If samples were to be collected from Brandwacht, Paradyskloof and Die Boord on a particular day, those which were collected from Brandwacht would bear bright green, those from Paradyskloof bright pink and those from Die Boord light blue stickers. This procedure enabled collection vehicles to collect samples from more than one area per collection round before offloading samples. Not requiring crews to keep bags from particular areas separate served to minimise potential sampling errors and also overburdening crews with excessively complex instructions.

The days on which samples were collected from particular areas corresponded with the municipal refuse removal schedules for each area. Arrangements were made with the Solid Waste Management Department, the municipal authority which is responsible for the collection of HSW, to ensure that the collection crews who collected samples for the characterisation studies were given a head start to collect samples before the arrival of the compactor vehicles of the department. It was essential to coordinate the collections of samples with the department in this manner, as a failure to do so could have precluded the possibility of collecting samples.

Before each team headed out to collect samples, the numbers of samples which were to be collected from each area, which had been determined during the sampling phases of the studies, were clearly communicated to the teams. For the purposes of this study, a single sample was defined as a single black bag of HSW which had been generated by a single household, placed in a wheelie bin for kerbside collection by a municipal vehicle, for disposal by landfill. In cases in which the wheelie bins of households contained more than one black bag, only one bag would be collected as a sample. If households did not place their HSW into their wheelie bins in black bags and instead used the wheelie bins as receptacles, collection crews were required to decant the waste into black bags to create samples. Although the crews were instructed to use simple random sampling to collect the bags, to ensure an equal spread of samples from each area, a minimum of one sample from each street or road in collection areas was stipulated, with more samples to be collected from longer streets or roads than from shorter ones.

After the required numbers of samples had been collected or once a collection vehicle had reached capacity, the vehicle transported the samples to a central facility for weighing and sorting, tasks which were performed by a designated team and supervisors. At the sorting facility, the vehicle was offloaded and the bags were grouped according to the colours of the stickers which had been placed on them. Then each bag was individually weighed and the sorting process commenced in accordance with the procedure which was explained in sub-section 3.4. The respective masses and volumes of HSW which were collected during the characterisation studies of 2012 and 2017 are summarised in Table 3.3. Where no collection took place at a specific location for the corresponding year, it is indicated by a dash.

Table 3.3: Masses and volumes of HSW which were collected during the characterisation studies of 2012 and 2017

Area	Mass collected (kg)		Uncompacted volume collected (m^3)	
	2012	2017	2012	2017
1. Cloetesville	272.79	466.19	2.73	6.94
2. Jamestown	216.81	768.43	2.34	11.53
3. Uniepark	70.38	730.9	0.77	10.47
4. Kayamandi	193.8	1 606.82	1.63	23.31
5. Idas Vallei	251.74	546.6	2.38	9.16
6. Die Boord	194.58	273.75	2.52	3.69
7. Kylemore and Farms	N.C.*	753.9	N.C.	11.59
8. Welgevonden	215.91	161.59	2.37	3.00
9. Mostertsdrift	N.C.	663.93	N.C.	10.55
10. Paradyskloof	243.89	409.55	2.70	5.84
11. Raithby	N.C.	483.84	N.C.	7.06
12. Pniel	N.C.	463.79	N.C.	6.36
13. Brandwacht	45.6	423.02	0.38	6.03

14.	Jonkershoek	N.C.	277.94	N.C.	4.66
15.	Simonswyk	105.03	361.16	1.32	4.90
16.	La Collline	N.C.	233.74	N.C.	4.39
17.	Klapmuts	N.C.	253.42	N.C.	4.44
18.	Onder Papegaaiberg	N.C.	249.76	N.C.	4.05
19.	CBD	N.C.	1 086.56	N.C.	17.32
20.	Franschhoek	N.C.	1 809.25	N.C.	27.57
21.	Devon Valley	N.C.	339.8	N.C.	6.45
22.	Krigeville	N.C.	278.41	N.C.	5.08
23.	Koelenhof	N.C.	488.07	N.C.	7.06
24.	Rozendal	110.118	N.C.	0.81	N.C.
25.	Universiteitsoord	134.18	N.C.	1.66	N.C.
26.	Dalsig	138.353	N.C.	1.74	N.C.
27.	Enkanini	531.75	N.C.	3.27	N.C.
TOTAL		**2 724.93**	**13 130.42**	**26.62**	**201.45**

*** = Not Collected (excluded from study at that time)**

It needs to be emphasised that households were not notified that the studies were about to be conducted, as prior knowledge could potentially have altered the behaviour of their members with respect to the types of waste which they placed outside their homes for collection, thereby compromising the validity of the findings.

3.4 METHODOLOGIES EMPLOYED TO CARRY OUT THE SORTING PHASES

Section 2.2.3 of the literature review provided a detailed overview of the sorting methodologies which different researchers have used to conduct relevant waste characterisation studies. The review was intended to provide an appropriate basis for evaluating the methods which were used to sort the waste into fractions in the characterisation studies of 2012 and 2017. As it was noted in sub-section 3.3, the collection phases ended with the individual weighing of each bag of waste. From this point, the sorting phase commenced, from which most of the raw data for the characterisation studies was obtained. The methodology which was used to carry out the sorting phase in the study of 2017 drew mainly on the procedure which was suggested by the guideline of the DEA&DP (2017).

The diagram in Figure 3.2 illustrates the layout of the sorting operation. The sorting team consisted of a team of sixteen sorters, who are represented by dark green circles, and two supervisors, who are represented by light green circles. The four sorting tables are represented by dark blue rectangles and the two data capturing tables are represented by yellow rectangles. Each sorting table was staffed by four sorters and each supervisor was responsible for two tables. Each sorting table was issued with a specific number of 20-litre plastic buckets, which are represented by white squares. The numbers of plastic buckets which each team received were dependent on the numbers of categories into which the waste was sorted. As it is explained in the detailed discussion which follows, the numbers of categories were different for the studies of 2012 and 2017. Each supervisor had access to a laptop computer, relevant software and a scale, which is depicted in the diagram as a dark red square. All team members were issued with adequate PPE, which consisted of aprons or overalls, depending on which were available, gloves and masks.

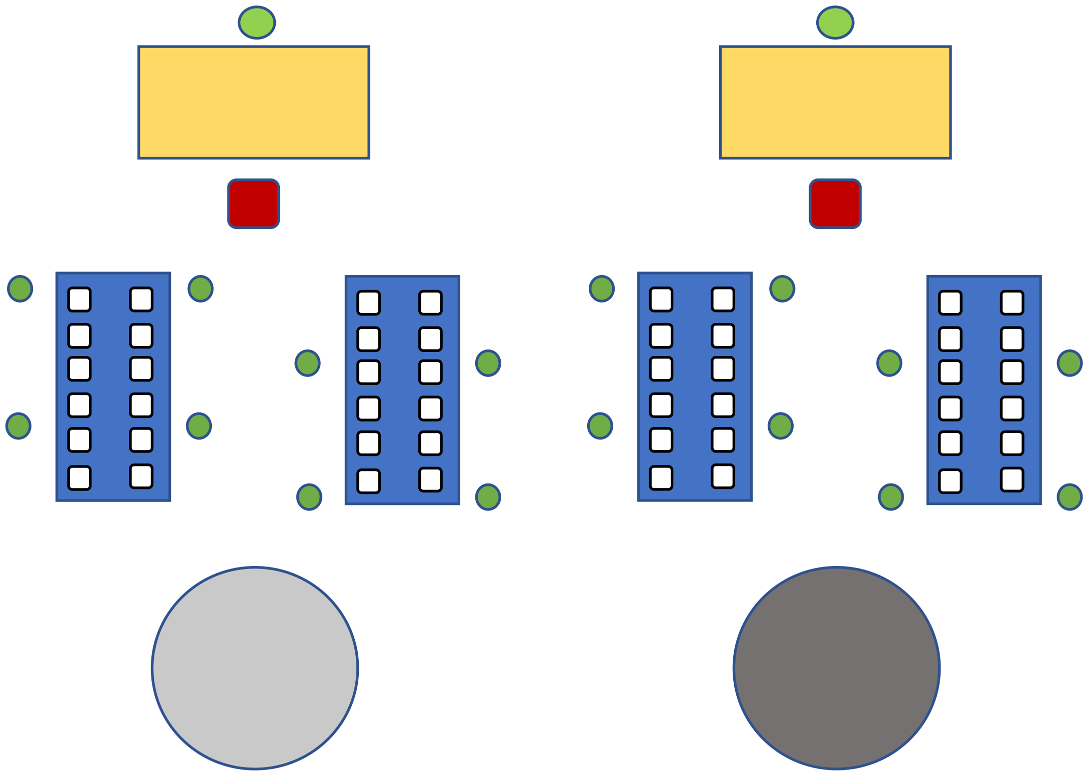


Figure 3.2: Schematic representation of the sorting operation

The sorting process commenced with the selecting of a bag of unsorted HSW from the stockpile of samples which had just been delivered by the collections team, which is represented in Figure 3.2 as a large light grey circle. The unopened bag was then weighed on the scale and its mass was captured by the supervisor on a Microsoft Excel spreadsheet. The origin of this bag, with respect to the area from which it had been collected, was also noted by the supervisor.

After the initial mass of the sample had been recorded, the sorting team proceeded to open the bag. Great caution needed to be exercised, because the contents of the bag were unknown and could contain sharp or hazardous material which could potentially result in injury if the waste were to be handled incorrectly. Secondly, the black bag which had contained the sample could be reused after the waste had been characterised, thereby minimising the creation of additional and unnecessary plastic bag waste.

Once the contents of the bag were on the table, the sorting process commenced. During the study of 2012, the waste stream was divided into seven different fractions. In 2017, the same seven fractions were used as a baseline, to ensure that comparisons could be drawn between the findings of the two studies. Some of the fractions were then further divided into sub-fractions, a procedure which permitted deeper understanding to be obtained of the various waste fractions than had been possible in 2012.

The first column of Table 3.4 enumerates the main fractions which were used during the studies of both 2012 and 2017, namely hard plastics, plastic wrap/packaging, metals, glass, paper/cardboard, organic waste and 'others', while the second enumerates the final fractions which were used in 2017.

Table 3.4: Waste fractions used in 2012 and 2017

Main fractions: 2012 and 2017	Final fractions: 2017
1. Hard plastics	1. Hard plastics
2. Plastic wrap/packaging	2. Plastic wrap/packaging
3. Metals	3. Metals
4. Glass	4. Glass
5. Paper/cardboard	5. Paper/cardboard
6. Organic waste	6. Food waste 7. Garden waste 8. Leachate
7. Other	9. Tetra Pak cartons 10. Household hazardous waste 11. Extruded Polystyrene (EPS), e.g. Foamalite 12. Tissues 13. Ash 14. Electronic waste (E-waste) 15. Small furniture items 16. Maize meal bags 17. Textiles 18. Residual 'other'

As it can be seen from Table 3.4, the creation of sub-fractions in 2017 resulted in the original seven fractions which were used in 2012 being increased to eighteen individual fractions.

Once the entire contents of a black bag had been sorted into relevant fractions, the platform scale was zeroed to account for the weight of the 20-litre buckets into which the fractions had been placed and each fraction was individually weighed and the data was captured by a supervisor. The uncompacted volume of each fraction was also captured, by estimating the volumes of each 20-litre bucket which had been filled with a specific waste stream. As an example, if half of a bucket was filled with metals after the sorting had been completed, the supervisor would indicate 50% in the 'volume' column of the spreadsheet. Conversely, if the amount of material representing one waste fraction exceeded the capacity of one 20-litre bucket, additional buckets were used until all of the waste had been placed in buckets. The masses and volumes of the additional buckets were added to those of the first bucket in these cases. Consequently, it was not uncommon for the volume of a particular waste stream to exceed 100%. If three 20-litre buckets were used to represent one waste stream, it was acceptable to capture a maximum of 300% (DEA&DP 2017).

When all of the buckets had been weighed and the volumes which their contents filled had been estimated, the supervisors endeavoured to ascertain whether the total calculated mass corresponded with the mass weight of the unopened bag in question. This procedure enabled the supervisors to detect immediately any instances of incorrect data having been captured as a consequence of initial unopened masses not corresponding with total calculated masses. Errors of this sort were remedied by re-weighing and re-capturing the data from each bucket, thereby minimising potential errors with respect to capturing data.

After the checks had been completed and the supervisors were satisfied that the data which had been captured was correct, the sorting team moved on to the final step of the sorting phase. This step entailed separating all salvageable recyclables from the non-salvageable recyclables and non-recyclable waste. Recyclables are defined as any items or materials which are classified as recyclable for the purposes of the separation at source project of the Stellenbosch Local Municipality. Table 3.5 provides comprehensive lists of items which are classified as being recyclable and those which are not recyclable.

Table 3.5: Recyclable and non-recyclable items for the purposes of the separation at source initiative of the Stellenbosch Local Municipality

Recyclable items	Non-recyclable items
1. Office paper	1. Disposable diapers or sanitary items
2. Newspapers	2. Chemicals, acids or solvents
3. Magazines	3. Paint
4. Flattened and folded cardboard	4. Toothpaste tubes
5. Glass or plastic bottles and jars	5. Clear food punnets (thermoform)
6. Empty bags, bottles and containers	6. Dog food packets
7. Bread tags	7. Washing powder packets
8. Cling wrap	8. Crisp packets
9. Food tins and cans	9. Motor oil containers
10. Foil	10. Organic waste (food and garden waste)
11. Scrap metal	11. Clothing or shoes
12. Empty aerosol cans	12. Wet, dirty or contaminated items
13. Tetra Pak cartons	13. Household hazardous waste
14. Polystyrene products	

Source: Stellenbosch Municipality (2018)

Consequently, the term ‘salvageable recyclables’ refers to any of the items which could be salvaged and diverted from landfill as a result of having been sorted and characterised. These categories of items were deemed to be salvageable only if they exhibited a relatively low degree of contamination, in the sense that their physical and chemical characteristics remained relatively unchanged, even after potential exposure to non-recyclable materials such as food waste. Fractions such as glass, metals or hard plastics could be salvaged in most cases, as these can be more readily cleaned after they have been contaminated and are less prone to high levels of contamination than recyclable materials such as paper waste. All categories of salvageable recyclables which had been recovered from the sorting process were combined according to fractions and placed in clear bags in the removal area, which is represented by the large dark grey circle in Figure 3.2, for collection and further beneficiation by the contractor who was responsible for recycling at the Small Materials Recovery Facility.

Waste fractions such as paper or cardboard were more difficult to salvage, as even low degrees of contamination are likely to result in their being classified as non-salvageable recyclables. Non-salvageable recyclables, together with all non-recyclable waste, are collectively referred to as ‘tailings’. For the purposes of this study, tailings included food waste, as the Municipality did not have an operational food waste beneficiation facility. All tailings were placed in black bags in the removal area, which is represented by the dark grey circle in Figure 3.2, for collection by municipal compactor trucks and final disposal at the DVLS. This procedure was repeated for each unsorted sample.

The diagram in Figure 3.3 provides a schematic representation of the steps which were followed in the sorting procedures in the characterisation studies of 2012 and 2017.

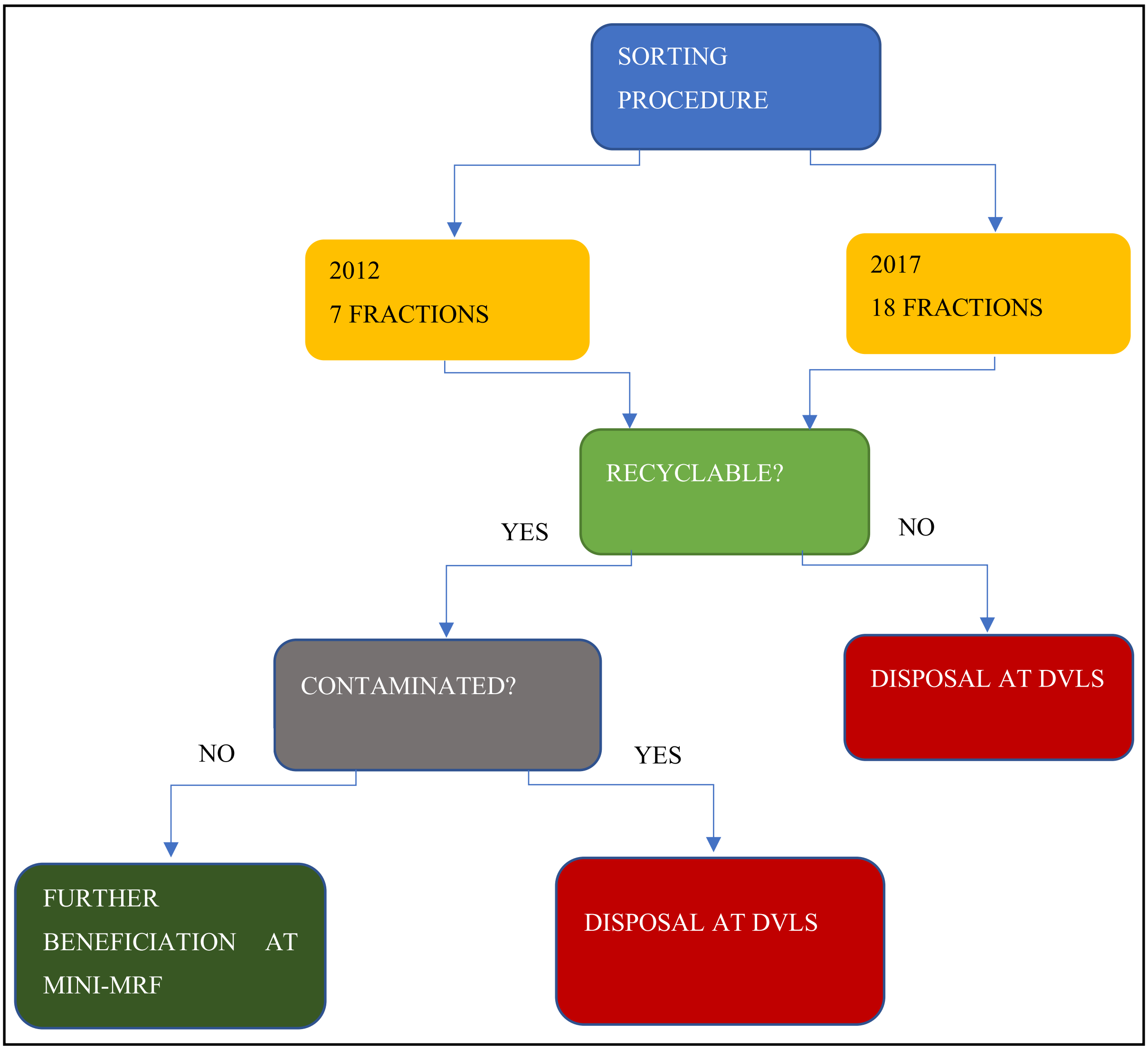


Figure 3.3: Steps followed in the sorting procedures for the characterisation studies of 2012 and 2017

At the end of each day, both the sorting area and all equipment which had been used was thoroughly cleaned with disinfectant to maintain a safe and healthy workplace. Salvaged recyclables and tailings were also removed each day, to ensure that the sorting activities did not result in the creation of hazards.

In 2012, 2 724.93 kg of waste was sorted over a period of 10 days and in 2017 a total of 13 130.42 kg was sorted over a period of 40 days. The raw data which was obtained from the sorting phases provided the basis for the phase of the characterisation during which the data was analysed, which is covered in detail in the sections which follow.

3.5 METHODOLOGY EMPLOYED TO ANALYSE THE DATA

Three software packages were used to analyse the data which the waste characterisation study generated: Microsoft Excel 2016, ArcGIS (ArcMap 10.6.1) and Statistica 13.

3.5.1 Methodology 1 – Basic analysis

Section 3.4 details the procedures which the supervisors followed to capture data pertaining to both mass and volume for each waste fraction in Microsoft Excel 2016.

The unit in which the mass of each waste fraction was captured during the sorting phase was the kilogram (kg), which did not require any further conversion. By contrast, as the estimated volumes were captured as percentages of a 20-litre container, they needed to be converted to cubic metres. The step was a crucial one, as the figures which were obtained provided an indication of the physical space which the uncompacted materials would occupy on a landfill site. Although the mass of landfill material is ultimately relatively irrelevant, it is of the greatest relevance to establish how full a landfill site is (Haider 2012, pers com). In accordance with the recommendations of the DEA&DP (2012), the following formula was used to make the conversions:

$$Volume\ m^3 = Estimated\ volume\ (\%)\ x\ capacity\ of\ bucket\ (l)\ /\ 100\%\ /\ 100$$ Equation 3

The calculations permitted waste profiles to be developed for each of the areas from which samples were collected in the characterisation studies of 2012 and in 2017. In addition, waste profiles could also be developed for each waste fraction which was used in the two studies. Volumes of waste were calculated for each area from which samples had been collected.

A comparative analysis was carried out to enable comparisons to be made between the findings of the studies of 2012 and 2017. The volumes of waste which was landfilled per annum were calculated by determining the uncompacted density (ρ) for each waste fraction by means of the following formula:

$$\rho = \frac{m}{V}$$ Equation 4

where m is mass in kilograms

V is volume in cubic metres (total uncompacted volume) of each waste fraction captured during the 2017 waste characterisation study.

The densities which are calculated can, in turn, be used to determine the uncompacted volume (V) of each fraction which is landfilled per annum by means of the following formula:

$$V = \frac{m}{\rho}$$ Equation 5

where m is mass in kilograms

ρ is density

3.5.2 Methodology 2 – Spatial analysis

ArcMap 10.6.1 was utilised to visually represent the spatial changes identified in this study.

3.5.3 Methodology 3 – Statistical analysis

The raw data which was captured during the waste characterisation process was also statistically analysed to determine statistical significance utilising the software package Statistica 13. An analysis of variance (ANOVA) was performed to determine whether or not the change in each waste fraction by weight and volume over time was statistically significant. The analysis was performed with a confidence interval of 95% and the results were depicted visually in LsMeans graphs.

A Levene's test for homogeneity of variance was conducted for each waste fraction by mass and volume, to determine whether or not the change in each fraction by weight and volume over time per area was statistically significant. Once again, the confidence interval was set at 95% and the results were depicted visually in LsMeans graphs.

Finally, Spearman's rank correlation coefficient was used to determine the statistical dependence between the rankings of waste generation rates and the influence which household income, household size and population density have on them.

3.6 CONCLUSION

The detailed account of the research methodology undertaken during this study has by no means happened by chance. It is the opinion of this researcher that there are certain critical details of other studies that are left unreported, making the studies less useful. The results obtained by the utilisation of above methodology will be discussed in the chapter overleaf.

CHAPTER 4: PRESENTATION AND ANALYSIS OF THE FINDINGS

4.1 INTRODUCTION

The detailed data pertaining to the masses and volumes of HSW which had been generated in areas which fall under the jurisdiction of the Stellenbosch Local Municipality, which was obtained from the collection and sorting of 554 samples in 2012 and 3 419 in 2017, is stored in an appropriate database. The presentation, discussion and analysis of the findings of the research study upon which this thesis is based are predicated upon answering the research questions which were articulated in section 1.4 of Chapter 1 and a meaningful evaluation of the extent to which the following objectives have been met:

4.1 To determine the composition of the residual portion of HSW in 2017.

4.2 To determine the quantities of the fractions of HSW which have been identified which are landfilled each year, according to the data which was obtained in the characterisation study of 2017.

4.3 To compare the findings of the HSW characterisation study of 2012 with those of this study, to determine spatial and temporal changes which can be observed in overlapping areas.

4.4 To correlate the quantity and composition of waste with relevant economic parameters for households.

This chapter is devoted to a comprehensive overview of the findings which emerged from the analysis of the waste characterisation data.

4.2 DETERMINATION OF THE COMPOSITION OF THE RESIDUAL PORTION OF HSW IN THE STUDY OF 2017

The 3 419 samples which were characterised during the study of 2017 had a combined total mass of 13 130.42 kilograms and an uncompacted volume of 201.45 cubic metres. The residual portion of the HSW stream refers to waste which is landfilled. It comprises mainly non-recyclables and organic waste, which are disposed of in black bags. As had been the case in the study of 2012, all samples were sorted into seven main fractions. The organic waste and ‘other’ fractions were subsequently divided into constituent fractions, in order to permit an increased understanding of these highly varied waste fractions.

4.2.1 Composition of residual HSW in the characterisation study of 2017

The pie chart in Figure 4.1 illustrates the overall composition of the residual portion of the HSW stream by mass. It depicts the contributions with respect to their combined and averaged masses of the seven main fractions as percentages of the total waste stream from the samples which were collected from all twenty-three areas which were surveyed in the characterisation study of 2017.

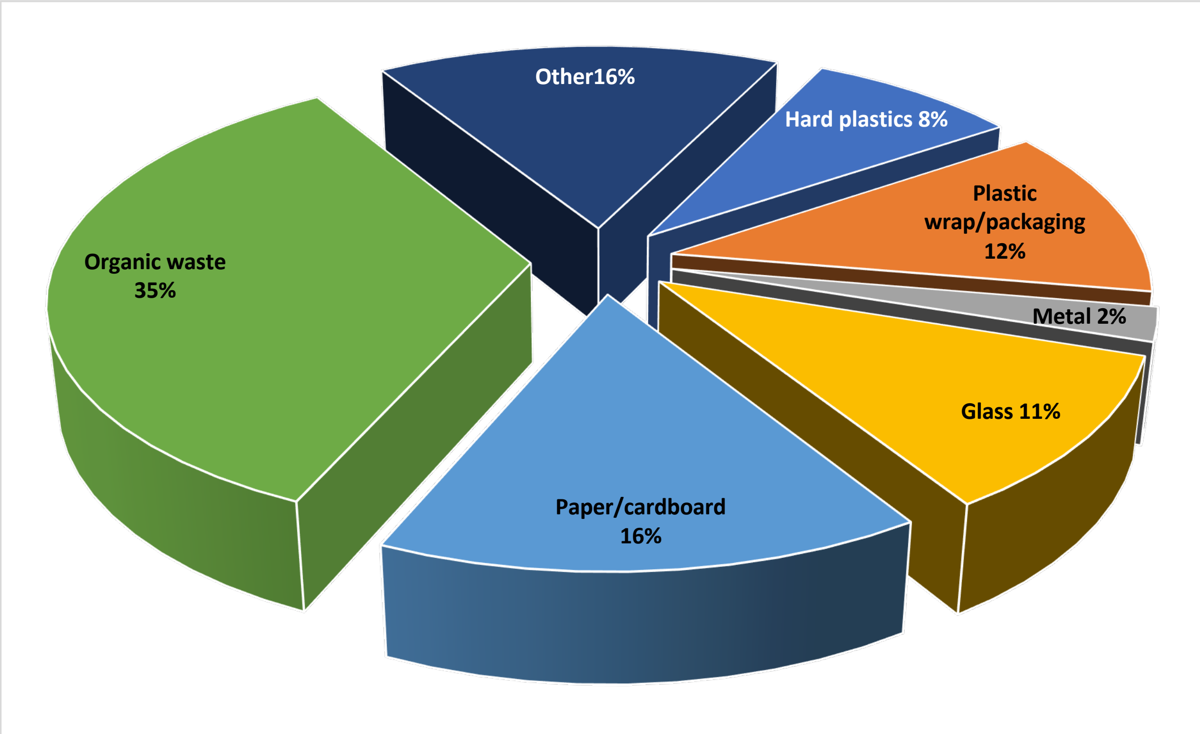


Figure 4.1: 2017: Overall composition of landfill bound portion of HSW by mass Source: Author

Organic waste represented the predominant portion by mass by accounting for 35%, while the paper/cardboard and 'other' fractions each accounted for 16%. The plastic wrap/packaging and glass fractions contributed 12% and 11% respectively, hard plastics 8% and metals 2%.

The pie chart in Figure 4.2 depicts the distributions of the combined and averaged volumes for each waste fraction as percentages of the total waste stream from the samples which were collected from all twenty-three areas which were surveyed in the waste characterisation study of 2017.

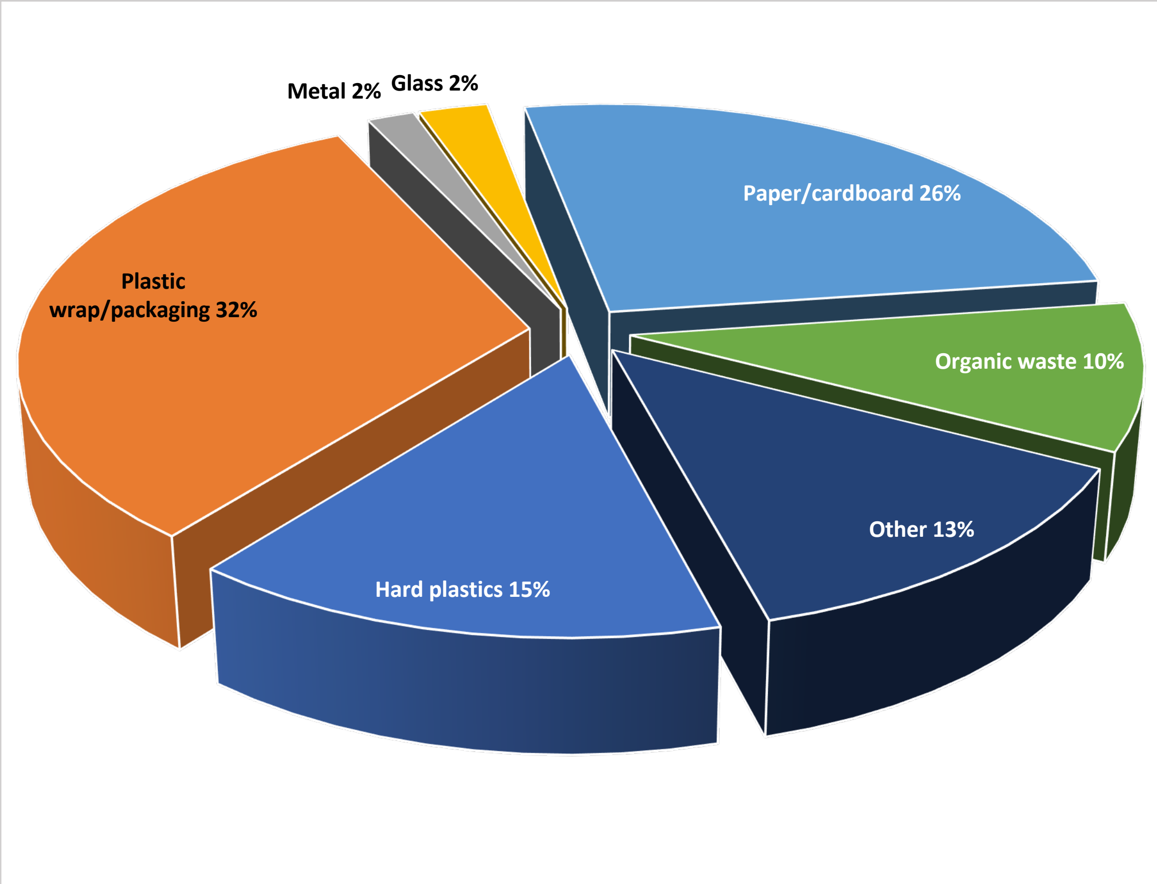


Figure 4.2: **2017: Overall composition landfill bound portion of HSW by volume** **Source: Author**

The largest waste fraction of the waste stream by volume was that of the plastic wrap/packaging which comprised 32% of the overall volume, as opposed to only 12% by mass. Although the items which fall into this waste stream are light, collectively they constitute large volumes of waste, particularly if the waste is not compacted, as was the case when the volumes of waste fractions were estimated in this characterisation study. Conversely, while organic waste constituted the largest fraction of the waste stream by mass, by volume it ranked only fifth among the seven fractions and contributed a mere 10% to the overall waste stream. Paper/cardboard (26%) and hard plastics (15%) were the second and third largest fractions with respect to the volumes which they contributed to the waste stream.

4.2.2 Detailed breakdown of the organic waste fraction

The organic waste fraction was further sub-divided into three fractions, namely, food waste, garden waste and leachate.

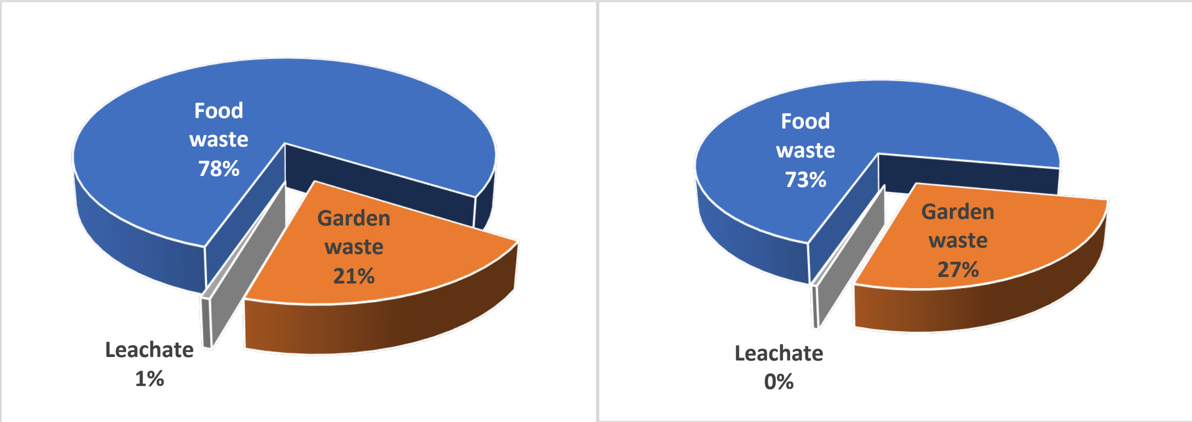
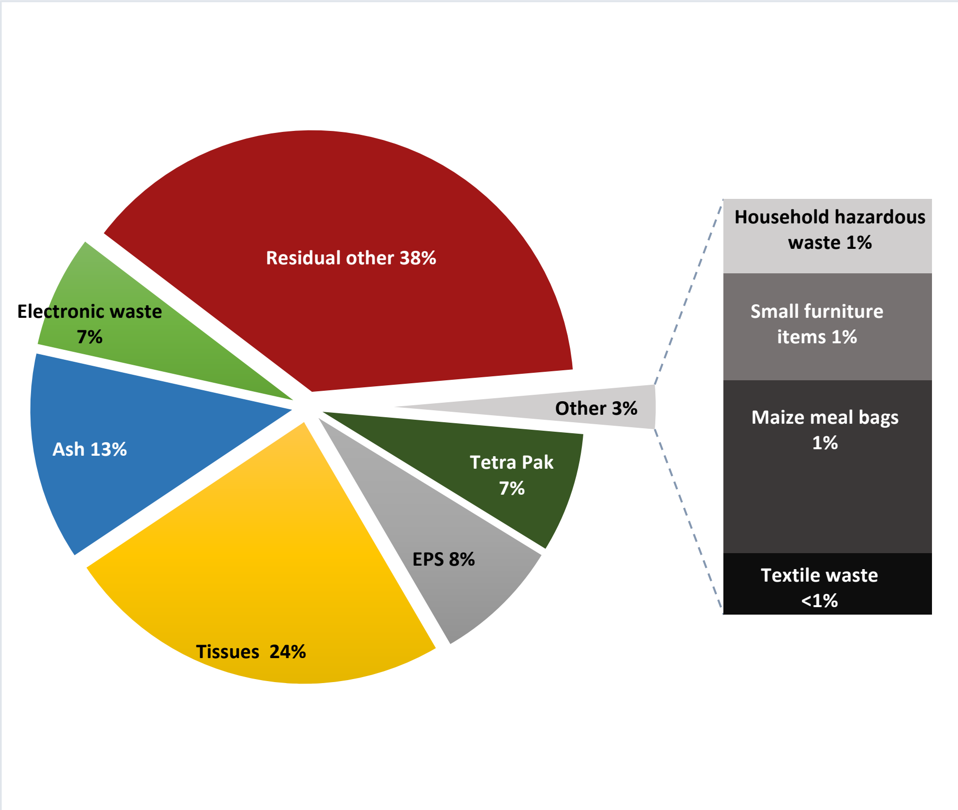


Figure 4.3: 2017: Compositions of landfill bound organic waste by mass (left) and by volume (right) Source: Author

Food waste represented the largest fraction of the organic waste stream with respect to both mass and volume, comprising 78% and 73% respectively, while garden waste comprised 21% by mass and 27% by volume. Leachate was present in insignificant quantities.

4.2.3 Detailed breakdown of the 'other' fraction

The waste fraction which was designated 'other' was further sorted into Tetra Pak cartons, household hazardous waste, extruded polystyrene (EPS), tissues, ash, electronic waste, small furniture items, maize meal bags, textile waste and residual 'other'.



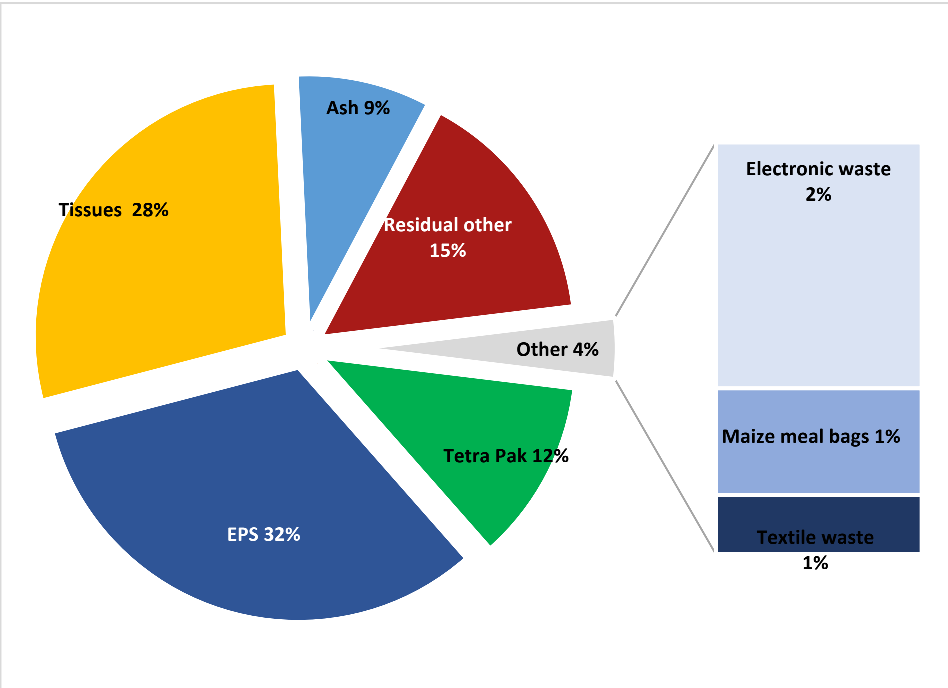


Figure 4.4: 2017: Composition of the landfill bound 'other' HSW fraction by mass (top) and volume (bottom) Source: Author

The residual other fraction was the largest in the 'other' waste stream by mass and accounted for 38%, while the tissues fraction accounted for 24%. The extruded polystyrene fraction was the largest by volume and accounted for 32%, while tissues accounted for 28% and residual other 15%.

4.2.4 Compositions of HSW in each area surveyed in 2017

The composition of HSW for each area which was surveyed in the study of 2017 was individually determined. Please refer to Appendix 1 for bar graphs which depict the compositions of HSW with respect to average masses and volumes of fractions per bag for each area.

4.3 TYPES AND QUANTITIES OF WASTE LANDFILLED PER ANNUM

The mass of waste which was landfilled per annum was calculated by making use of the data which was obtained from the waste characterisation study and combining it with existing data pertaining to the quantities of waste which are landfilled at the DVLS. Table 4.1 summarises the tonnages of HSW which were landfilled at the DVLS from July of 2014 to June of 2018, according to the relevant annual reports of the Stellenbosch Local Municipality.

Table 4.1: Tonnages HSW landfilled at the DVLS from July of 2014 to June of 2018

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Avg
14/15	3244	3136	3436	2403	3539	3369	3295	3159	3829	3745	3262	3475	3324
15/16	3277	3506	3572	3953	3758	4093	3694	3905	3550	4449	4066	3372	3766
16/17	3102	476	3192	3225	3371	3038	107	2865	3367	3048	3336	3018	2679
17/18	2987	3112	3132	3310	3506	3258	3114	3243	3036	3015	3291	3099	3175
Avg	3153	2558	3333	3223	3544	3440	2553	3293	3446	3564	3489	3241	**3236**

Source: Stellenbosch Municipality (2015; 2016; 2017; 2018)

The average quantity of HSW which was landfilled per month during the 4-year period was calculated to be 3 236.15 tons, as it is reflected in the lower right-hand cell of Table 4.1, which is equivalent to 38 833.75 tons per year.

The findings pertaining to objective 1 of the characterisation study of 2017, namely, to determine the composition of the residual portion of the HSW which was generated by the areas which were surveyed, are reflected as percentages by mass in column (2) of Table 4.2. This information, combined with the figures pertaining to landfill tonnages which the municipality released, was used to extrapolate the masses and volumes of each of the fractions which were landfilled per year. The figures are summarised in columns (4) and (5) of Table 4.2.

The volumes of waste which were landfilled per annum are provided in column (3) of Table 4.2 and were calculated by determining the uncompacted density (ρ) for each waste fraction by means of the following formula:

$$\rho = \frac{m}{V} \qquad \text{Equation 4}$$

Where m is the total mass in kilograms; and

$V =$ is the total uncompacted volume in cubic metres.

The respective densities were, in turn, used to determine the uncompacted volume (V) of each fraction which was landfilled per annum, by means of the following formula:

$$V = \frac{m}{\rho}$$ Equation 5

Where m is mass in kilograms; and

ρ is the density of the fraction.

The calculations are provided in column (5) of Table 4.2. The steps which have been enumerated needed to be followed to determine the volumes of each fraction, as waste is only weighed at the DVLS and not measured by volume as well.

Table 4.2: Quantities of each waste fraction landfilled per annum (2017)

(1)	(2)	(3)	(4)	(5)
Waste fraction	**Contribution to waste stream**	**Uncompacted density (kg/m^3)**	**Tons/a landfilled**	**m^3/a landfilled (uncompacted)**
Hard plastics	8.36%	36.02	3 244.59	90 077.46
Plastic wrap/packaging	12.10%	26.91	4 699.07	174 621.70
Metal	2.37%	91.3	920.75	10 084.88
Glass	10.97%	293.13	4 261.71	14 538.63
Paper/cardboard	15.49%	40.77	6 015.19	147 539.61
Organic waste	34.61%	251.07	13 440.42	57 933.28
Other	16.10%	173.2	6 252.02	91 307.94
TOTAL	**100.00%**	**N/A**	**38 833.75**	**526 491.96**

Of the total of 38 833.75 tons of HSW which is estimated to be landfilled annually, the largest contributor to this waste stream by mass is the organic waste fraction, with an estimated total 13 440.42 t/a, which is estimated to consume 57 993.28 cubic metres of landfill airspace over a 12-month period. Table 4.3 provides a more detailed breakdown of the individual sub-fractions of the organic waste fraction which are landfilled. The largest fraction by uncompacted volume is that of plastic wrap/packaging, which is estimated to consume 174 621.70 cubic metres of airspace per annum.

Table 4.3: Quantities of organic waste sub-fractions landfilled per annum (2017)

Organic waste sub-fraction	Contribution to organic waste stream	Uncompacted density (kg/m^3)	Tons/a landfilled	m^3/a landfilled (uncompacted)
Food waste	78.51%	251.07	10 552.07	42 028.40
Garden waste	20.86%	179.12	2 803.67	15 652.47
Leachate	0.63%	335.44	84.67	252.41
TOTAL	**100.00%**	**N/A**	**13 440.42**	**57 933.28**

As it can be seen in Table 4.3, it is estimated that 10 552.07 tons of food waste is landfilled annually, which would consume 42 028.40 cubic metres of airspace per annum.

Table 4.4 provides a detailed breakdown of the quantities of the sub-fractions of the 'other' fraction which are landfilled.

Table 4.4: Quantities of sub-fractions of the 'other' waste fraction landfilled per annum (2017)

Sub-fraction	Contribution to 'other' waste stream	Uncompacted density (kg/m^3)	Tons/a landfilled	m3/a landfilled (uncompacted)
Tetra Pak cartons	7.41%	44.35	463.27	10 445.77
Household hazardous waste	0.49%	167.57	30.47	181.83
EPS	7.83%	16.72	489.4	29 270.33
Tissues	24.01%	58.74	1 501.16	25 556.01
Ash	12.84%	104.39	802.79	8 792.88
Electronic waste	6.92%	208.05	432.4	2 078.35
Small furniture items	0.70%	183.15	43.78	239.04
Maize meal bags	1.14%	164.64	71	431.24
Textile waste	0.40%	50.47	25.17	498.71
Residual other	38.27%	173.2	2 392.54	13 813.74
TOTAL	**100.00%**	**N/A**	**6 252.02**	**91 307.94**

Table 4.4 demonstrates that the residual other sub-fraction makes the largest contribution by mass to the waste stream with an estimated 2 392.54 tons per annum and the extruded polystyrene sub-fraction the largest by volume with an estimated 29 270.33 cubic metres per annum.

Extruded polystyrene had the lowest density at 16.72 kilograms per cubic metre. Of the 18 waste fractions which were identified during the waste characterisation study, it consumed the most airspace per kilogram of landfill in uncompacted form. The second lightest material per cubic metre was the plastic wrap/packaging portion of the waste stream, of which 1 cubic metre of landfill airspace which was filled with the material would have a mass of only 26.91 kilograms. On the other end of the spectrum, glass, with a ratio of 1 m^3 : 293.13 kg, and leachate, with a ratio of 1 m^3 : 335.44 kg, consume the least airspace when they are disposed of as uncompacted landfill.

It needs to be emphasised that all densities were calculated for uncompacted materials. As the compaction ratios were not calculated while the data for the characterisation study was being accumulated, it is not possible to ascertain the compacted densities of the individual fractions. Information pertaining to uncompacted waste materials is particularly crucial to determining the amounts of space which are required at diversion facilities to store unprocessed materials.

4.4 COMPARISONS BETWEEN THE FINDINGS OF THE CHARACTERISATION STUDIES OF 2012 AND 2017 TO DETERMINE SPATIAL AND TEMPORAL CHANGES

The third objective of the characterisation study of 2017 was to compare the compositions of the residual HSW streams in the studies of 2012 and 2017 in order to identify spatio-temporal changes. This sub-section is devoted to an assessment of data from the ten areas which were surveyed in both the waste characterisation studies of 2012 and 2017, namely, Cloetesville, Jamestown, Uniepark, Kayamandi, Idas Valley, Die Boord, Welgevonden, Paradyskloof, Brandwacht and Simonswyk. As it has been explained, in the study of 2012, samples were sorted into seven main fractions and not further subdivided. Although the same procedure was followed in 2017, some fractions were further subdivided to yield a total of eighteen fractions. In order to enable meaningful comparisons to be made between the findings of the two studies, only the seven main sorting fractions are considered, namely, hard plastics, plastic wrap/packaging, metals, glass, paper/cardboard, organic waste and other.

The comparative evaluation is predicated upon adequately answering the following questions:

- Sub-section A: Have the contributions of any individual waste fractions to the waste stream increased or decreased over time? All areas are summed and averaged and waste fractions are discussed individually, as is depicted in the green rectangle in Figure 4.5.

- Sub-section B: Have the quantities of waste which are landfilled from each individual area increased or decreased over time, with respect to spatial and temporal changes? Although each area is considered and discussed individually, all waste fractions are summed and averaged and referred to as the total waste stream and depicted in the red rectangle in Figure 4.5.

- Sub-section C: Have the contributions of any specific waste fractions to the waste stream increased or decreased over time, with respect to spatial and temporal changes in the areas which have been surveyed? All areas and all waste fractions are considered and discussed individually, as is depicted in the purple rectangle in Figure 4.5.

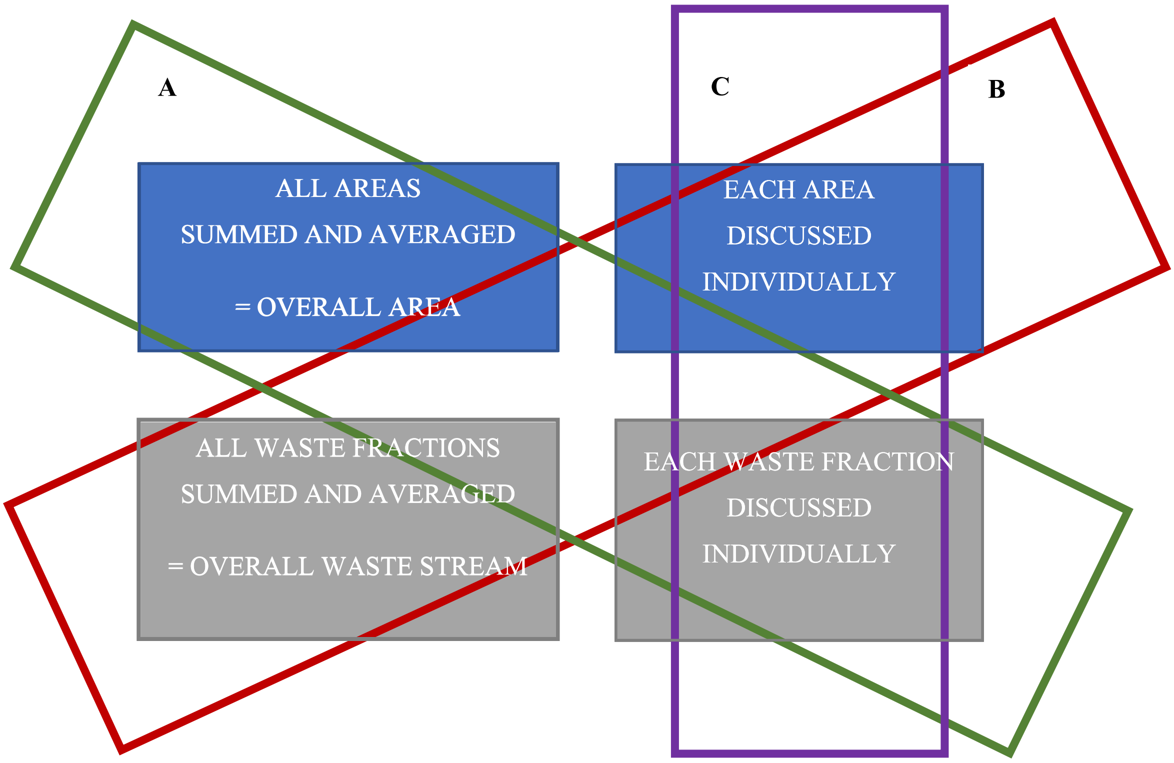


Figure 4.5: **Schematic representation of comparisons between the findings of the characterisation studies of 2012 and 2017**

4.4.1 Comparative analysis of the overall compositions of HSW with respect to waste fractions which the findings of the characterisation studies of 2012 and 2017 generated

The overall compositions of the HSW which were generated by the areas which were surveyed are depicted in the four doughnut charts in Figure 4.6 and Figure 4.7. The charts illustrate the contributions as percentages of each main fraction to the total waste stream, which have been combined and averaged for all ten overlapping areas by both weight and volume

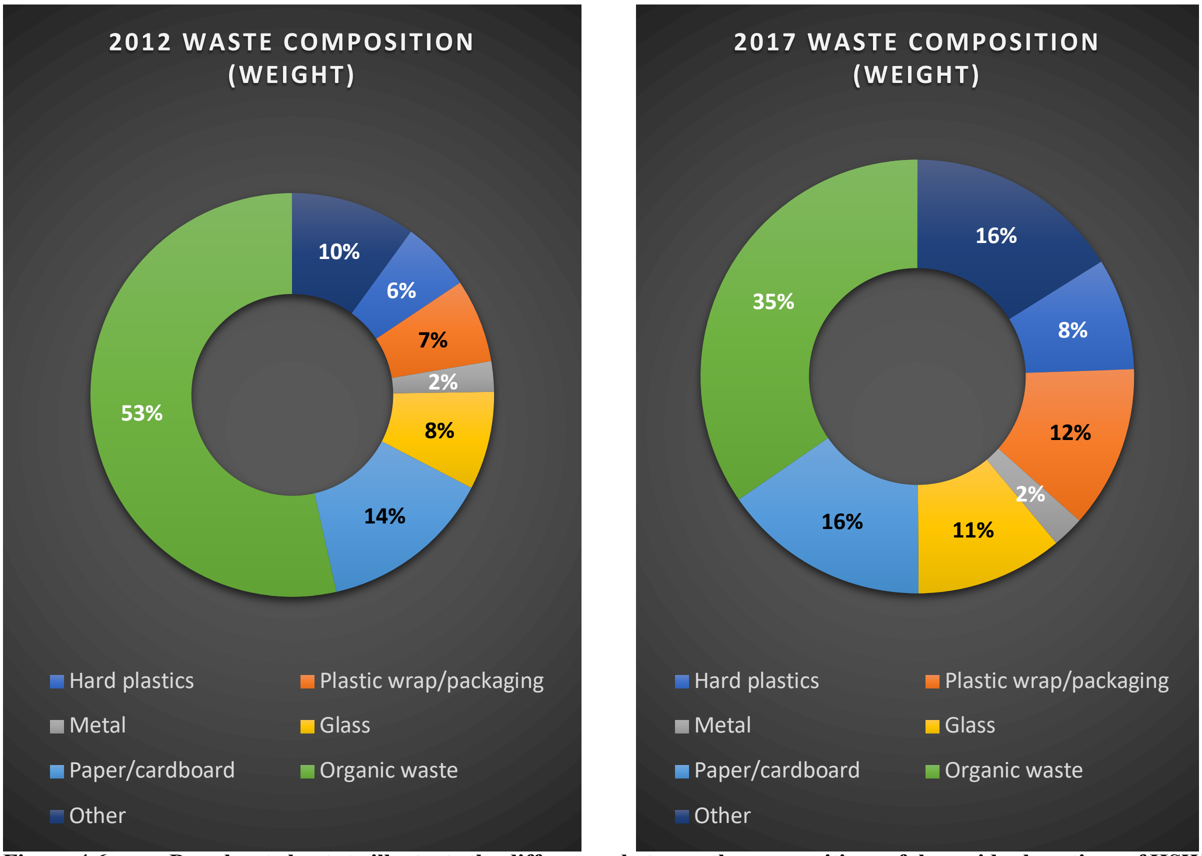


Figure 4.6: Doughnut charts to illustrate the differences between the compositions of the residual portions of HSW which were determined in the characterisation studies of 2012 (left) and 2017 (right) by weight

Source: Author

Organic waste contributed the most to the total waste stream at 53% and 35% in 2012 and 2017 respectively and metals the least, contributing a mere 2% in both studies.

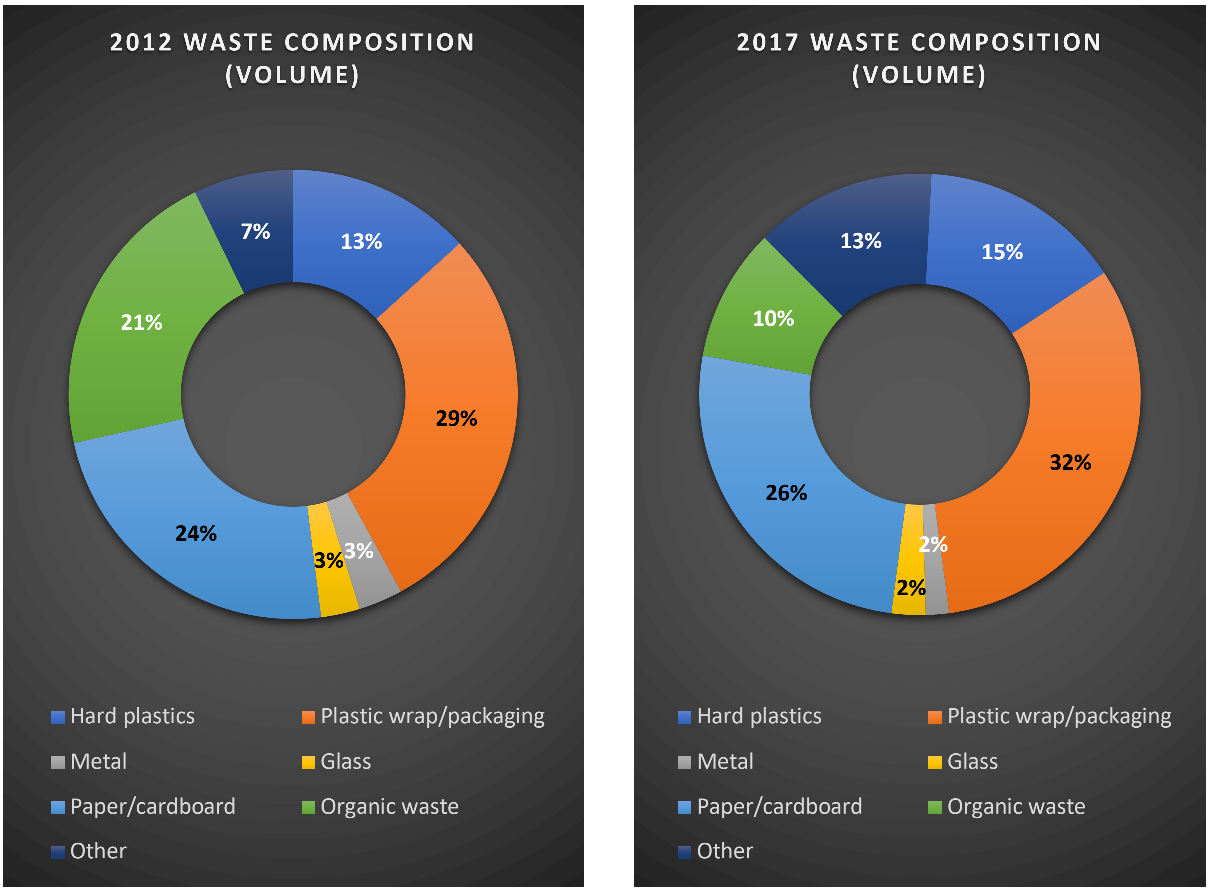


Figure 4.7: Doughnut charts to illustrate the differences between the compositions of residual portions of HSW which were determined in the characterisation studies of 2012 (left) and 2017 (right) by volume Source: Author

By volume, however, plastic wrap/packaging was the largest contributor to the waste stream in both 2012 and 2017, increasing from 29% to 32% over time. Organic waste's contribution decreased from 21% in 2012 to 10% in 2017.

4.4.1.1 Comparisons by mass for each fraction

It was possible to compare the masses in kilograms of each fraction which was landfilled in 2012 and 2017 by taking the data pertaining to the composition of HSW which was generated by the characterisation study of 2012 and performing the same analysis which is described in section 4.3 to arrive at the figures for the study of 2017.

The monthly average figure of 3 236.15 metric tons, which appears in the lower right cell of Table 4.1, upon which the calculations for the characterisation study of 2017 were based, was used to determine the masses in kilograms of each waste fraction which were landfilled on the basis of the data which the study of 2012 yielded. Table 4.5 summarises the calculations which were made.

Table 4.5: **Quantities of each waste fraction which were landfilled per annum (2012)**

(1)	(2)	(3)	(4)	(5)
Waste fraction	**Contribution to waste stream**	**Uncompacted density (kg/m³)**	**Tons/a landfilled**	**m³/a landfilled (uncompacted)**
Hard plastics	5.62	42.83	2 178.57	50 862.43
Plastic wrap/packaging	6.70	25.10	2 601.86	103 664.39
Metal	2.44	78.38	947.54	12 089.16
Glass	7.87	248.14	3 056.22	12 316.38
Paper/cardboard	13.86	56.99	5 382.36	94 442.82
Organic waste	53.49	253.32	20 772.17	82 000.80
Other	10.03	156.07	3 895.03	24 956.88
TOTAL	**100.00%**	**N/A**	**38 833.75**	**380 332.86**

The findings of the characterisation study of 2012 revealed that a total of 38 833.75 metric tons of HSW were landfilled in 2012 and that the largest contributor by mass to the waste stream was the organic waste fraction, which contributed a total of 20 772.17 metric tons per annum and consumed 82 000 cubic metres of landfill airspace over a 12-month period. Conversely, the largest fraction which was landfilled with respect to uncompacted volume was the plastic wrap/packaging, which consumed 103 664.39 cubic metres of airspace per annum.

The bar graph in Figure 4.8 provides a graphic representation of the comparative average masses, in metric tons, for each waste fraction which was landfilled in 2012 and 2017 respectively.

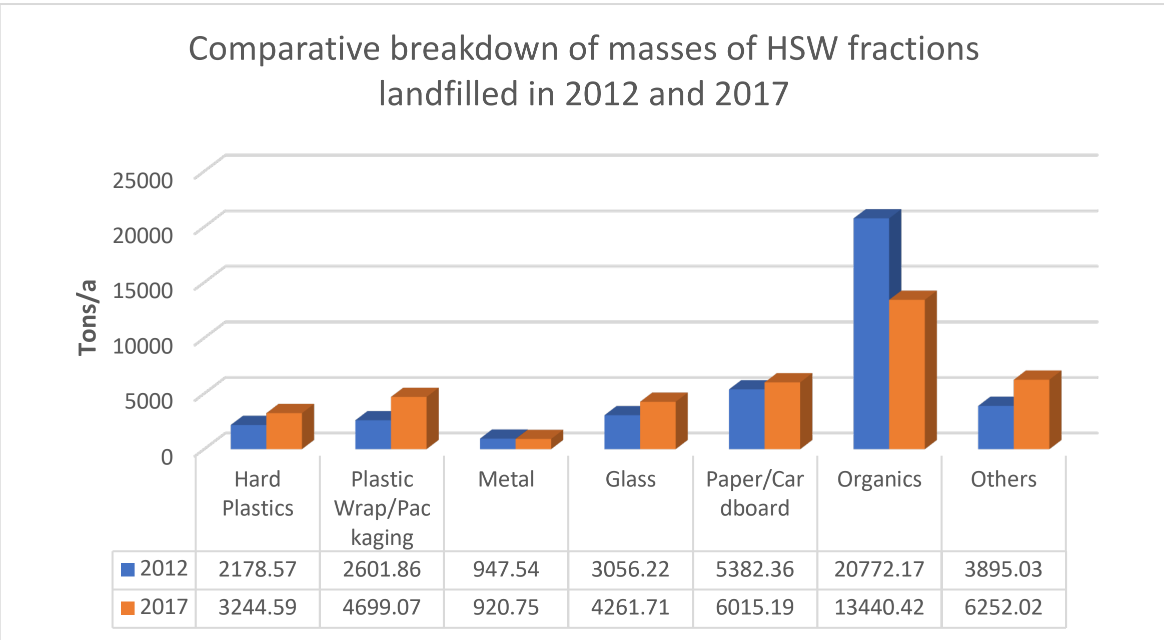
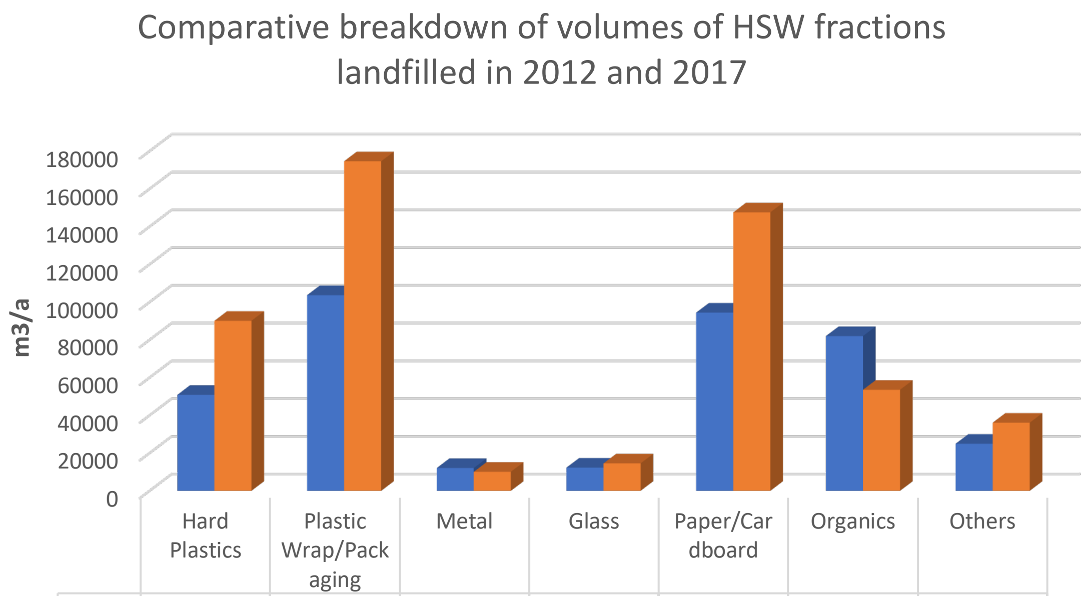


Figure 4.8: **Comparative breakdown of the masses of the seven main HSW fractions in tons per annum which were landfilled according to the data from the characterisation studies of 2012 and 2017**

The comparison reveals that the plastic wrap/packaging fraction increased more substantially by mass than any other fraction from 2012 to 2017, with 81% more plastic wrap/packaging having been landfilled in 2017 than in 2012. The increase for the 'other' fraction was also particularly high at 61%. The hard plastics, glass and paper/cardboard fractions increased by 49%, 39% and 12% respectively, while the mass of the metals fraction decreased by 3% and that of organic waste decreased significantly by 35%.

4.4.1.2 Comparisons by volume for each fraction

It was possible to compare the volumes, in cubic metres, for each fraction which was landfilled in 2012 and 2017, by taking the data pertaining to the composition of HSW which was generated by the characterisation study of 2012 and performing the same analysis which is described in section 4.3 to arrive at the figures for the study of 2017.



	Hard Plastics	Plastic Wrap/Packaging	Metal	Glass	Paper/Cardboard	Organics	Others
2012	50862.43	103664.39	12089.16	12316.38	94442.82	82000.80	24956.88
2017	90077.46	174621.70	10084.88	14538.63	147539.61	53532.56	36097.11

Figure 4.9: Comparative breakdown of the volumes of the seven main HSW fractions in cubic metres per annum which were landfilled according to the data from the characterisation studies of 2012 and 2017

The hard plastics fraction registered the largest volumetric increase of 77% from 2012 to 2017, while that of the plastic wrap/packaging fraction increased by 68%. The volumes of the paper/cardboard, other and glass fractions increased by 56%, 45% and 18% respectively, while the overall volume of the organic waste fraction decreased by 35% and that of the metals fraction decreased by 17%.

4.4.1.3 Overall summary and statistical significance of changes from 2012 to 2017

Statistical analyses were performed to determine whether or not the changes which had been identified were statistically significant. Table 4.6 summarises the findings which are covered in subsections 4.4.1.1 and 4.4.1.2 and also includes the p-values which were calculated for each change. If the p-value is less than 0.05, the difference is considered to be statistically significant.

Table 4.6: Summary of temporal changes and corresponding statistical analyses

Fraction	Change over time (2012 to 2017)			
	Mass	**p-value**	**Volume**	**p-value**
Hard plastics	+49%	**p<0.01**	+77%	**p<0.01**
Plastic wrap/packaging	+81%	**p<0.01**	+68%	**p<0.01**
Metal	-3%	**p<0.01**	-17%	**p<0.01**
Glass	+39%	p=0.89	+18%	**p=0.01**
Paper/cardboard	+12%	**p=0.02**	+56%	**p<0.01**
Organic waste	-35%	**p<0.01**	-35%	**p<0.01**
Other	+61%	**p=0.01**	+45%	**p<0.01**

It can be seen in Table 4.6 that all changes over time were found to be statistically significant, with p-values of less than 0.05, except for the increase in mass over time for the glass fraction. Please refer to Appendix 2.1 for graphical representations of these findings in the form of LsMeans graphs.

4.4.2 Overall comparison of waste streams generated by each individual area in 2012 and 2017

Figure 4.10 depicts the percentage changes in the masses of the overall waste streams in each individual area which was surveyed. Appendix 2.2 contains a tabular summary of the findings which are discussed in this sub-section.

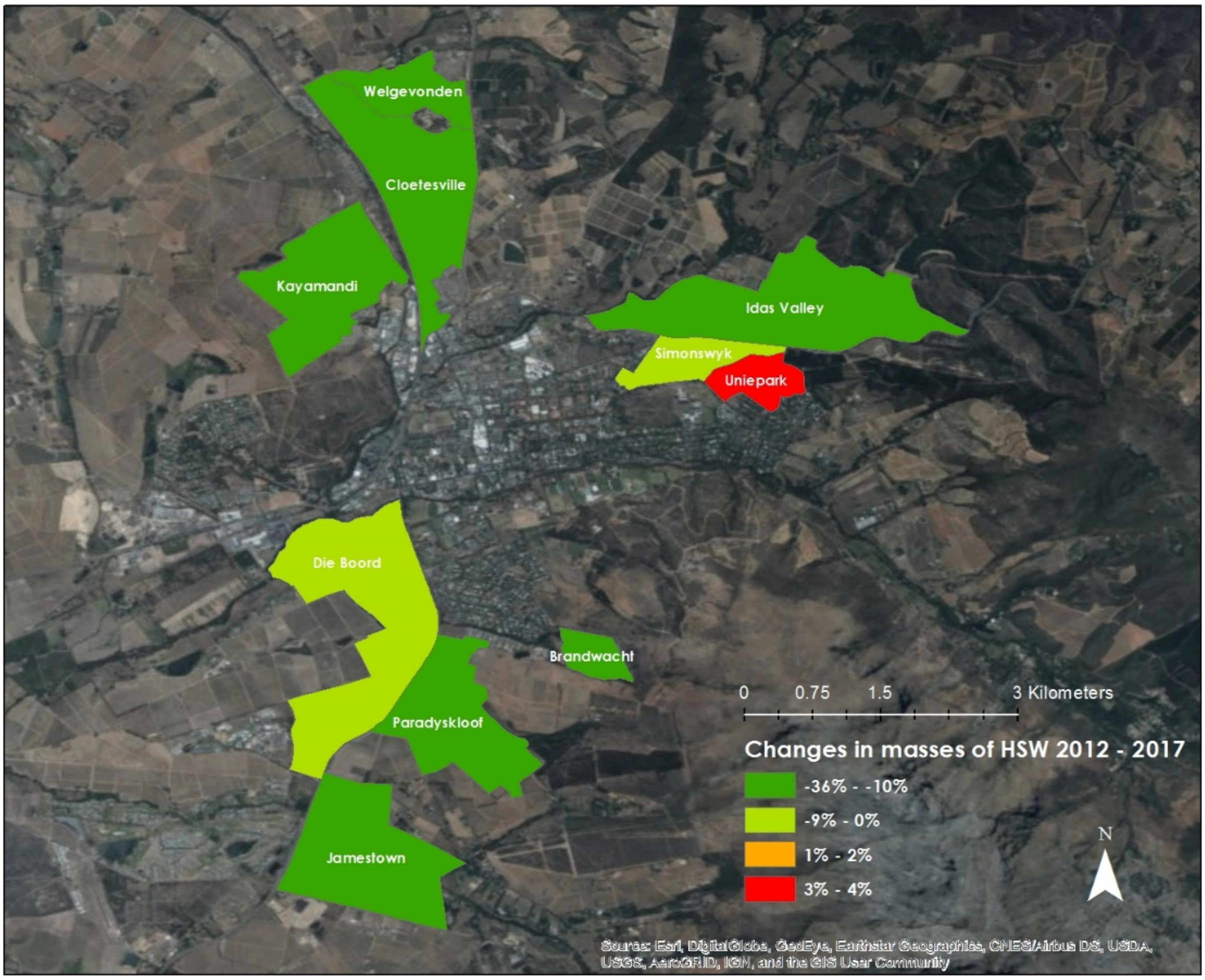


Figure 4.10: Overall percentage changes in the waste streams of individual areas over time by mass

It was found that the average masses of HSW which households disposed of had decreased in all areas which were surveyed, with decreases ranging from 7% to 36%, with the exception of Uniepark, where the mass of HSW which was consigned to landfill had increased by 4%.

Figure 4.11 depicts the percentage changes in volumes of the overall waste streams which were generated in each individual area.

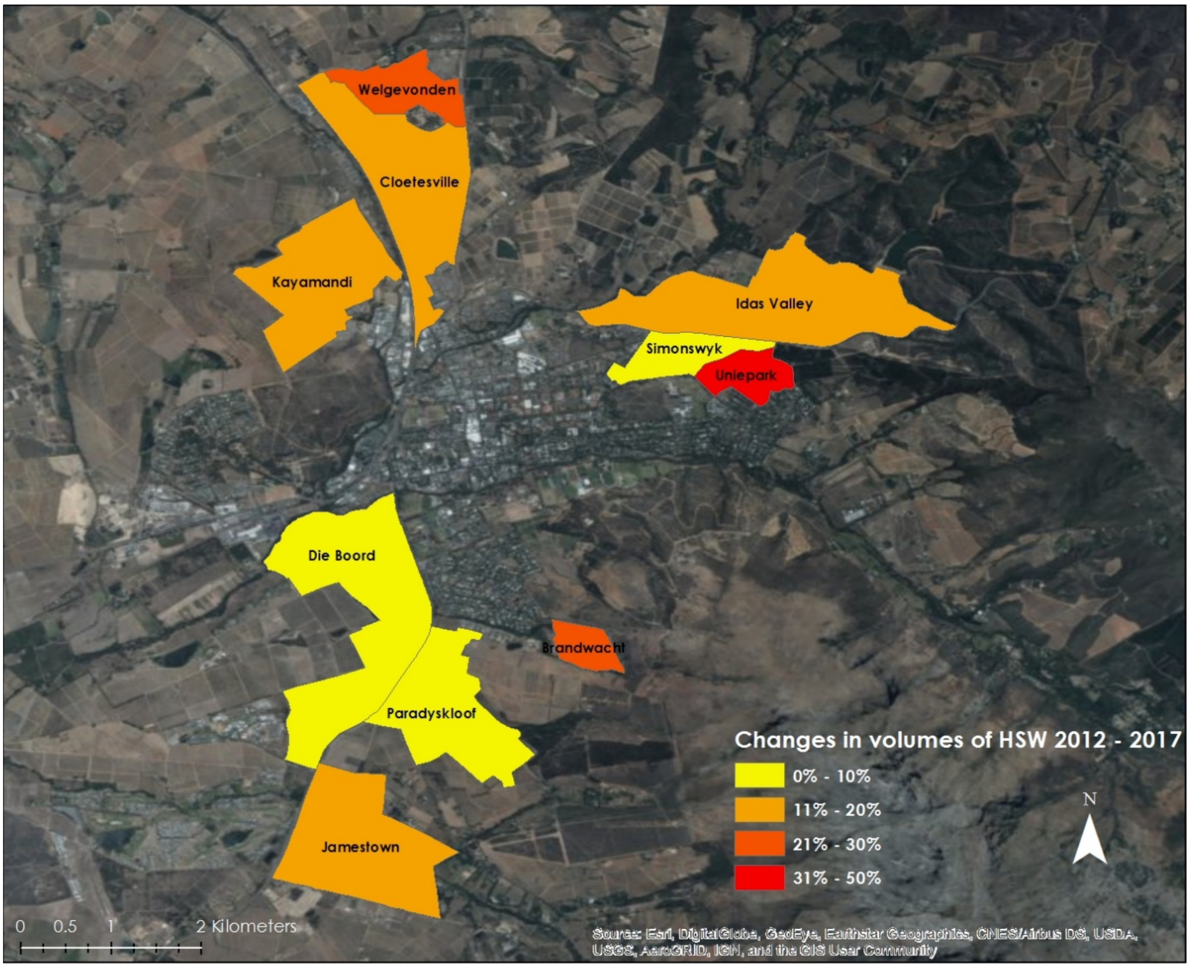


Figure 4.11: Overall percentage changes in the waste streams of individual areas over time by volume

Although the average volumes of HSW which each household disposed of were found to have increased in all areas, the rate of change in Uniepark was particularly high, in that the average volume per black bag which was disposed of had increased by 50%.

4.4.3 Changes in individual waste fractions in individual areas surveyed

This section is devoted to a detailed discussion of the changes which have been observed with respect to each specific fraction of the waste streams which are generated in each area. The findings are presented graphically in maps of the areas which were surveyed, which reflect the changes which have been observed from 2012 to 2017. Appendix 2.3 contains a tabular summary of these findings.

4.4.3.1 Hard plastics

Figure 4.12 depicts the percentage changes in the masses of hard plastics in each area which was surveyed during the characterisation studies of 2012 and 2017.

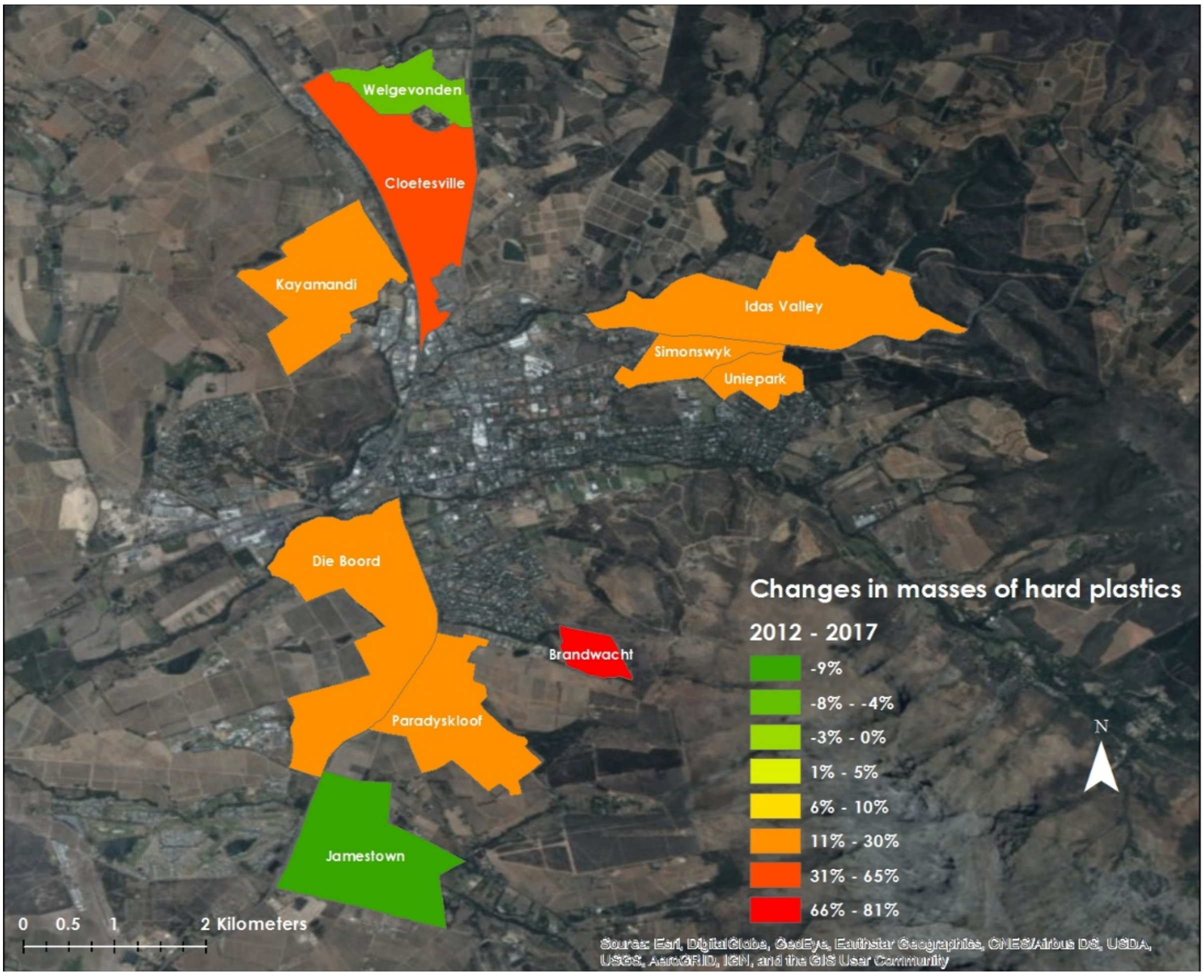


Figure 4.12: Percentage changes in masses of hard plastics in the waste streams of individual areas over time

While Jamestown and Welgevonden disposed of reduced masses of hard plastics which were destined to be used as landfill in 2017 by comparison with 2012, an increase of 81% was found for Brandwacht, an increase which was nonetheless not statistically significant (p=0.19). By contrast, statistical analyses revealed that the 65% increase in the disposal of hard plastics which was calculated for Cloetesville represented a statistically significant change (p=0.01).

Figure 4.13 depicts the percentage changes in the volumes of hard plastics which were generated in each area which was surveyed during the characterisation studies of 2012 and 2017.

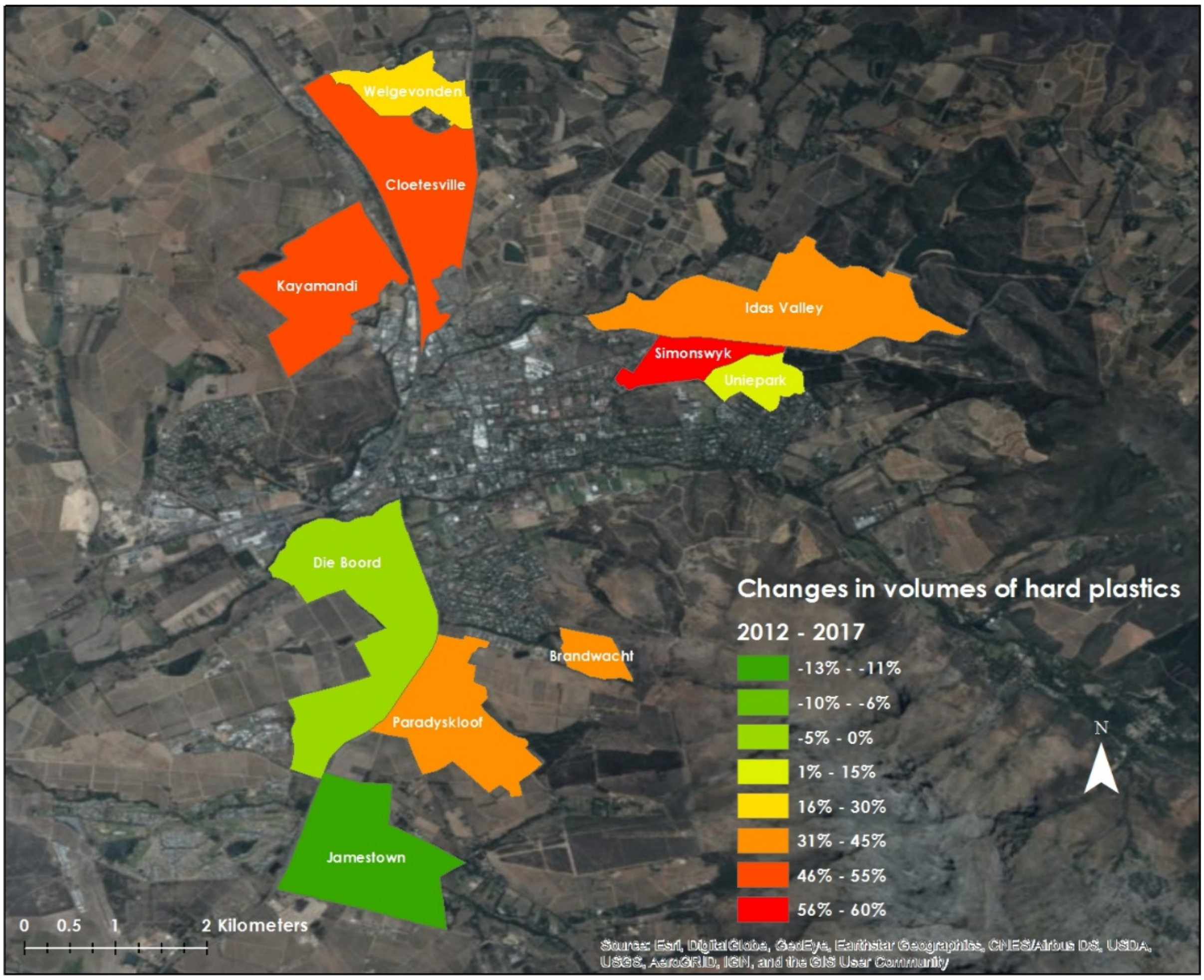


Figure 4.13: Percentage changes in volumes of hard plastics in the waste streams of individual areas over time

While Jamestown and Die Boord disposed of lower volumes of hard plastics in black bags which were destined for landfill in 2017 than in 2012, the volumes for Kayamandi, Cloetesville and Simonswyk had increased. Although In the case of Simonswyk the change was not statistically significant (p=0.09), the p-values for Kayamandi (p=0.02) and Cloetesville (p=0.02) denoted statistically significant changes with respect to volumes of hard plastics.

4.4.3.3 Plastic wrap/packaging

Figure 4.14 depicts the percentage changes in masses for the plastic wrap/packaging fractions of the HSW streams which were generated in the areas which were surveyed in the characterisation studies of 2012 and 2017.

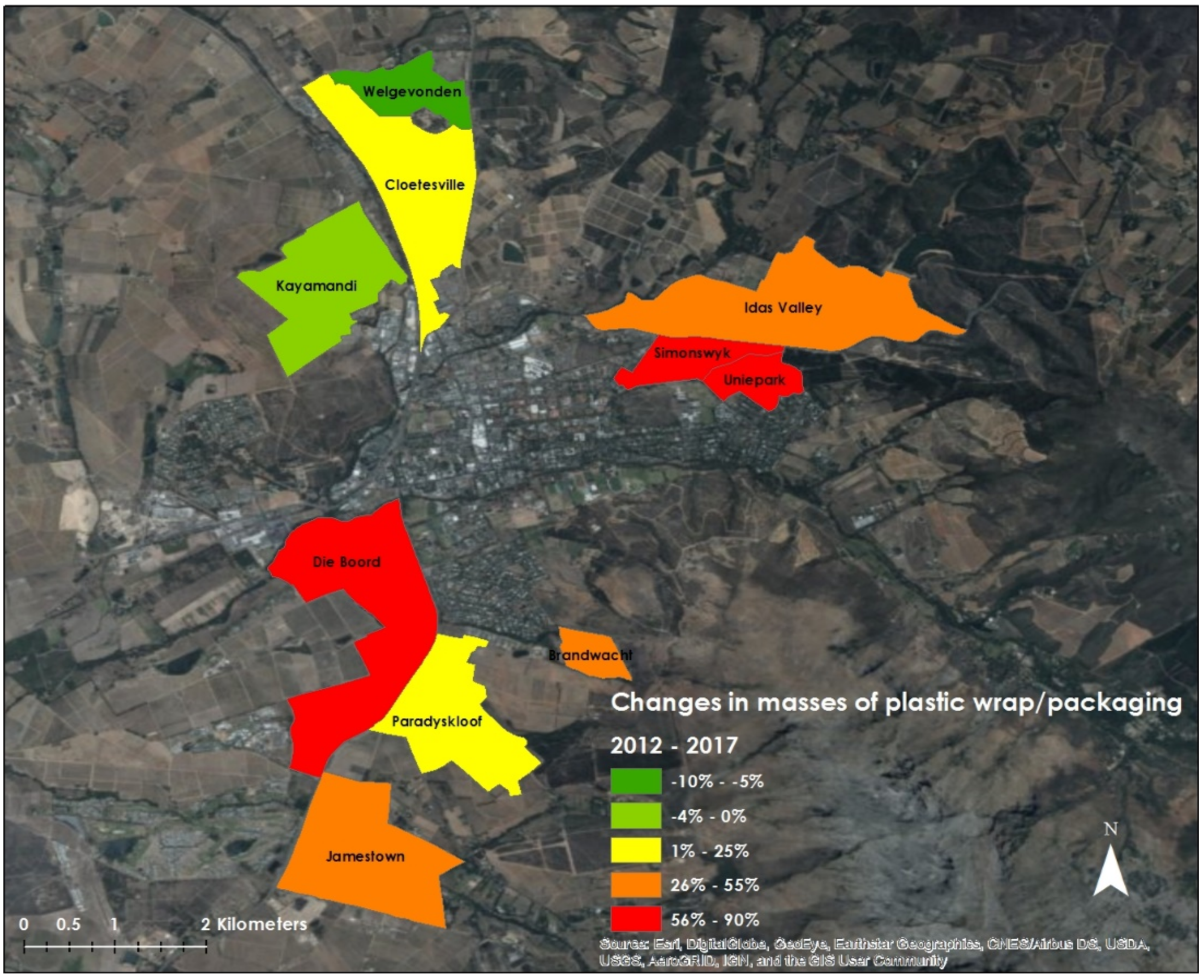


Figure 4.14: Percentage changes in masses of the plastic wrap/packaging fractions of the waste streams of individual areas over time

Although the masses of the plastic wrap/packaging fraction which Kayamandi and Welgevonden disposed of decreased from 2012 to 2017, the changes were not statistically significant, as the p-values which were calculated were 0.33 and 0.62 respectively. By contrast, the p-values which were calculated for the increases of up to 90% which were found for Die Boord ($p=0.01$), Simonswyk ($p=0.01$) and Uniepark ($p<0.01$) all reflected statistically significant changes.

Figure 4.15 depicts the percentage changes by volume for the plastic wrap/packaging fractions of the HSW streams which were generated in the areas which were surveyed in the characterisation studies of 2012 and 2017.

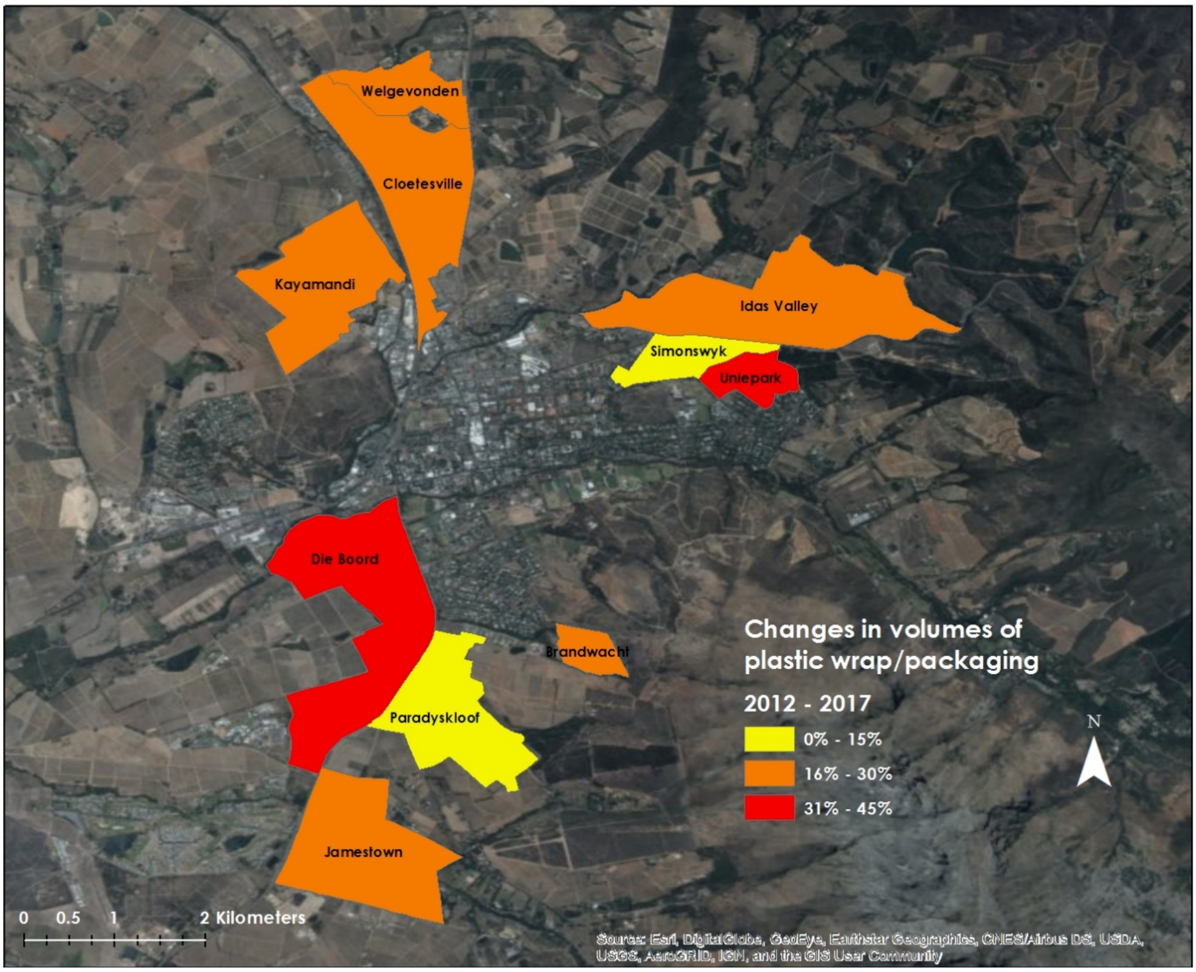


Figure 4.15: Percentage changes in volumes of the plastic wrap/packaging fractions of the waste streams of individual areas over time

The changes were statistically significant for all areas, apart from Paradyskloof ($p=0.23$). Jamestown and Die Boord disposed of significantly less plastic wrap/packaging by volume in 2017 than in 2012, as the p-values for both were <0.01. By contrast, Kayamandi ($p<0.01$), Cloetesville ($p<0.01$) and Simonswyk ($p=0.05$) were found to be disposing of much more of this fraction by volume than in 2012, with all changes yielding statistically significant p-values.

4.4.3.4 Metals

The changes in masses of metals in represented visually by Figure 4.16 below.

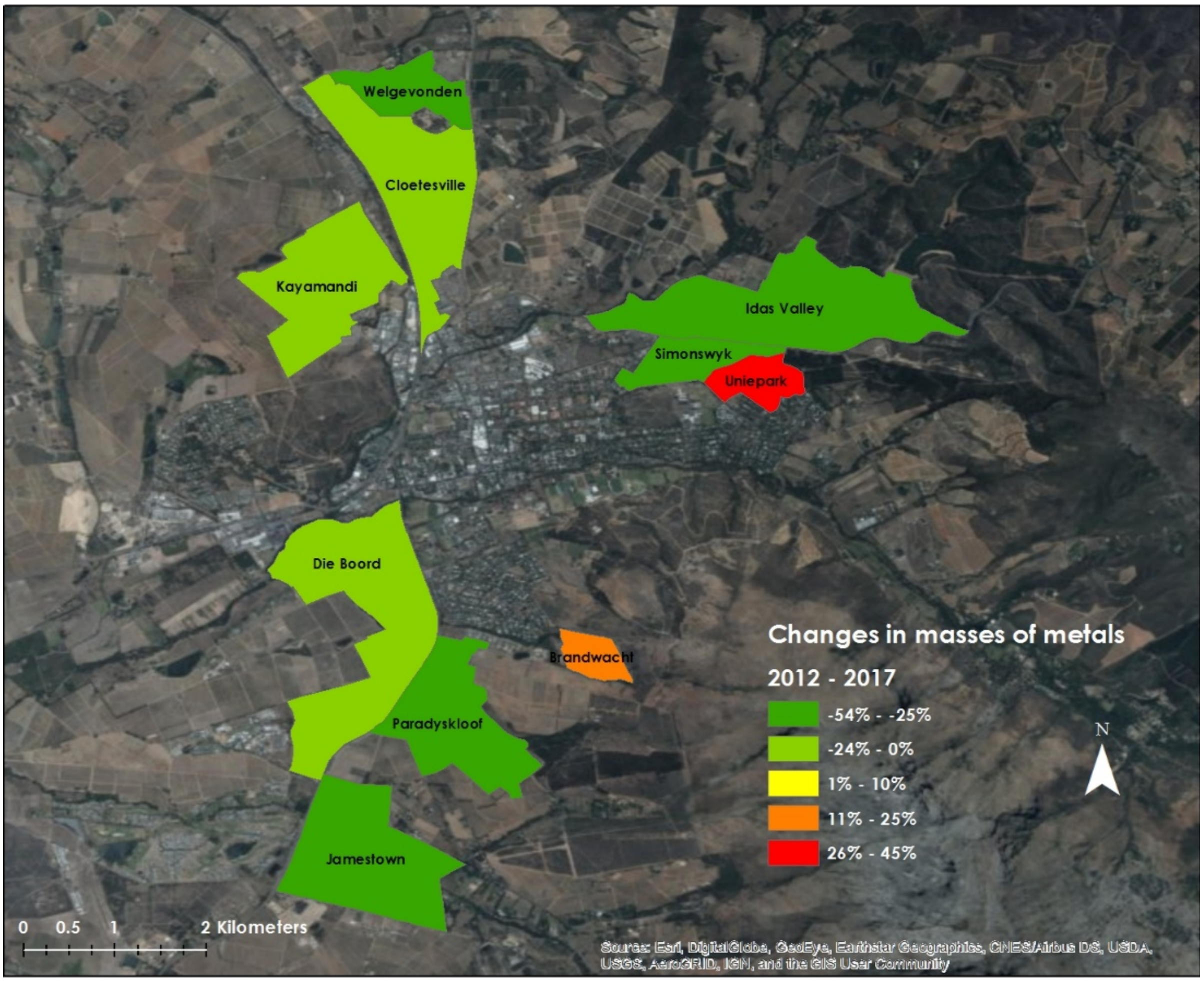


Figure 4.16: Percentage changes in masses of the metals fractions of the waste streams of individual areas over time

All areas, apart from Brandwacht and Uniepark, were found to be discarding lower masses of metals in their residual waste streams than in 2012. Although the increases in mass of 17% for Brandwacht and 43% for Uniepark were found not to be statistically significant with p-values of 0.99 and 0.54 respectively, the decreases of 54% for Welgevonden, 38% for Jamestown and 36% for Idas Valley's 36% were all found to be strongly significant, as they yielded very low p-values of $p<0.01$.

Figure 4.17 shows the changes over time in the volumes of metals discarded.

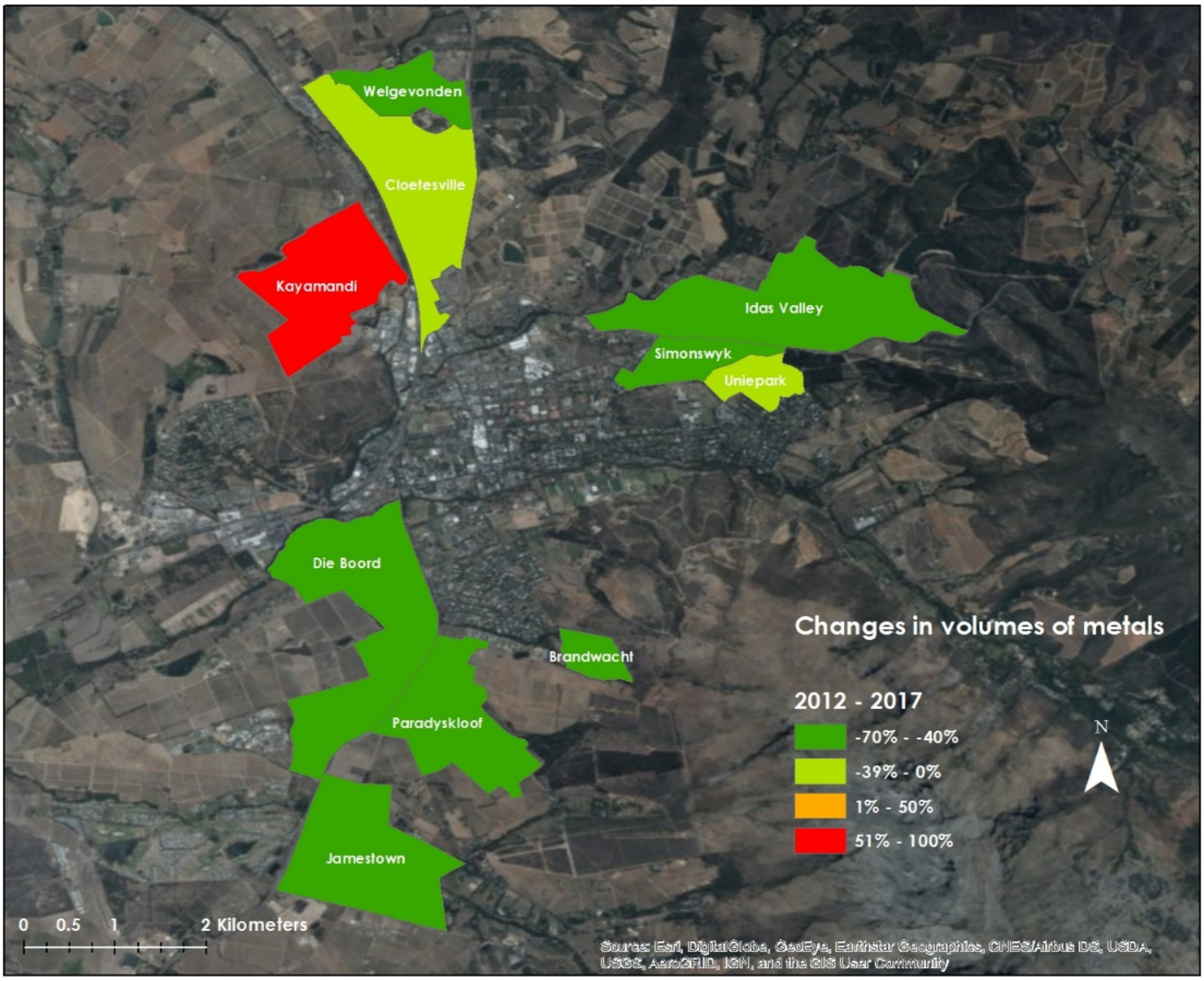


Figure 4.17: Percentage changes in volumes of the metals fractions of the waste streams of individual areas over time

Statistically significant calculations emerged for the decreases in the volumes of metals which were disposed of by most areas, including Jamestown ($p<0.01$), Idas Valley ($p<0.01$), Die Boord ($p=0.02$), Welgevonden ($p<0.01$), Paradyskloof ($p<0.01$) and Simonswyk ($p<0.01$). Conversely, an apparent anomaly was identified in the case of Kayamandi. Despite an increase of 100% in the volumes of the metals fraction which were disposed of in the area, a statistically insignificant p-value of 0.31 was calculated.

4.4.3.5 Glass

Figure 4.18 depicts the percentage changes in the masses of glass in each area which was surveyed during the characterisation studies of 2012 and 2017.

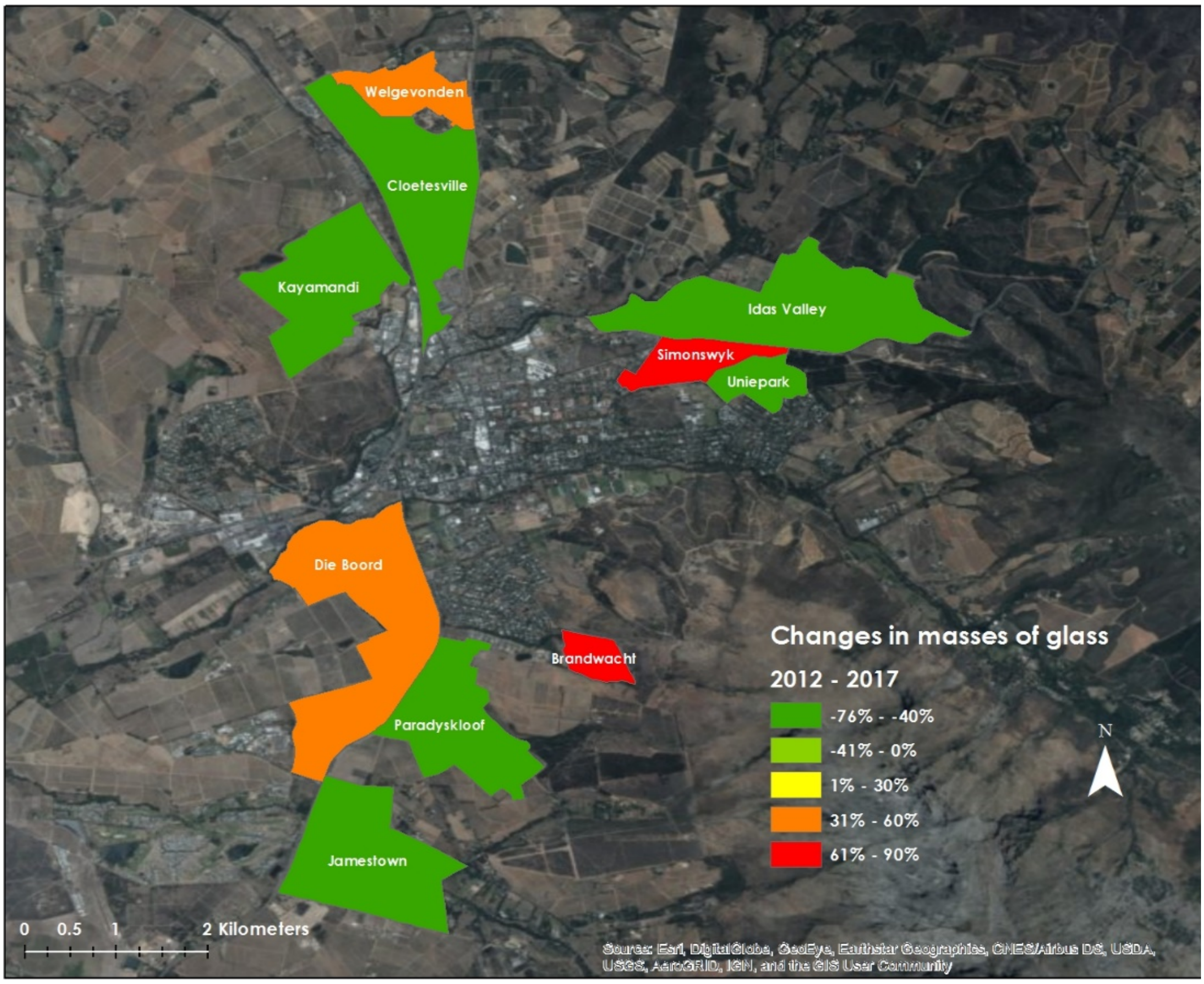


Figure 4.18: Percentage changes in masses of glass in the waste streams of individual areas over time

Jamestown exhibited the largest decrease by mass of 76% in the disposal of the glass fraction of the HSW stream from 2012 to 2017, a change which was found to be statistically significant ($p<0.01$). Conversely, the masses for Simonswyk and Brandwacht had increased by 87% and 64% respectively ($p>0.05$ in both cases). The 52% increase for Die Boord was also found to be statistically significant ($p=0.03$).

Figure 4.19 shows the changes over time in the volumes of glass discarded.

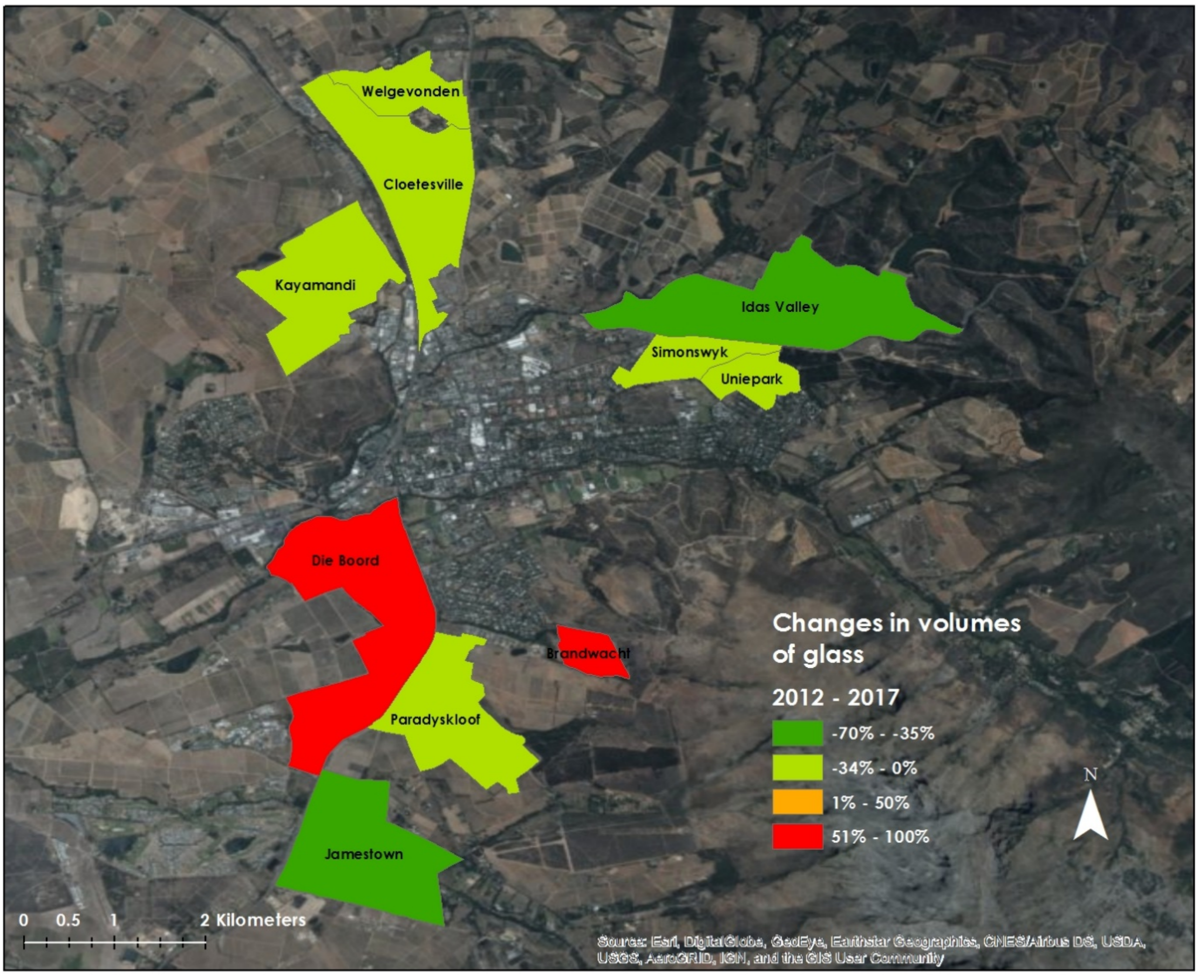


Figure 4.19: Percentage changes in volumes of glass in the waste streams of individual areas over time

The volumes of glass in the waste streams in several areas did not change at all, with 0% increases being found for Kayamandi, Welgevonden, Paradyskloof and Simonswyk. By contrast, a reduction of 67% for Jamestown appeared to be strongly statistically significant owing to a particularly low p-value ($p<0.01$), by comparison with the 100% increases for Die Boord ($p=0.34$) and Brandwacht, which were found not to be statistically significant, owing to p-values of 0.34 and 0.28 respectively.

4.4.3.6 Paper/cardboard

Figure 4.20 depicts the percentage changes in the masses of paper/cardboard in each area which was surveyed during the characterisation studies of 2012 and 2017.

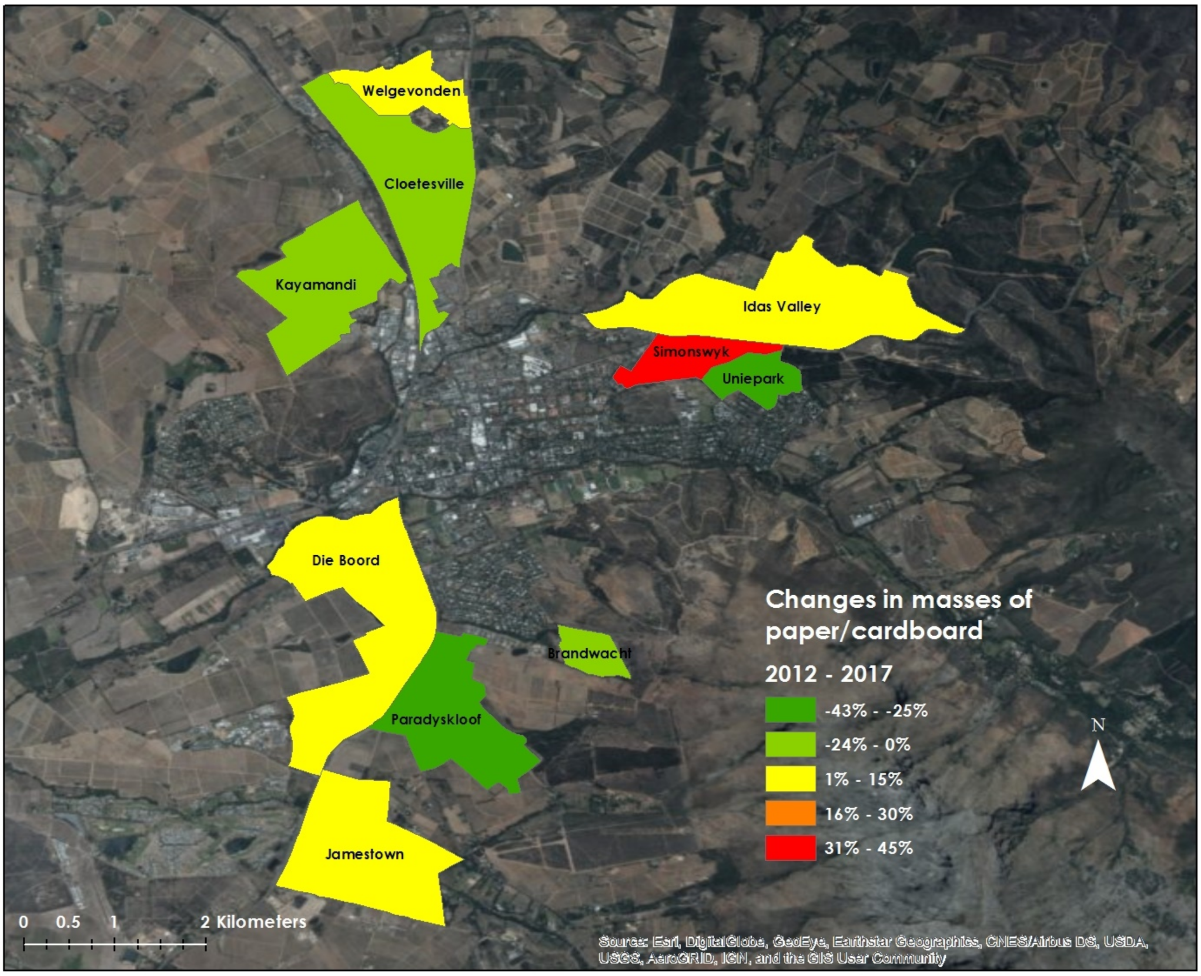


Figure 4.20: Percentage changes in masses of the paper/cardboard fractions in the waste streams of individual areas over time

Statistically significant changes from 2012 to 2017 with respect to masses of the paper/cardboard fractions were found in the waste streams of only two areas. A p-value of 0.01 was calculated for a decrease of 42% in Simonswyk and an even lower p-value of <0.01 was calculated for a decrease of 32% in Paradyskloof. Other large changes, such as a decrease of 43% in Uniepark, which yielded a p-value of 0.65, were found not to be statistically significant.

Figure 4.21 shows the changes over time in the volumes of paper/cardboard discarded.

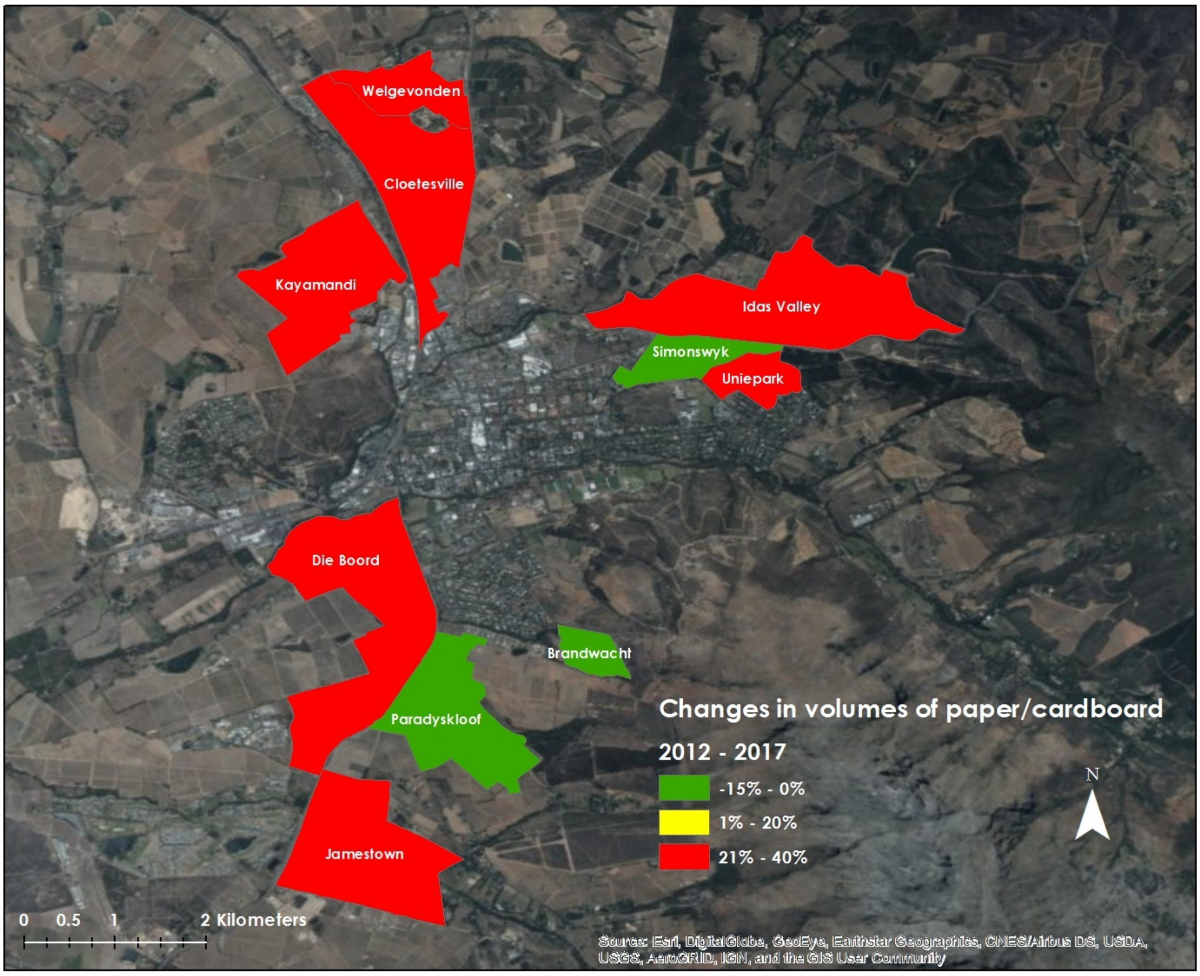


Figure 4.21: Percentage changes in volumes of the paper/cardboard in the waste streams of individual areas over time

Only in Simonswyk was a small decrease of15% found in the volume of the paper/cardboard fraction in the waste stream. The change yielded a statistically insignificant p-value of p=0.42. Although the volumes for Paradyskloof and Brandwacht remained constant, all of the other areas had increases of at least 21%. Statistically significant p-values were calculated for the increased volumes in Cloetesville (p=0.02), Kayamandi (p=0.01), Idas Valley (p<0.01) and Welgevonden (p=0.03).

4.4.3.7 Organic waste

Figure 4.22 depicts the percentage changes in the masses of organic waste in each area which was surveyed during the characterisation studies of 2012 and 2017.

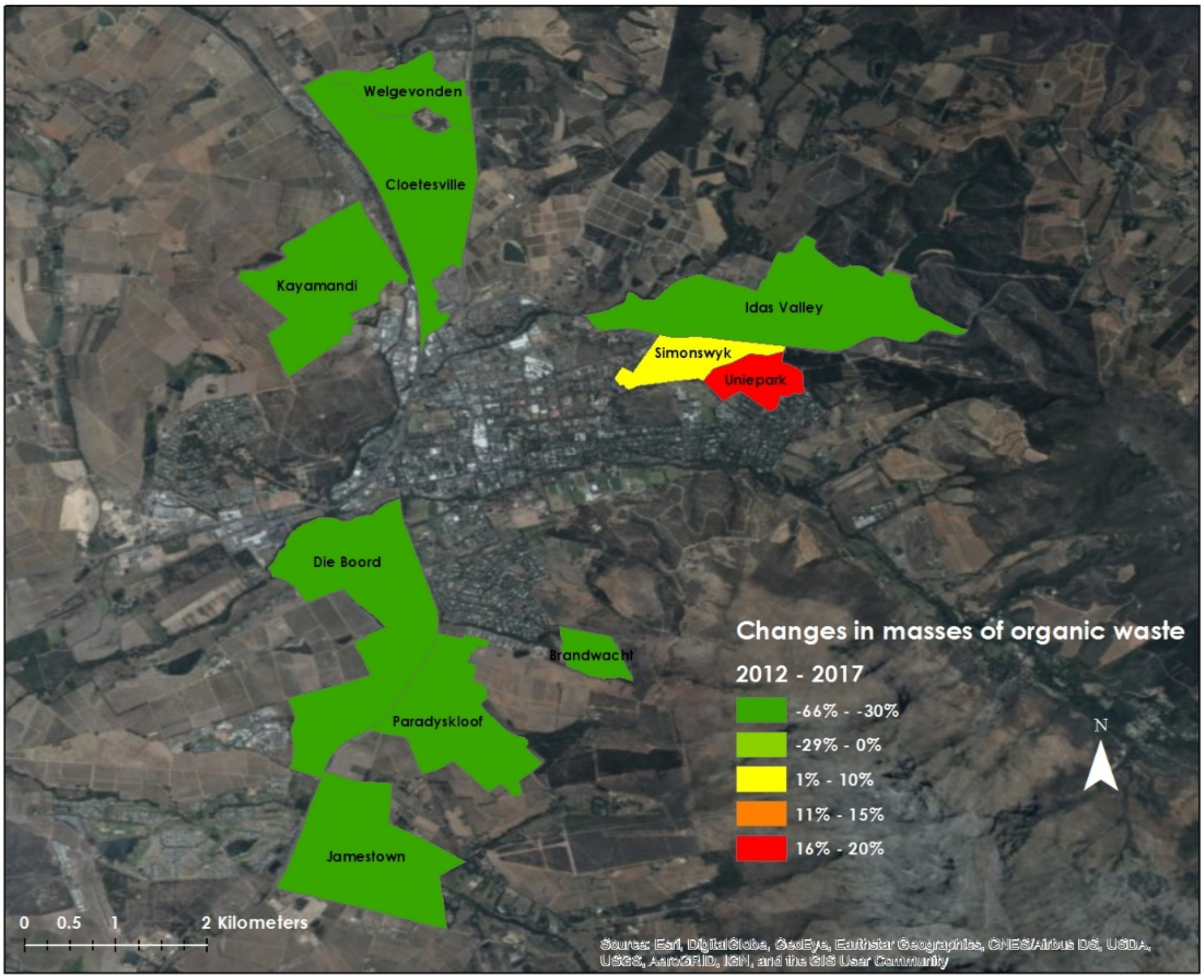


Figure 4.22: Percentage changes in masses of organic waste in the waste streams of individual areas over time

Particularly low p-values of less than 0.01 indicated that the changes in the masses of organic waste in the waste streams of Cloetesville, Jamestown, Kayamandi, Idas Valley, Welgevonden and Paradyskloof were strongly statistically significant. In these areas, the masses of organic waste had decreased by from 34% to 65%. By contrast, although the organic waste fraction of the waste stream of Uniepark had increased by an average of 18% since 2012, the p-value of 0.27 suggested that the change should not be considered to be a statistically significant one.

Figure 4.23 shows the changes over time in the volumes of organic waste discarded.

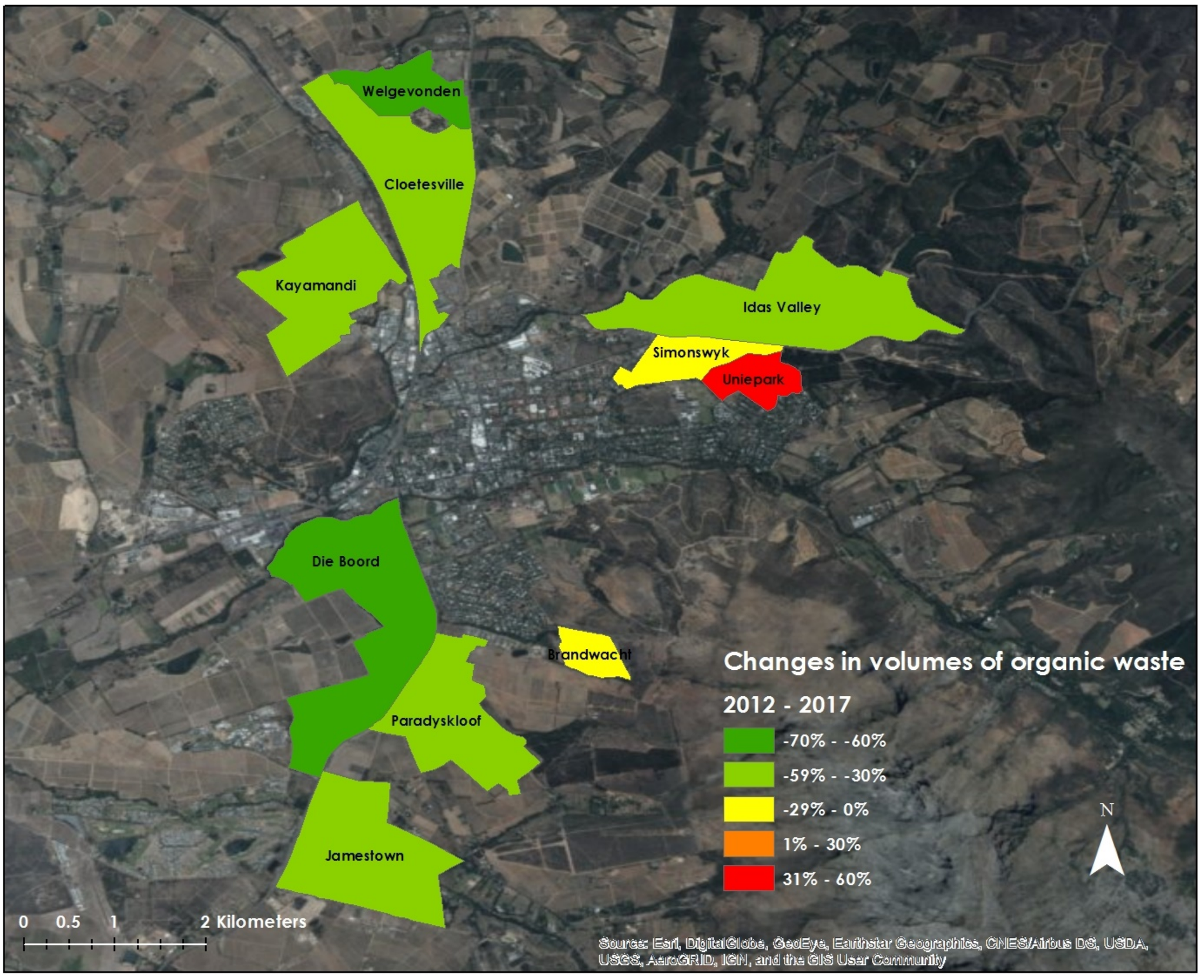


Figure 4.23: Percentage changes in volumes of organic waste in the waste streams of individual areas over time

The p-values of less than 0.01 which were calculated for the changes in volumes of organic waste in the waste streams of Cloetesville, Jamestown, Kayamandi, Idas Valley, Welgevonden, Paradyskloof and Die Boord were all strongly statistically significant. In these areas, the volumes of organic waste in their waste streams had decreased by from 33% to 67% since 2012. Although the organic waste fraction of the waste stream of Uniepark had increased by an average of 60% during the same period, the p-value of 0.14 suggested that the change should not be considered to be statistically significant.

4.4.3.8 The ‘other’ waste fraction

Figure 4.24 depicts the percentage changes in the masses of the ‘other’ waste fraction in each area which was surveyed during the characterisation studies of 2012 and 2017.

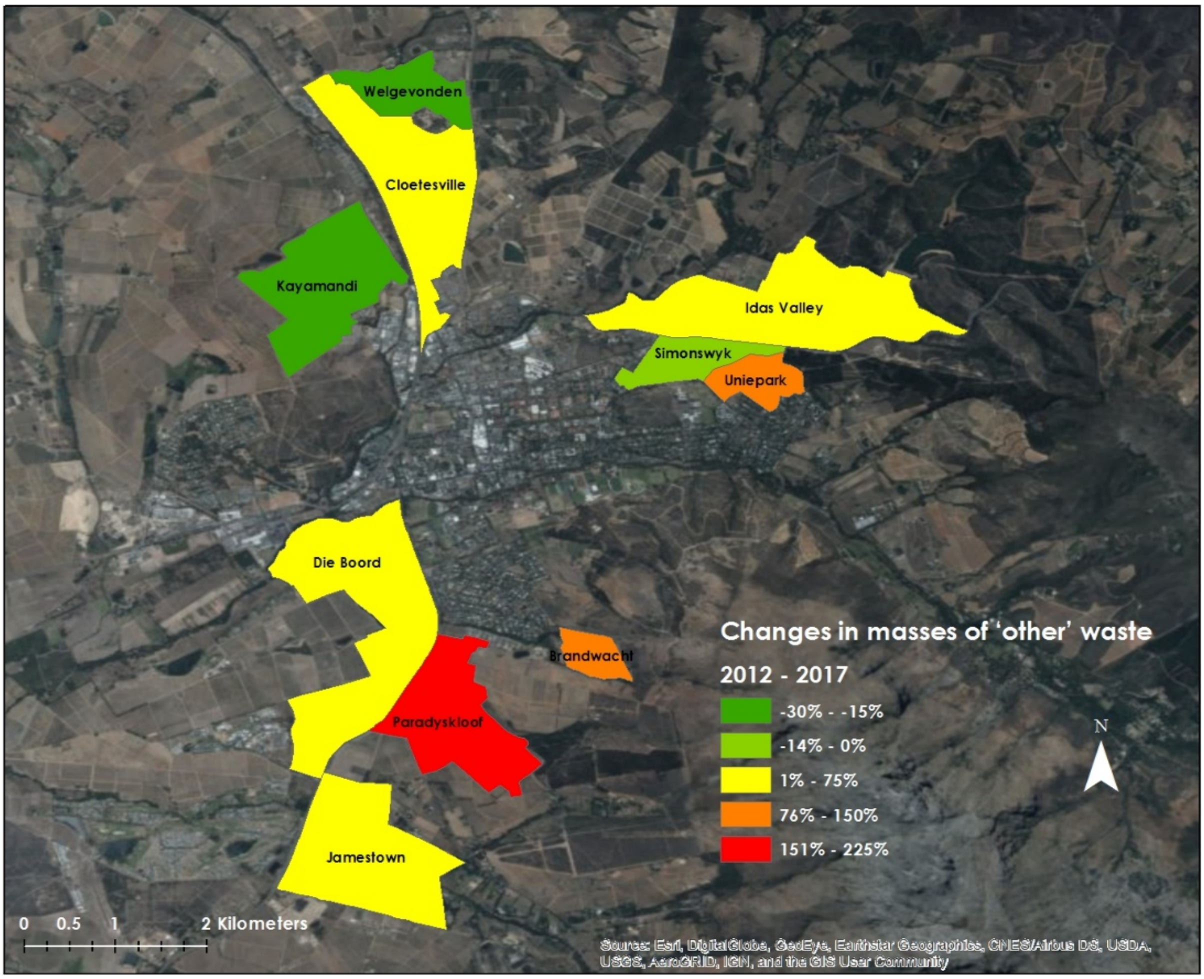


Figure 4.24: Percentage changes in masses of HSW classified as ‘other’ in the waste streams of individual areas over time

The largest spatial and temporal changes with respect to both mass and volume among the waste fractions were found in the ‘other‘ waste streams of the areas which were surveyed. Although there have been great increases in this waste fraction in several areas from 2012 and 2017, the calculation of p-values to determine the statistical significance of the increases appeared to generate some paradoxical findings. While the increase by mass of the fraction in Paradyskloof was 218% and generated a statistically significant p-value of 0.02, the 150% increase in Brandwacht yielded a statistically insignificant p-value of 0.30 for an increase which would be difficult to ignore. By contrast, the decrease of 30% in the mass of the fraction which was found for Kayamandi yielded a statistically significant p-value of 0.01.

Figure 4.25Figure 4.23 shows the changes over time in the volumes of the ‘other’ waste fraction discarded.

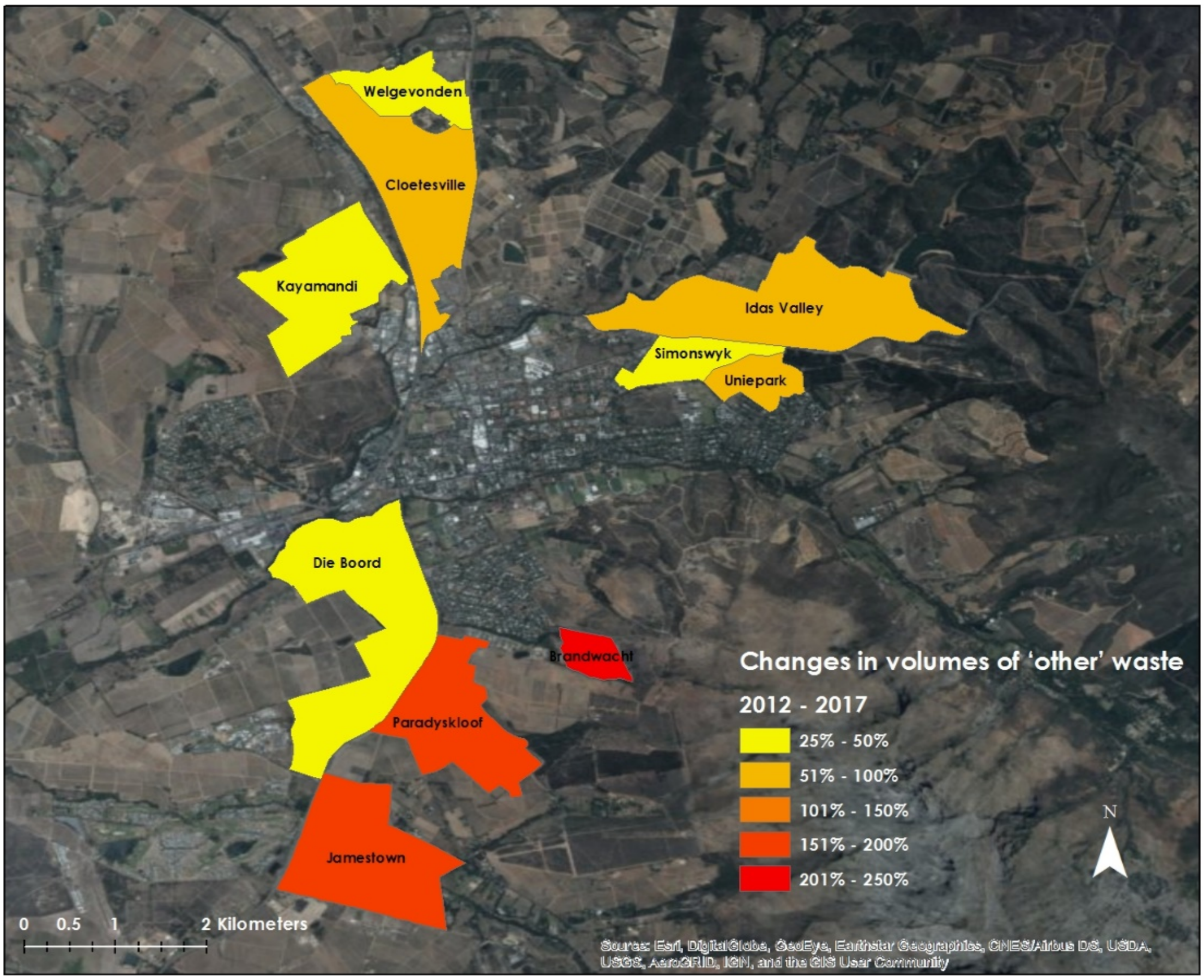


Figure 4.25: Percentage changes in volumes of HSW classified as 'other' in the waste streams of individual areas over time

It was found that volumes of the 'other' waste fraction had increased in all of the areas which were surveyed. The highest percentage increases also yielded statistically significant p-values: Brandwacht (+250%, p=0.05); Paradyskloof (+200%, p<0.01) and Jamestown (+200%; p<0.01). In addition, the increases of 100% for Uniepark (p=0.04), 80% for Cloetesville (p=0.01), 75% for Idas Valley (p=0.04) and 50% for Welgevonden (p=0.05) were all also statistically significant.

4.5 CORRELATIONS OF QUANTITIES AND COMPOSITIONS OF WASTE WITH RELEVANT ECONOMIC PARAMETERS FOR HOUSEHOLDS

Spearman's rank correlation coefficient was used to determine the statistical dependence between the rankings of waste generation rates and the influence which household income, household size and household density were found to have on them, according to the data which was obtained from the characterisation studies of both 2012 and 2017.

Table 4.7 summarises the economic parameters for each area which was surveyed.

Table 4.7: Economic parameters for each area surveyed

Area		Average household income*	Average household size	Density**
1.	Cloetesville	ZAR 103 694.18	5	1814
2.	Jamestown	ZAR 237 215.13	5	371
3.	Uniepark	ZAR 264 707.95	3	336
4.	Kayamandi	ZAR 42 607.51	3	6082
5.	Idas Valley	ZAR 144 302.30	4	1014
6.	Die Boord	ZAR 435 138.35	3	480
7.	Welgevonden	ZAR 398 359.20	2	1949
8.	Paradyskloof	ZAR 519 016.71	3	462
9.	Brandwacht	ZAR 592 431.93	3	265
10.	Simonswyk	ZAR 264 707.95	3	276

* Annual income; Statistics South Africa (2012)

** Number of households per km^2

Table 4.8 provides a concise summary of the strengths of correlations in relation to the values which are calculated for the coefficient *R*.

Table 4.8: Strengths of correlations

Strengths of correlations	
Value of coefficient *R* (positive or negative)	**Significance**
0.00 to 0.19	A very weak correlation
0.20 to 0.39	A weak correlation
0.40 to 0.69	A moderate correlation
0.70 to 0.89	A strong correlation
0.90 to 1.00	A very strong correlation

Source: Fowler, Cohen & Jarvis (2009)

4.5.1 Household income

It was found that there were negative correlations between household income and the waste fractions which are listed in Table 4.9.

Table 4.9: Comparison of correlations between household income and waste generation rates per fraction

	2012		2017	
Fraction	**R_s ***	**p-value**	**R_s**	**p-value**
Hard plastics (mass)	-0.65	0.01	-0.51	0.01
Hard plastics (volume)	-0.59	0.03	-0.56	<0.01
Plastic wrap/packaging (mass)	-0.63	0.02	-0.43	0.04
Metals (mass)	-0.68	<0.01	-0.47	0.02
Metals (volume)	-	-	-0.53	0.01
Paper/cardboard (mass)	-	-	-0.55	<0.01
Paper/cardboard (volume)	-	-	-0.50	0.01
Other (mass)	-0.54	0.04	-0.42	0.05
Other (volume)	-	-	-0.41	0.05

* R_S = value of coefficient Source: Author

The negative correlations imply that the rates at which the quantities of the fractions which are listed in the table are generated by the households increase inversely in relation to household income, in that low incomes are associated with high rates of generation.

4.5.2 Household size

Table 4.10: Correlations between household size and waste generation rates per fraction

	2012		2017	
Fraction	**R_s ***	**p-value**	**R_s**	**p-value**
Glass (volume)	-	-	-0.44	0.03
Paper/cardboard (mass)	-	-	0.52	0.01
Other (mass)	-	-	0.52	0.01
Other (volume)	-	-	0.61	<0.01

* R_S = value of coefficient Source: Author

While the negative correlation for volumes of glass implies that volumes increase inversely as sizes of households diminish, the positive correlations imply that masses of the paper/cardboard fraction and both masses and volumes of the 'other' fraction increase as the sizes of households increase.

4.5.3 Household density

Table 4.11: Correlations between household density and waste generation rates per fraction

	2012		2017	
Fraction	**R_s ***	**p-value**	**R_s**	**p-value**
Plastic wrap/packaging (mass)	0.61	0.02	-	-
Metals (mass)	0.55	0.04	-	-

* R_S = value of coefficient Source: Author

The positive correlations in Table 4.11 imply that the masses of the plastic wrap/packaging and metals fractions which are generated increase as the densities of households increase.

4.6 CONCLUSION

The vast number of statistical significant results obtained through this study are highly encouraging. However, the interpretation of these results, which is the next step, are crucial, and is done in the next chapter, Chapter 5.

CHAPTER 5: DISCUSSION OF THE FINDINGS

5.1 INTRODUCTION

The following section will discuss the findings set out in the previous chapter in more detail. This section will first discuss the similarities and differences between the 2012 and 2017 waste streams. Thereafter the correlation of the findings with the various economic parameters will be discussed.

5.2 COMPARISONS BETWEEN THE COMPOSITIONS OF WASTE STREAMS ACCORDING TO THE DATA WHICH WAS OBTAINED FROM THE CHARACTERISATION STUDIES OF 2012 AND 2017

A comparison of the waste characterisation data of 2012 and 2017 suggests that the average weekly quantities for the disposal of heavy waste fractions with high density, such as organic waste, have decreased over time, while those of light waste fractions with low density, such as the plastic wrap/packaging fraction, have increased to a significantly greater degree. Accordingly, the findings suggest that the waste stream has become lighter but more bulky over time. Large increases in volumes of HSW have a direct bearing upon the numbers of households from which individual municipal refuse collection vehicles are able to collect waste before they are required to empty their loads at the DVLS, as the capacity of the vehicles is highly dependent upon their compaction equipment and the compactibility of waste materials. This overall finding underscores the necessity of capturing data pertaining to both mass and volume in any waste characterisation study.

As it has been emphasised, the data concerning volumes of waste refers to uncompacted materials. The value of data pertaining to uncompacted volumes of waste which is generated should not be underestimated, particularly for the purpose of determining the amounts of space which are required at diversion facilities to store unprocessed waste materials, which by their very nature are uncompacted. In order to obtain a sufficiently comprehensive understanding of the changes which occur with respect to the composition of waste streams over time, changes in the behaviour of consumers need to be taken adequately into account. Behavioural changes become evident when the items which comprise individual waste fractions are broken down. Accordingly, in this chapter each waste stream is discussed individually and reasons for changes which are observed are postulated, in relation to both consumer behaviour and changes in methods of packaging.

5.2.1 Hard plastics

Since 2012, the mass of hard plastics which has been landfilled has increased by 49% and the volume by 77%. This finding indicates that considerably more items which are made from hard plastics are being bought, used, and discarded by households in 2017 than in 2012. It was determined that a total of 3 244.59 tons of hard plastics, which would have consumed an estimated 90 077.46 cubic metres of landfill airspace if the waste had been left uncompacted, was generated in 2017 in the area which falls under the jurisdiction of the Stellenbosch Local Municipality. This waste bypassed the separation at source programme and was landfilled.

During the waste characterisation study of 2017, it was observed that the hard plastics fraction of the waste stream was made up mainly of packaging materials and post-consumer waste including PET plastic bottles which had contained soft drinks or water, polystyrene (PS) thermoform packaging such as clamshell fruit punnets, high-density polyethylene (HDPE) bottles which had held milk, non-carbonated drinks or cleaning products, polypropylene (PP) tubs and lids and a wide range of smaller polystyrene items, such as disposable cutlery, pen barrels and cases for compact discs or digital versatile discs. It was observed that thermoform food packaging was more commonly found in samples which had been collected from higher income than from lower income areas. This finding could stem from a tendency for thermoform packaging to contain either luxury items such as fresh herbs or ready-made on-the-go foods such as sandwiches and wraps, which are usually sold at relatively high prices. Items which were particularly common in the waste streams of low-income areas and notably absent from those of their high-income counterparts were empty hard plastic wine bottles in various sizes which range from 500 ml to 5 litres. Wines which are packaged in these containers sell at low prices and often have a high alcohol content.

At the time of the conducting of the waste characterisation study, the Western Cape in South Africa was in the middle of the worst drought which it had suffered in more than a century (Van Dam, 2017). The Western Cape Government declared a state of emergency owing to the severity of the drought. In turn, the Stellenbosch Local Municipality instituted level 4 water restrictions, which limited households to a maximum of 100 litres of municipal drinking water per person per day (Stellenbosch 2017). In order to alleviate pressure on this scarce commodity, many consumers started buying and consuming bottled drinking water instead of tap water. In addition, some consumers elected to drink bottled water as they were concerned about the quality of tap water, owing to the levels of dams being at a record low (Leitch 2017). This change in the purchasing patterns of consumers had a direct effect upon the quantities of solid waste which were generated in Stellenbosch, as prodigious numbers of PET water bottles inflated the volumes of hard plastics waste streams, particularly 5-litre bottles. Although the sudden proliferation of large PET plastic bottles would have contributed to increased masses of hard plastics in local waste streams, the contributions to uncompacted volumes would have been considerably greater, as the uncompacted density of 5-litre water bottles is very low.

5.2.2 Plastic wrap/packaging

Since 2012, the mass of the plastic wrap/packaging fraction of the waste stream which is landfilled has increased by 81%, while the volume has increased by 68%. Consequently, it is evident that the numbers of items which are packaged in plastic wrap which are purchased have risen dramatically from 2012 to 2017. The plastic wrap/packaging fraction of the waste stream which was generated and landfilled in the Stellenbosch municipal area amounted to a total of 4 699.07 tons. It bypassed the separation at source programme and would have consumed 174 621.70 cubic metres of landfill airspace if it had been left uncompacted.

The items which comprised the bulk of the plastic wrap/packaging fraction were mainly low-density polyethylene-based (LDPE), such as grocery bags, frozen food and milk sachets, small plastic bags which had contained products such as bread, cling film and, to a lesser extent, bubble wrap. The waste fraction was also augmented by a number of categories of materials and products, such as polypropylene-based biscuit wrappers and plastic sheets, non-recyclable layered or multi-material mixed polymer packaging of crisps, popcorn and chocolate and multi-layer materials which are used to package long-life products such as cheese and processed meats.

The large volumes of multi-layer crisp packets, wrappers from individually packaged sweets and PP biscuit wrappers which low-income areas generated could not be disregarded. Many of the products which are packaged in this manner are sold for as little as from ZAR 0.10 to ZAR 1.00 and their wrappers make significant contributions to the plastic wrap/packaging fractions of the waste streams of low-income areas. As no single factor could be identified as being primarily responsible for the dramatic increases in the quantities in the plastic wrap/packaging fractions of the waste streams of the areas which were surveyed over 5-year period, it was concluded that changes in the packaging of many consumer items could provide a plausible reason. There can be little doubt that significantly increased quantities of basic items reach households in a form of plastic wrap packaging.

5.2.3 Metals

Since 2012, the mass of metals which is landfilled has decreased by 3% and the volume by 17%. It was determined that a total of 920.75 tons of metals, which would have consumed an estimated 10 084.88 cubic metres of landfill airspace if it had been left uncompacted, were generated in the Stellenbosch municipal area. As this recyclable waste was not processed by the separation at source programme, it was landfilled.

It was found that the metals fraction comprised mainly cans which had contained foods and beverages and metal bottle caps. While approximately 60% of all of the aluminium cans which had contained beverages in the low- and medium-income areas had contained alcoholic beverages, the figure was of the order of only 40% in the high-income areas. It was evident that consumers in higher-income areas displayed a preference for alcoholic beverages in bottles, particularly in the cases of beverages such as beer and cider. Canned food containers were more prevalent in the waste streams of low-income areas by comparison with those of medium- and high- income areas. In many cases, canned foods such as vegetables are more affordable in South Africa than their fresh counterparts, which could account for the preponderance of food cans in the waste streams of low-income areas. In addition, as canned foods do not require to be kept in refrigerators, they meet the needs of lower-income households which lack refrigerators and freezers. The statistical analysis revealed that there was a statistically significant negative correlation between household income and the amount of metal waste which is generated in an area, with respect to both mass ($p=0.02$) and volume ($p=0.01$). This finding served to confirm that the lower the incomes of households are, the more metal waste they are likely to generate.

The metals category of the waste stream also included significant quantities of ad hoc metal items, many of which stemmed from renovation or decoration projects, such as nails, screws and metal offcuts. It was also considered to be noteworthy that many single cutlery items such as stainless-steel forks, knives and spoons were found in the waste stream and sorted into the metals fraction. As they were not damaged, it was presumed that the items had accidentally became waste materials, during the clearing of plates after meals.

Among the reasons which were proposed for the decrease in landfilling of the metals fractions of waste streams were the emergence and increasing role of the informal waste sector, in the form of street waste pickers, a general increase in participating in recycling activities and changing packaging trends. Street waste pickers are active in the town area of Stellenbosch and sort through wheelie bins which contain residual waste early in the mornings, before the refuse compactor vehicles do their rounds. There are several buy-back centres in Stellenbosch which accept a number of different types of recyclables, including steel and aluminium cans. It has been widely noted by residents of Stellenbosch that there has been an increase in street waste picking activities in town, an observation which is frequently expressed in the form of complaints to the municipality by residents who are concerned for their safety and privacy (Utter Rubbish 2016).

Although an increase in participation in recycling activities by residents could also make a significant contribution to decreasing the tonnages of metals which are landfilled, it could be anticipated that the decrease would be accompanied by similar decreases in the landfilling of other recyclable fractions. As the trend is not evident, it would be reasonable to assume that any decrease in the landfilling of metals owing to increased participation in recycling by residents could result from greater general awareness of the recyclability of metals than of other fractions. While there may be a measure of uncertainty or confusion concerning whether other waste fractions can be recycled, the public has frequently been requested not to dispose of metal items such as cans in waste which is destined to be landfilled.

The decrease in landfilled metal waste could also be influenced by changes in packaging occurring. It is likely that many items which were packaged in cans in 2012 are now packaged in other materials. Tomato paste provides an apt example. Although it was available to consumers in canned form only for several decades, it is now available in cans, glass jars, multi-layered sachets and also PET or PP containers which are sealed with LDPE liners.

5.2.4 Glass

Since 2012, the mass of glass which is landfilled has increased by 39% and the volume by 18%. It emerged from the findings that a total of 4 261.71 tons of glass, which would have consumed 14 538.63 cubic metres of landfill airspace if it had been left uncompacted, was generated in the Stellenbosch municipal area in 2017. The glass was not processed by the separation at source programme and, instead, was landfilled.

The findings revealed that the glass fraction comprised mainly jars which had contained food products and bottles which had contained either beverages or condiments. It was estimated that approximately 80% of the bottles which had contained beverages had contained alcoholic beverages and 20% soft drinks. Differences with respect to the quality, prices and types of alcoholic beverages which were purchased and consumed in the different income areas were clearly discernible during the conducting of the waste characterisation study. In the low-income areas and some of the medium-income areas, bottles which had contained inexpensive distilled liquors such as vodka and rum were disposed of more commonly than in the high-income areas. Conversely, bottles which had contained triple-distilled whiskies and vodkas and expensive cognacs were common in the glass fractions of the waste streams of high-income areas. The high-income areas also disposed of large quantities of glass bottles which had contained red, white or sparkling wines, a sub-fraction which was almost completely absent from the waste streams of low-income areas.

Smaller glass items, such as empty bottles which had held medications, perfumes or deodorants and broken glass items such as windowpanes and wine glasses were also found. The statistical analysis produced a statistically significant negative correlation between the volumes of glass which are generated and the sizes of households ($p = 0.03$). As this finding suggests that smaller households generate more glass than larger ones, additional research would need to be conducted to determine the factors which are responsible for the apparent phenomenon. It could be suggested that smaller households tend to purchase more foods which are sold in glass jars, which are usually long-life products which spoil less rapidly than fresh produce.

The increase in the quantity of glass which is landfilled could also be compounded by the expressed unwillingness of many residents to continue to dispose of glass through the separation at source programme. Several incidents have been reported to the municipality in which glass items which have been placed in clear bags have shattered outside of homes upon collection (Haider 2018, pers com). The clear bags into which recyclables are placed are placed alongside wheelie bins which contain refuse, for collection and transporting by the recycling contractor to the Small Materials Recovery Facility for further sorting. The integrity of the bags tends to deteriorate throughout the day when they are exposed to sunny weather conditions, particularly during summer months. When the clear bags are collected, some are prone to tearing, especially when they are heavy or overloaded, and glass items shatter outside the homes of the residents who have placed the bags on the kerbs for collection. As the collection crews are usually not equipped to remove the broken glass in these instances, the responsibility falls to the members of the households concerned, much to their dismay. In one instance, a glass bottle from a bag which tore while it was being hefted onto a collection vehicle broke the sunroof of a vehicle which was parked outside a home (Pretorius 2018, pers com).

5.2.5 Paper/cardboard

Since 2012, the mass of paper and cardboard which is landfilled has increased by 12% and the volume by 56%. In 2017 the Stellenbosch municipal area generated 6 015.19 tons of paper and cardboard, which would have consumed 147 539.61 cubic metres of landfill airspace if it had been left uncompacted, none of which was processed by the separation at source programme. The statistical analysis produced a positive correlation between the sizes of households and the disposal of waste which fall into the paper/cardboard fraction.

Office paper, newspapers, magazines, brown paper bags and take-away food cartons, thin cardboard inserts which are used in the packaging of products and cigarette boxes all comprised prominent components of the waste fraction. In the lower income areas, cigarette boxes were found which bore many of the different brands which are associated with the illegal cigarette trade. According to Mathe (2018), illegal brands of cigarettes are sold for prices which are as much as 73% lower than those of their legal counterparts. By contrast, boxes from well-known legal cigarette brands were found in the paper/cardboard fractions of the waste streams of medium- and high-income areas.

The items which were found to account for the bulk of the paper/cardboard fractions of waste streams were boxes which had contained dry foods and corrugated and non-corrugated cardboard boxes. Large numbers of the cardboard boxes could be easily identified as the packaging which had contained items which had been ordered from popular online shopping portals such as Takealot, UCOOK and Superbalist. The widespread adoption of online shopping could account for some of the increase which was observed and the packaging was found more frequently in the paper/cardboard fractions of the waste streams of high-income areas than in those of medium- to low-income areas.

5.2.6 Organic waste

Since 2012, the mass and volume of organic waste which is landfilled has decreased by 35%. Organic waste is automatically landfilled, as it is not processed by the separation at source programme. A total of 13 440.42 tons of organic waste, which would have consumed an estimated 36 097.11 cubic metres of landfill airspace if it had been left uncompacted, was generated and landfilled in the Stellenbosch municipal area in 2017.

The organic waste consisted mainly of kitchen waste, in the form of inedible portions of vegetable and animal-derived foods, such as vegetable peelings, seeds, pips and bones, which are usually classified as unavoidable food waste, and also scraps and leftovers. In some cases, rotten, mouldy or expired foods were also disposed of. In addition, this fraction also contained garden waste, such as branches, leaves and grass cuttings.

It was found that households in lower-income areas disposed of mainly starch-based foods such as potato peels or leftover rice or maize meal. Evidence of wastage of food was hardly ever observed in the waste streams of lower-income areas, whereas in higher-income areas food which had passed its expiry date was frequently discarded. In one case, fruit was discarded for no apparent reason and in another, a whole roasted chicken was consigned to a black bag for disposal. Potato peels were not usually observed in the organic waste fractions of the waste streams of higher-income areas. Although additional research would need to be conducted to explain this finding, potential reasons could include the possibility that potatoes may be consumed less frequently in high-income areas than they are in low-income areas or that potatoes tend to be cooked and consumed unpeeled in high-income areas for health reasons. Inedible portions of fruit and vegetables were evident in the food waste streams of higher-income areas.

Although masses and volumes of organic waste have declined from 2012 to 2017, organic waste remains the largest waste fraction households dispose of in black bags. The Western Cape Government has imposed a ban upon the disposal of organic waste by landfill, which is due to come into effect in 2026, and set a target for achieving a 50% diversion by 2021 (ORASA 2018). Consequently, there is an urgent need for the Stellenbosch Local Municipality to formulate and implement an effective plan for diverting organic waste. As the municipality has already begun to implement a shredding and chipping programme for garden waste, which contributes towards achieving the target for diverting organic waste, it is imperative to implement a complementary programme to facilitate the diversion of food waste. In addition, the separation of food waste from the rest of the residual waste stream would undoubtedly increase the downstream recyclability of other waste fractions, particularly waste fractions such as the paper/cardboard fraction, which is highly susceptible to absorbing moisture and subsequent contamination by organic waste.

The decline in the quantity of organic waste disposed of could be attributed, in part, to changing habits and practices of consumers, such as the growing popularity of home composting and worm farms and increased efforts by households to reduce the amounts of food waste which they generate. In addition, after the waste characterisation study of 2012 the municipality repealed the tariff which had been instituted for disposing of garden waste at the DVLS (Haider 2019 pers com). This initiative encouraged households to make use of the free service, as opposed to renting an additional wheelie bin from the municipality to dispose of their garden waste. The Western Cape drought most likely also contributed to lower garden waste generation rates.

5.2.7 Other waste

Since 2012, the mass of the waste which falls into the ‘other’ fraction which has been landfilled without being processed by the separation at source programme has increased by 61% and the volume by 45%. The sharp increases are indicative of the increasingly varied and complex composition of the waste stream. It was determined that the landfilled ‘other’ waste which was generated in the Stellenbosch municipal area in 2017 amounted to a total of 6 252.02 tons, which would have consumed an estimated 36 097.11 cubic metres of landfill airspace if it had been left uncompacted.

When the changes in the volumes of the ‘other’ fraction were subjected to statistical analysis, it emerged that the increases were statistically significant in seven of the ten areas which were surveyed. The volumes for Jamestown and Paradyskloof both increased by 200% ($p<0.01$ for both). The increase for Brandwacht was greater still, at 250%. The mass of the ‘other’ waste fraction which was generated by Paradyskloof increased by 218% ($p=0.02$). These increases represented the largest changes which were observed for all areas and waste fractions during the entire study.

Of all of the waste fractions, the ‘other’ fraction is by far the most varied. The ‘residual other’ sub-fraction made the largest contribution to this waste stream by mass and the items which comprised it were extremely diverse. Sanitary waste represented the largest segment of the sub-fraction, which included disposable baby and adult diapers and feminine hygiene products. Disposable baby diapers were found to make the largest contribution to the residual waste fractions of both Jamestown and Paradyskloof and made correspondingly significant contributions to the large increases with respect to both mass and volume in ‘other’ waste which both areas generated. As the sub-fractions which are discussed in this section were not used during the characterisation study of 2012, it is not possible to make comparisons between the compositions of the ‘other’ waste streams in 2012 and 2017. Nonetheless, the observations from the study of which are recorded in this section are considered to be highly relevant to the objectives of both studies.

Broken ceramic-based items, such as cups, saucers, plates and bowls, household cleaning items such as sponges, rags, mops and broom heads and vacuum cleaner bags, dust, sweepings, cigarette butts, pieces of leather and rubber offcuts, synthetic and natural hair and pharmaceutical waste, in the form of unused medications, were all characterised as residual ‘other’ waste. Many miscellaneous items which could be assumed to have resulted from the clearing out of garages also contributed to the waste fraction and were noted to make the largest single contribution to the ‘other’ waste stream of Brandwacht.

The ‘tissues’ sub-fraction, which accounted for 24% of the ‘other’ fraction by mass and 28% by volume consisted of used and discarded facial tissues, toilet paper, serviettes, wet wipes and paper kitchen towels.

By volume the extruded polystyrene waste fraction dominated the waste stream at 32%, as a consequence of the inherent bulky properties of the material. It is designed to provide the maximum amount of protection possible to the products which are packaged in it. It was found in the waste stream in a wide range of different forms, including foam takeaway coffee cups, packing foam, seed trays and punnet trays which had contained meat or vegetables, with the latter being the most common.

Although the textiles sub-fraction contributed very little to the overall waste stream with respect to either mass or volume, it was still considered to be noteworthy that more clothes were discarded in the lower-income areas than in the higher-income ones. Although further studies would be required to obtain an in-depth understanding of this phenomenon, it is postulated that lower-income households are likely to purchase inexpensive clothes, which are often made from poor quality materials. As the clothes often do not have long lifespans, they are highly likely to be discarded. Another likely contributory factor could be the tendency for residents of higher-income areas not to dispose of clothing or shoes by discarding them and placing them in refuse bags for removal, but rather to donate them to charities or individual people who are able to make use of them. Consequently, the items are likely to reach the ends of their lifespans in lower-income households, which eventually dispose of them.

Although electronic waste and household hazardous waste are two sub-fractions which are usually present in relatively small quantities in waste streams, they can potentially have adverse environmental consequences if they are not treated correctly. Items which were observed to comprise the electronic waste sub-fraction during the characterisation study of 2017 included charger cables and small household appliances which were no longer functional, such as kettles, toasters, blenders and items of electronic hardware. Items which could be classified as household hazardous waste included AAA, AA, 9V and rechargeable batteries, fluorescent tubes and light bulbs, unused pesticides and insecticides, used and discarded motor oil, motor oil containers and sharps, such as discarded insulin syringes. None of these items should be disposed of by means of normal waste disposal systems.

5.3 CORRELATIONS OF QUANTITIES AND COMPOSITIONS OF WASTE WITH RELEVANT ECONOMIC PARAMETERS FOR HOUSEHOLDS

The most surprising and significant result which was obtained from the correlation analysis was the negative correlation between household income and the quantities of waste which falls into the hard plastics, metals, paper/cardboard and ‘other’ waste fractions, by both mass and volume, and of the plastic wrap/packaging fraction by mass which households generate. The finding is a surprising one, as it is widely perceived that more affluent areas dispose of more waste than less affluent ones (Al-Khatib et al. 2010; Aziz et al. 2011; Edjabou et al. 2012; Ozcan et al. 2016 Kaza et al. 2018). Conversely, this finding does not actually indicate that the quantities of the waste fractions which have been enumerated increase as household income diminishes. The actual import of the finding is that as household income diminishes, the quantities of these waste fractions are disposed of as a component of the residual portion of the waste stream, owing to not making use of the separation at source programme.

Accordingly, the findings are quite logical, because nine of the ten overlapping areas which were surveyed during the characterisation studies of 2012 and 2017 have access to the separation at source programme. The exception is Kayamandi, the area which has the lowest average household income. Consequently, it could be anticipated that large quantities of waste would be disposed of in Kayamandi, because the entire waste stream of the area was studied during the waste characterisation studies, as opposed to only portions of the waste streams of the other nine areas. For this reason, it is recommended that in order to make an accurate assessment of the waste stream of the area by comparison with those of the other areas, in future studies not only the residual portion of the waste streams of areas should be sampled and characterised, but also the materials which are processed by the separation at source programme, in order to obtain an accurate understanding of the entire waste streams of areas.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

This final chapter will conclude this thesis by summarising the study by means of reflecting on the study objectives; highlighting some recommendations for future waste characterisation studies; elaborating on waste characterisation reporting protocols and calculating potential waste diversion from landfill figures for the study area.

6.2 SUMMARY OF FINDINGS

This study took the form of a characterisation of the residual portion of the HSW fraction which was generated in the Stellenbosch municipal area in 2017. A total of 3 419 samples were collected from twenty-three different areas. These samples were sorted into seven main fractions and further subdivided into eighteen sub-fractions.

The raw data which was obtained from the waste characterisation was analysed to determine the overall waste composition, by both mass and volume. Table 6.1 summarises the waste composition for 2017.

Table 6.1: 2017: Waste composition by mass and volume

Waste fraction		% contribution by mass	% contribution by volume
1.	**Hard plastics**	**8%**	**15%**
2.	**Plastic wrap/packaging**	**12%**	**32%**
3.	**Metals**	**2%**	**2%**
4.	**Glass**	**11%**	**2%**
5.	**Paper/cardboard**	**16%**	**26%**
6.	**Organic waste**	**35%**	**10%**
	6.1 Food waste	78% of 35%	73% of 10%
	6.2 Garden waste	21% of 35%	27% of 10%
	6.3 Leachate	1% of 35%	0% of 10%
7.	**Other**	**16%**	**13%**
	7.1 Tetra Pak cartons	7% of 16%	12% of 13%
	7.2 Household hazardous waste	1% of 16%	0% of 13%
	7.3 Extruded polystyrene	8% of 16%	32% of 13%
	7.4 Tissues	24% of 16%	28% of 13%
	7.5 Ash	13% of 16%	9% of 13%

7.6 Electronic waste	7% of 16%	2% of 13%
7.7 Small furniture items	1% of 16%	0% of 13%
7.8 Maize meal bags	1% of 16%	1% of 13%
7.9 Textile waste	0% of 16%	1% of 13%
7.10 Residual other	38% of 16%	15% of 13%

It was found that organic waste constituted the largest waste fraction by both mass and volume which households disposed of, the plastic wrap/ packaging constituted the largest fraction by uncompacted volume.

The data pertaining to the composition of HSW from the characterisation study of 2017 was compared with the findings of the earlier study of 2012, which had been conducted in the same municipal area. As ten of the twenty-three areas which were surveyed in 2017 overlapped with the areas which were surveyed in 2012, spatial and temporal changes in the composition of HSW were determined for these ten areas, in relation to the seven main waste fractions which had been used in both studies. It emerged from the comparative analysis that the composition of the residual waste portion was becoming lighter in mass but significantly more bulky, which could have severely adverse implications for the rapidly shrinking landfill airspace which is available. Conversely, the compactibility of waste materials could, in turn, also have a great influence on the volumes of waste which can be accommodated in the landfill airspace which is available.

The most pronounced changes over time by mass were a statistically significant 81% increase in the plastic wrap/packaging waste fraction ($p<0.01$) and a statistically significant 35% decrease in the organic waste fraction ($p<0.01$). By contrast, the greatest changes over time with respect to volumes of waste were a statistically significant 45% increase in the 'other' fraction ($p<0.01$) and a statistically significant 17% decrease in the metals fraction ($p<0.01$).

Calculating Spearman's rank correlation coefficient revealed that there was a negative correlation between household income and the quantities of the hard plastics, metals, paper/cardboard and 'other' waste fractions by mass and volume and the plastic wrap/packaging fraction by mass which were generated. This finding could potentially be attributed to the lack of a separation at source programme in the low-income areas in the municipal area. It was also determined that there was a negative correlation between household size and the volumes of glass which were produced.

Accordingly, it is recommended that the separation at source programme should be implemented in all areas which fall under the jurisdiction of the Stellenbosch Local Municipality, in order to maximise the diversion of recyclable waste from being used as landfill. The implementation of the programme in new areas could entail making use of the three-bag system at the outset.

As the findings of this study reveal quite conclusively that the residual portion of the waste stream in the areas which were surveyed is becoming lighter but considerably more bulky, the meagre resources which are available with respect to landfill airspace underscore the necessity of compaction during the transporting and disposal of HSW in the absence of recycling programmes, and also the necessity of characterising waste with respect to both mass and volume.

6.3 REFLECTION ON OBJECTIVES

The first objective aimed to determine the composition of the residual portion of HSW in 2017. Organic waste represented the predominant portion by mass by accounting for 35%, while the paper/cardboard and 'other' fractions each accounted for 16%. The plastic wrap/packaging and glass fractions contributed 12% and 11% respectively, hard plastics 8% and metals 2%. The largest waste fraction of the waste stream by volume was that of the plastic wrap/packaging which comprised 32% of the overall volume, as opposed to only 12% by mass. Although the items which fall into this waste stream are light, collectively they constitute large volumes of waste, particularly if the waste is not compacted, as was the case when the volumes of waste fractions were estimated in this characterisation study. Conversely, while organic waste constituted the largest fraction of the waste stream by mass, by volume it ranked only fifth among the seven fractions and contributed a mere 10% to the overall waste stream. Paper/cardboard (26%) and hard plastics (15%) were the second and third largest fractions with respect to the volumes which they contributed to the waste stream.

The second objective aimed to determine the quantities of the fractions of HSW landfilled each year, according to the data which was obtained in the characterisation study of 2017. Table 4.2 details the approximate mass and volume of each waste fraction generated within the study area, based on the waste composition determined in objective 1. It has been calculated that 38 833.75 tons of HSW, equivalent to 526 491.96 m3 uncompacted HSW was landfilled in 2017 in the study area.

The third objective aimed to compare the findings of the 2012 HSW characterisation study with those of the 2017 study, to determine the spatial and temporal changes which can be observed in overlapping areas. These results were shown in Section 4.4 and further discussed in Section 5.2.

The fourth objective aimed to correlate the quantity and composition of waste with relevant economic parameters for households. These results were shown in Section 4.5 and further discussed in Section 5.3.

6.4 RECOMMENDATIONS FOR FUTURE WASTE CHARACTERISATION STUDIES

The following recommendations are made for future waste characterisation studies which are conducted in the study area:

- A future characterisation study should entail not only collecting data concerning the uncompacted density of each waste fraction, but should also entail determining the compacted density of each. This data would permit accurate assessments to be made of the landfill airspace which could be saved through the implementation of appropriate waste minimisation initiatives.
- It would be beneficial during the conducting of a future study to ask a representative of each household which participates to complete a survey questionnaire to provide basic information concerning their households, such the numbers of members which they comprise and their annual household incomes.

- It is recommended that in future studies, the ‘hard plastics’ and ‘plastic wrap/packaging’ fractions should be replaced with ‘recyclable plastics’ and ‘non-recyclable plastics’ fractions.

- It is almost a truism to maintain that the value of a waste characterisation increases in accordance with the level of detail which is achieved and that the more waste fractions into which samples are divided, the more detailed will be the information which is generated. By contrast, the ultimate aim of a characterisation study is to determine the potential use of each fraction, a consideration which needs to be borne in mind during the planning phases of individual studies.

6.5 REPORTING PROTOCOLS FOR WASTE CHARACTERISATION STUDIES

In the absence of a standardised waste characterisation methodology, every researcher needs to supply at least the following details to enable other researchers to make effective use of the data which they obtain:

- The numbers of households within their study areas
- The numbers of samples which they have collected and sorted
- The methods which they employ to collect samples
- The masses of the samples which they have collected and sorted
- The uncompacted volumes of the samples which they have sorted and the compacted volumes, if they are available
- The numbers of main and sub- fractions into which their samples are sorted
- Per capita waste generation rates, if they are calculated

6.6 POTENTIAL FOR DIVERSION FROM LANDFILL

The value of waste characterisation studies lies in their ability to influence decisions which increase the effectiveness with which HSW streams can be managed. In the case of the Stellenbosch Local Municipality, reliable data would assist the municipality to determine how to maximise the diversion of waste from landfill to overcome the limitations which are imposed by its severe shortage of landfill airspace.

Table 6.2 summarises the approximate composition of each waste fraction by volume on the basis of observations which were made during the conducting of the study and assessments of the potential of each sub-fraction to be diverted from landfill. The potential for diversion of all fractions, apart from the organic waste fraction, is based on the information which the municipality issued concerning the categories of items which are either accepted or rejected at the Small Materials Recovery Facility (please refer to Table 3.5 in section 3.4 of Chapter 3). Although organic waste does not fall within the remit of the separation at source programme, it has been allocated a diversion potential figure, as it can be successfully diverted from landfill through other means, such as composting or anaerobic digestion. In those instances in which diversion potential has a 100% rating, it is assumed that materials are received at the Small Materials Recovery Facility in a usable form, in that they are uncontaminated and unbroken. Consequently, the figures which denote potential for diversion need to be interpreted in the context of a best-case scenario and not necessarily as reflecting the actual potential for diversion of each fraction. Table 6.2 provides a summary of high-level calculations of potentials of individual waste fractions and sub-fractions for diversion from landfill at present rates of disposal.

Table 6.2: Potential of sub-fractions for diversion from landfill in cubic metres per annum

Sub-fraction	% of main fraction	m^3/a landfilled (uncompacted)	Diversion potential	Potential diversion m^3/a (uncompacted)
PET soft drink/water bottles	55%	49 542.60	100%	49 542.60
PS thermoform packaging	15%	13 511.62	0%	0.00
HDPE bottles	20%	18 015.49	100%	18 015.49
PP tubs and lids	5%	4 503.87	100%	4 503.87
Smaller PS items	2%	1 801.55	100%	1 801.55
Other hard plastics	3%	2 702.32	0%	0.00
SUB-TOTAL HARD PLASTICS	**100%**	**90 077.46**	**82%**	**73 863.52**
LDPE-based soft plastics	35%	61 117.60	100%	61 117.60
PP-based soft plastics	15%	26 193.26	100%	26 193.26
Multi-layered mixed polymers	50%	87 310.85	0%	0.00
SUB-TOTAL PLASTIC WRAP/PACKAGING	**100%**	**174 621.70**	**50%**	**87 310.85**
Steel cans and bottle caps	50%	5 042.44	100%	5 042.44
Aluminium cans	30%	3 025.46	100%	3 025.46
Hardware	10%	1 008.49	100%	1 008.49
Other smaller metal items	10%	1 008.49	0%	0.00
SUB-TOTAL METALS	**100%**	**10 084.88**	**90%**	**9 076.39**
Whole glass bottles and jars	80%	11 630.90	100%	11 630.90
Broken glass items	15%	2 180.79	0%	0.00
Broken flat glass	5%	726.93	0%	0.00

SUB-TOTAL GLASS	**100%**	**14 538.63**	**80%**	**11 630.90**
Dry food packaging	50%	73 769.81	100%	73 769.81
White office paper	10%	14 753.96	100%	14 753.96
Newspapers	5%	7 376.98	100%	7 376.98
Magazines	5%	7 376.98	100%	7 376.98
K4 cardboard	20%	29 507.92	100%	29 507.92
Food contaminated paper/cardboard	5%	7 376.98	0%	0.00
Paper/cardboard items containing other materials	5%	7 376.98	0%	0.00
SUB-TOTAL PAPER/CARDBOARD	**100%**	**147 539.61**	**90%**	**132 785.649**
Food waste	73%	42 291.29	100%	42 291.29
Garden waste	27%	15 641.99	100%	15 641.99
SUB-TOTAL ORGANIC WASTE	**100%**	**57 933.28**	**100%**	**57 933.28**
Tetra Pak cartons	12%	10 956.95	100%	10 956.95
Extruded polystyrene	32%	29 218.54	100%	29 218.54
Tissues	28%	25 566.22	0%	0.00
Ash	9%	8 217.71	0%	0.00
Electronic waste	2%	1 826.16	0%	0.00
Maize meal bags	1%	913.08	100%	913.08
Textile waste	1%	913.08	0%	0.00
Residual other	15%	13 696.19	0%	0.00
SUB-TOTAL OTHERS	**100%**	**91 307.94**	**45%**	**41 088.57**

TOTAL DIVERSION	**586 103.50**	**71%**	**413 689.17**

Up to 71% by volume of all HSW which is being disposed of at the DVLS at present can be diverted from landfill if a rigorous and strictly monitored separation at source policy is implemented at the household level. This material would occupy the equivalent of 413 698.17 cubic metres of landfill airspace in uncompacted form. Although a system which would accommodate such high diversion figures would undoubtedly be extremely costly to implement, the costs should be evaluated by means of a cost-benefit analysis against those which would be entailed by transporting waste to neighbouring municipalities or regional landfill sites when no local landfill airspace is available.

The disposal of organic waste is responsible for most of the undesirable attributes which are associated with general landfill sites. Organic waste generates methane gas and is also responsible for unpleasant odours and attracting vermin and pests to sites. As disposing of organic waste by landfilling it will be prohibited by 2026 and also in view of its contribution of 35% of the overall waste stream by mass, it is recommended that an appropriate organic waste diversion plan for the Stellenbosch municipal area should be formulated and implemented, preferably through the implementation of a separation at source programme which upgrades the present two-bag system to a three-bag system.

It is recommended that the implementation of the separation at source programme should be extended to all areas which fall under the jurisdiction of the Stellenbosch Local Municipality. Improved education and awareness concerning the waste crisis with which the municipality is faced at present is also equally crucial.

A waste characterisation study can be successfully utilised as a reliable tool to gather information about the composition of a waste stream. Stellenbosch Municipality can utilise the information generated through this research to shape their waste diversion strategies. Studies like this should be conducted in all municipalities in South Africa, to guide and inform integrated waste management strategies.

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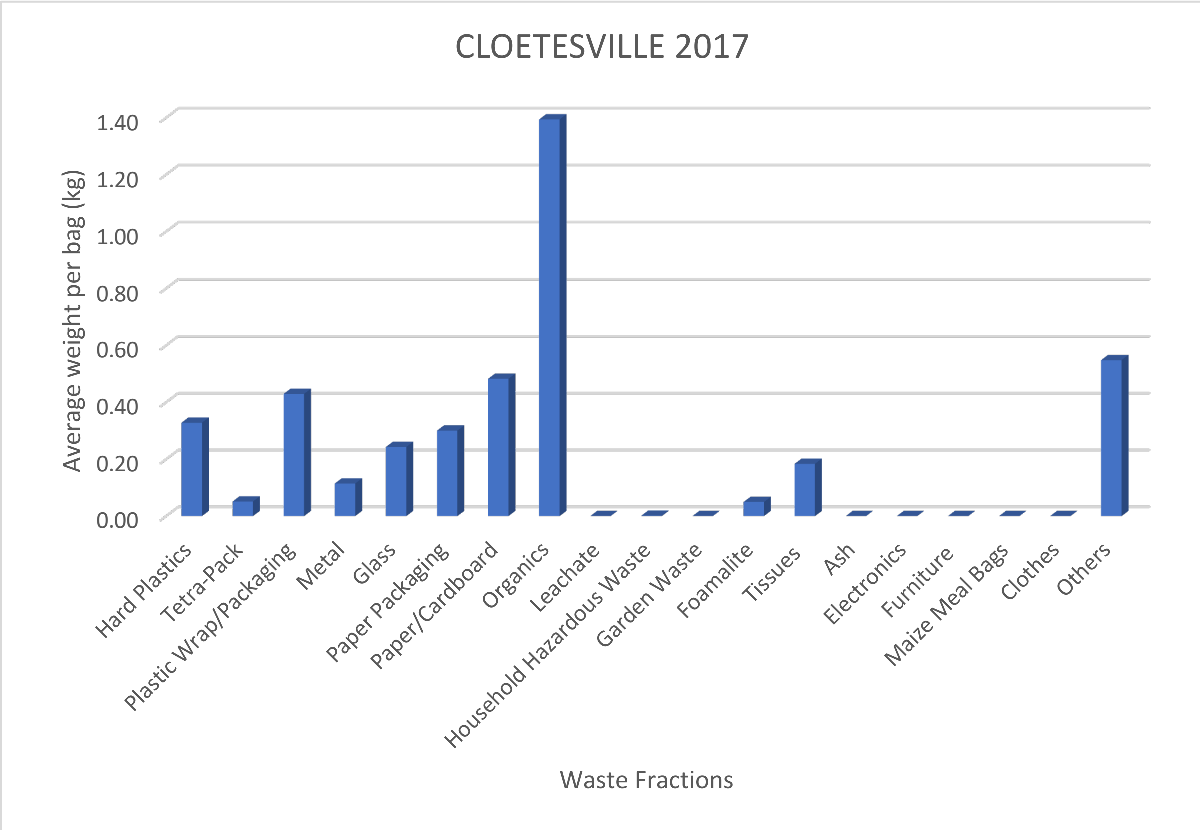
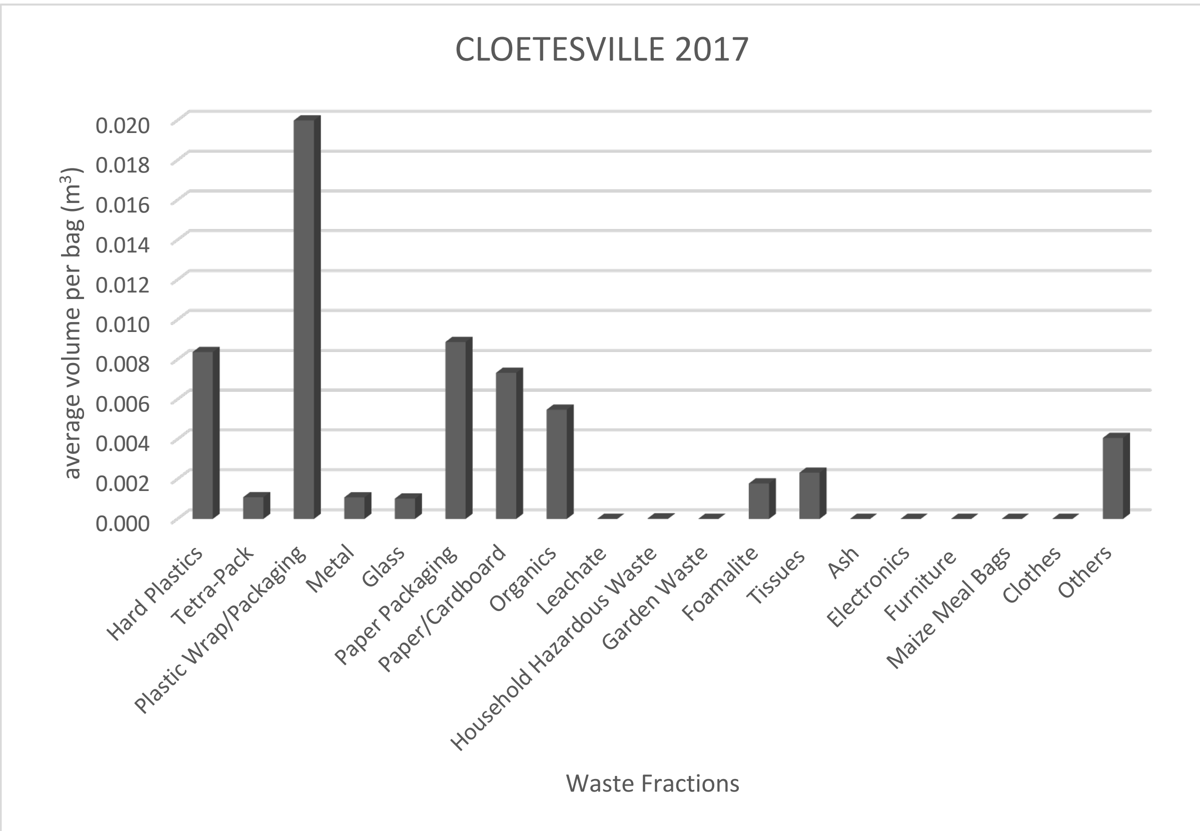
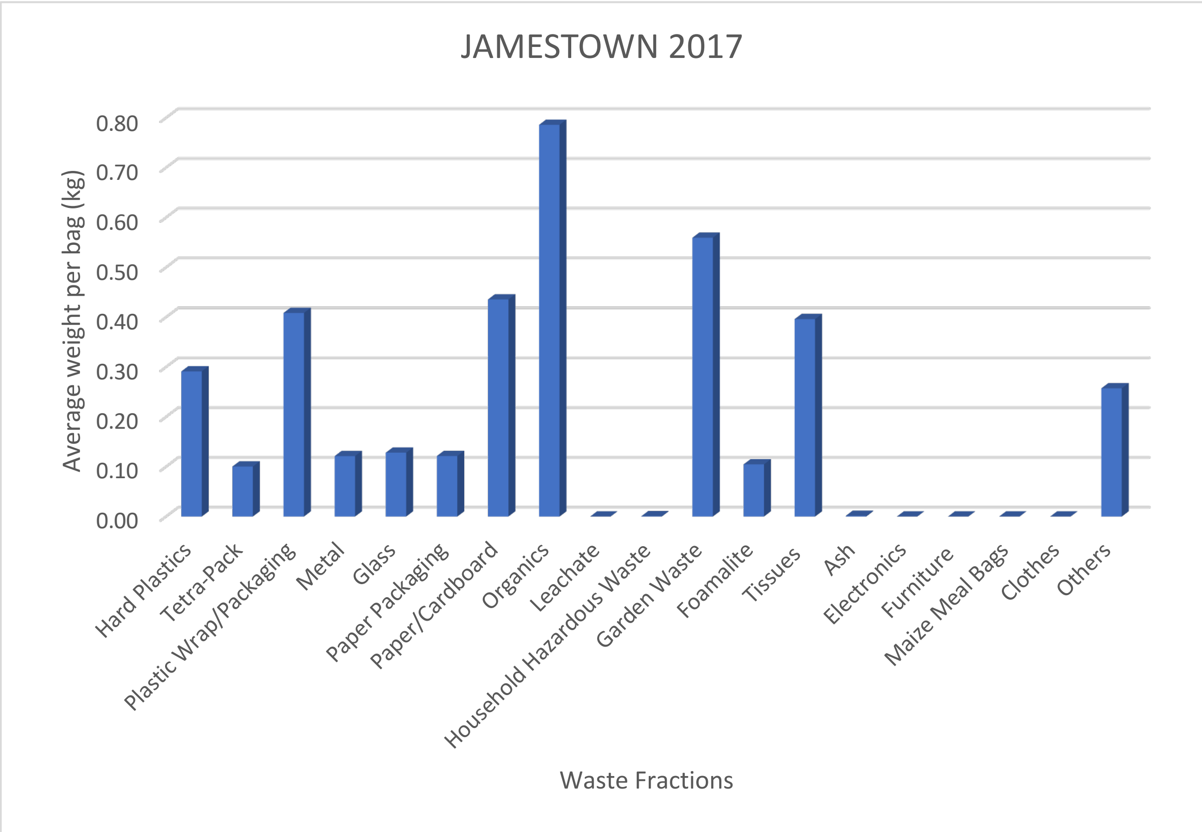
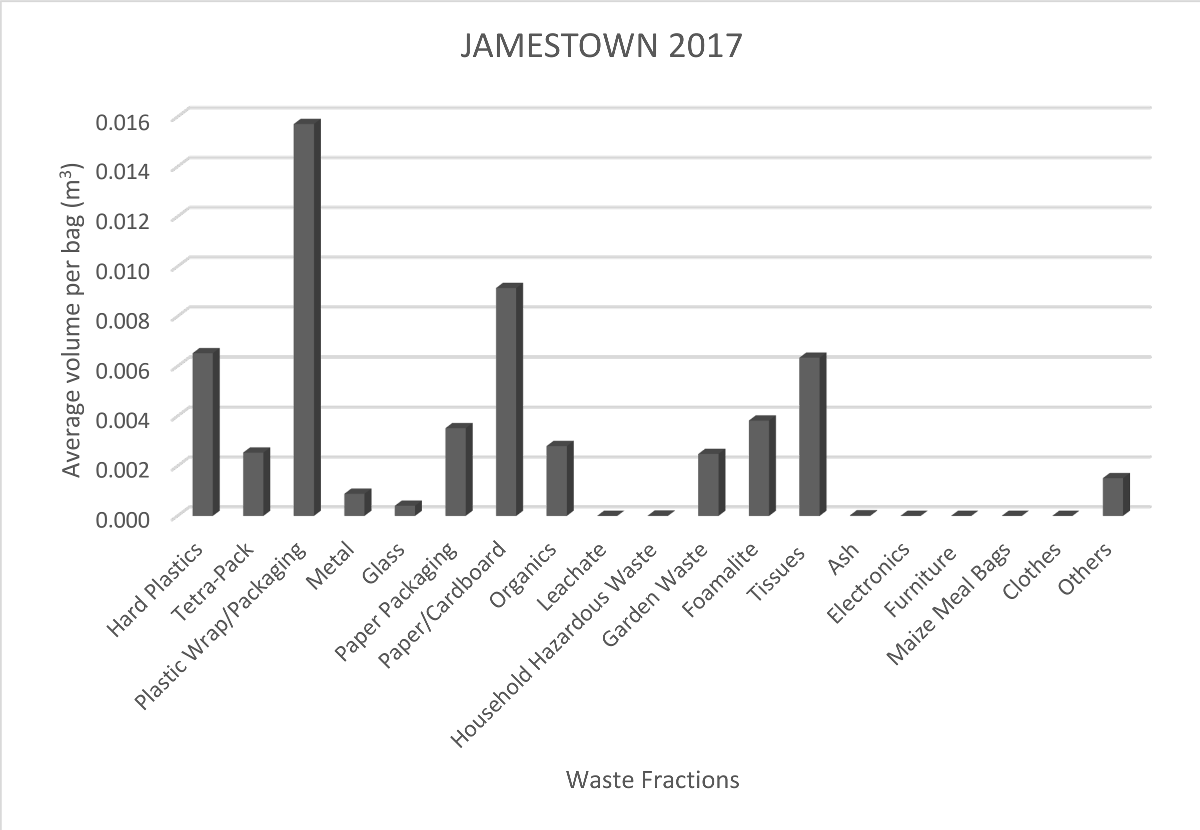
APPENDIX 1

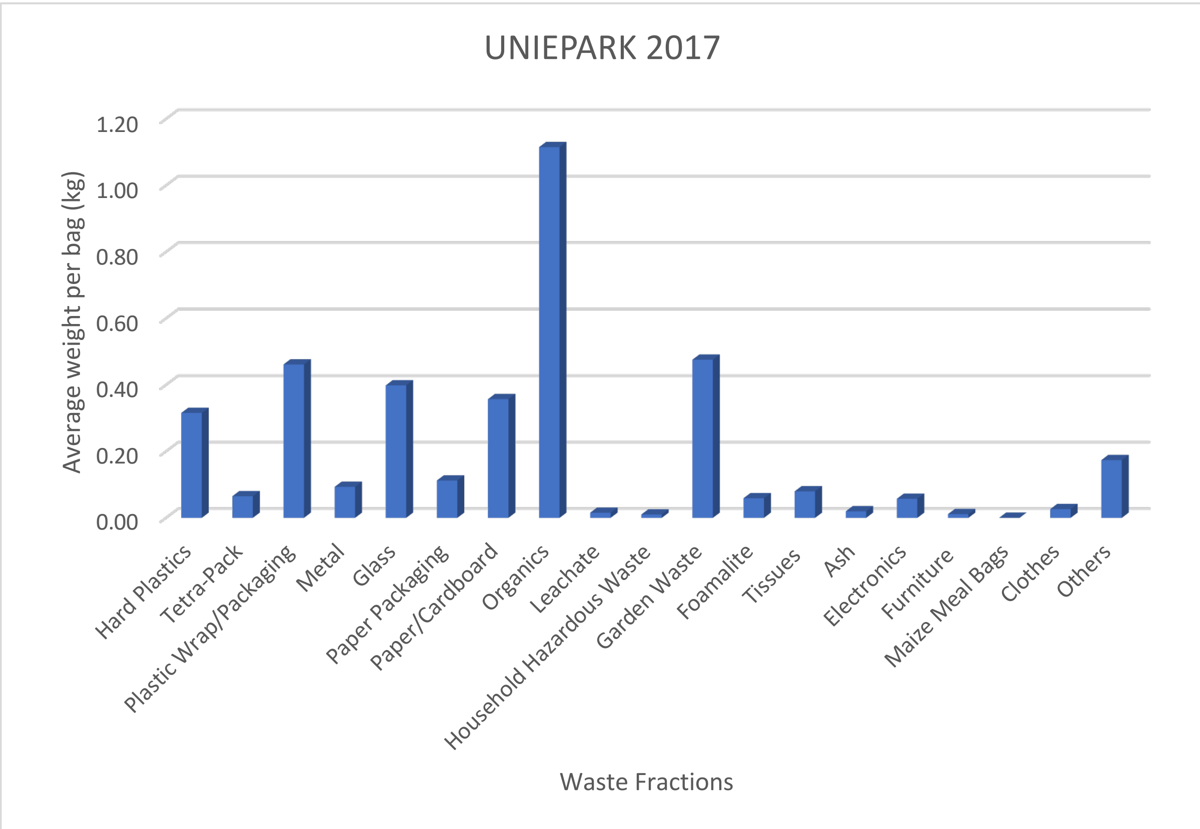

CLOETESVILLE 2017
Average weight per bag (kg)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

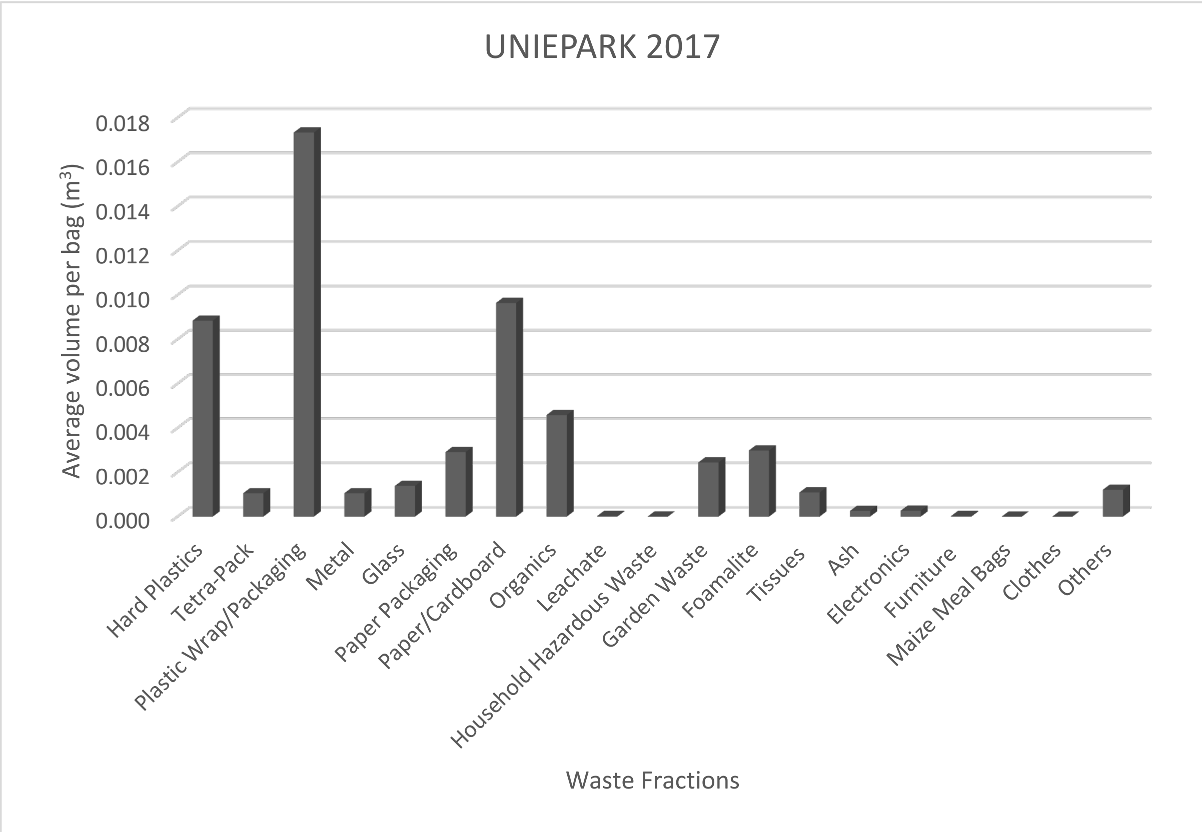

CLOETESVILLE 2017
average volume per bag (m³)
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

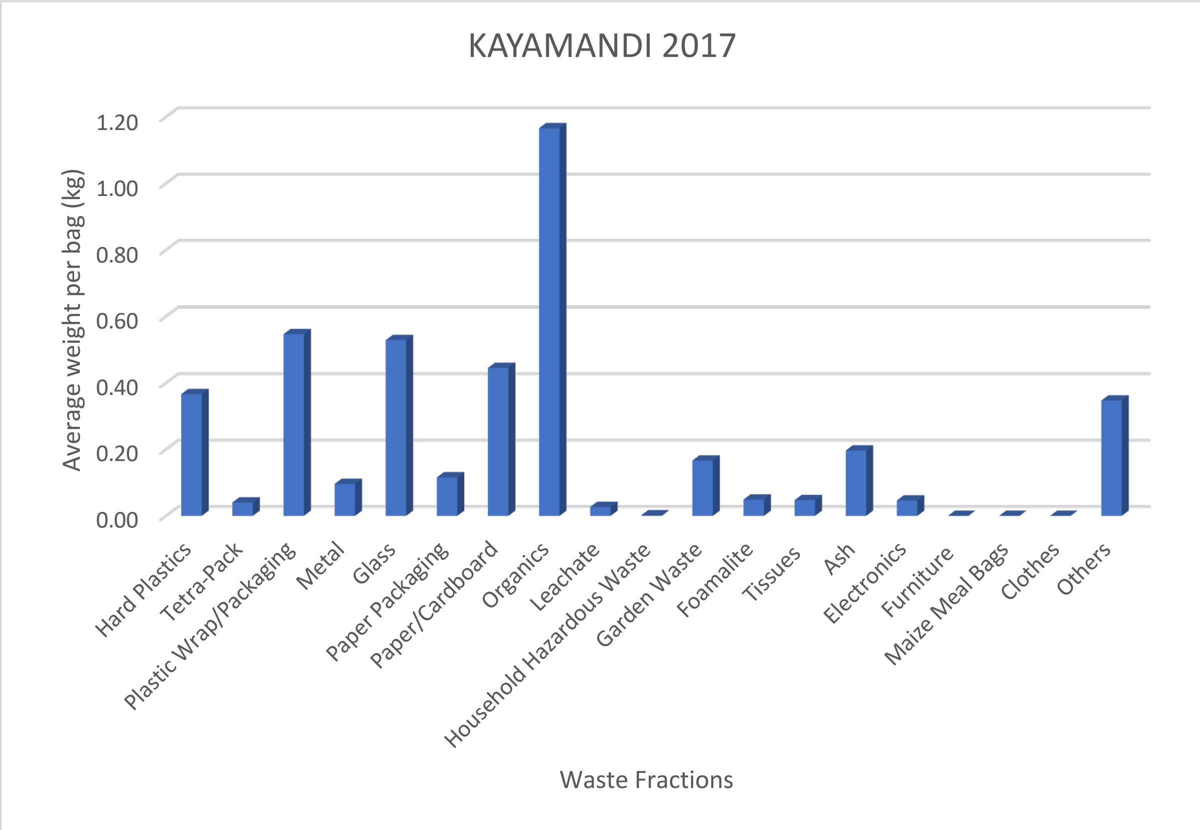


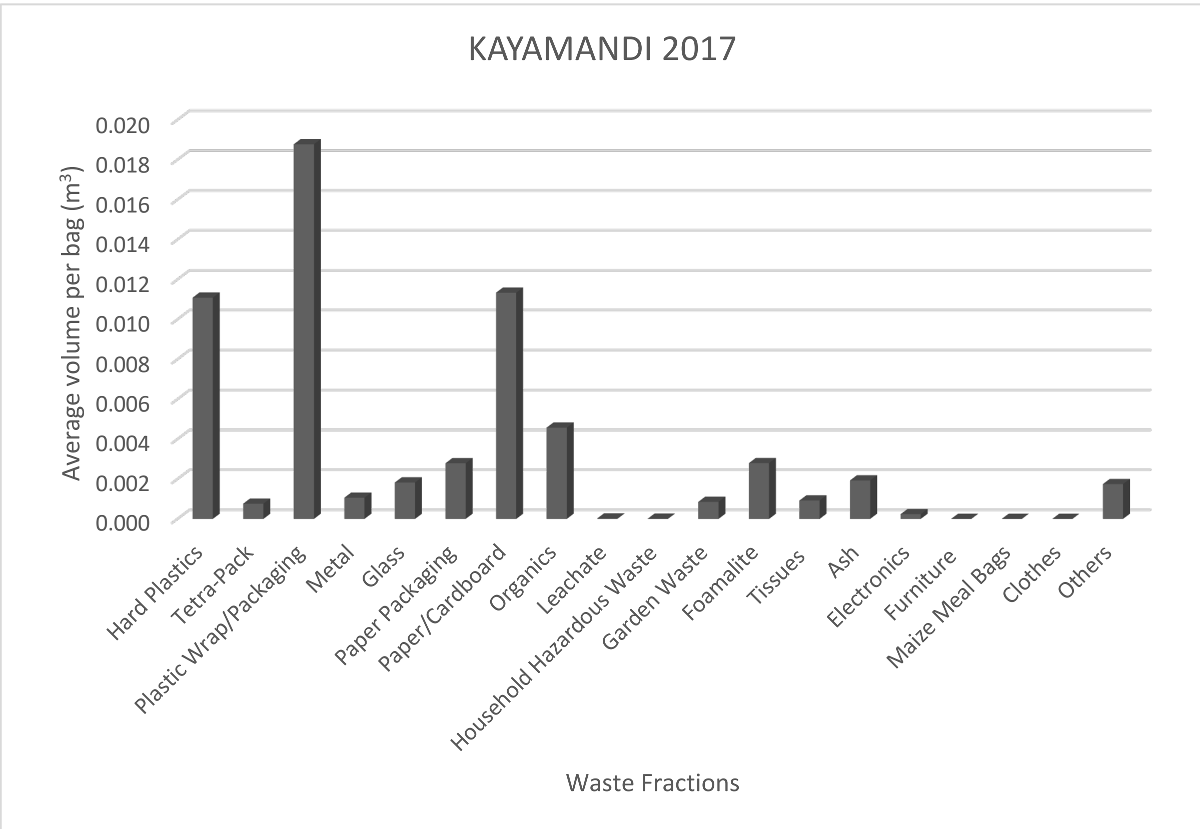
JAMESTOWN 2017
Average weight per bag (kg)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

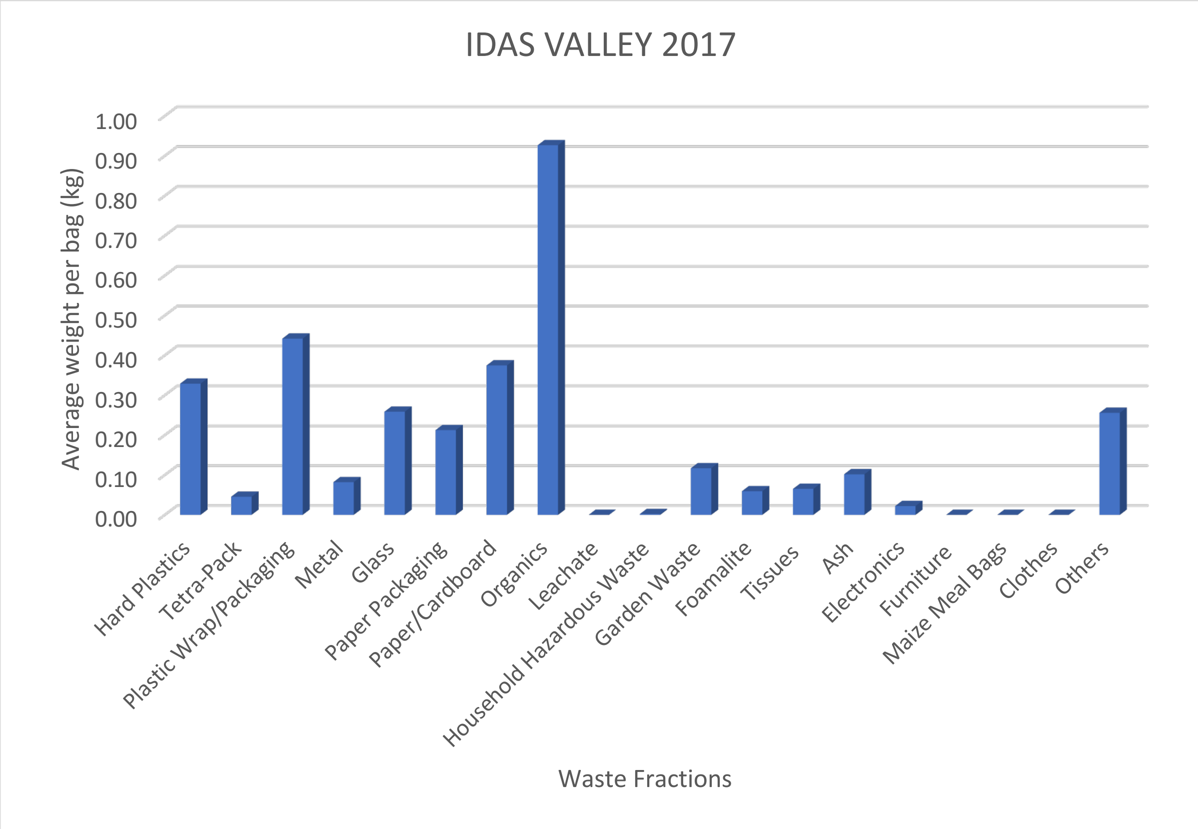

JAMESTOWN 2017
Average volume per bag (m³)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


UNIEPARK 2017
Average weight per bag (kg)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

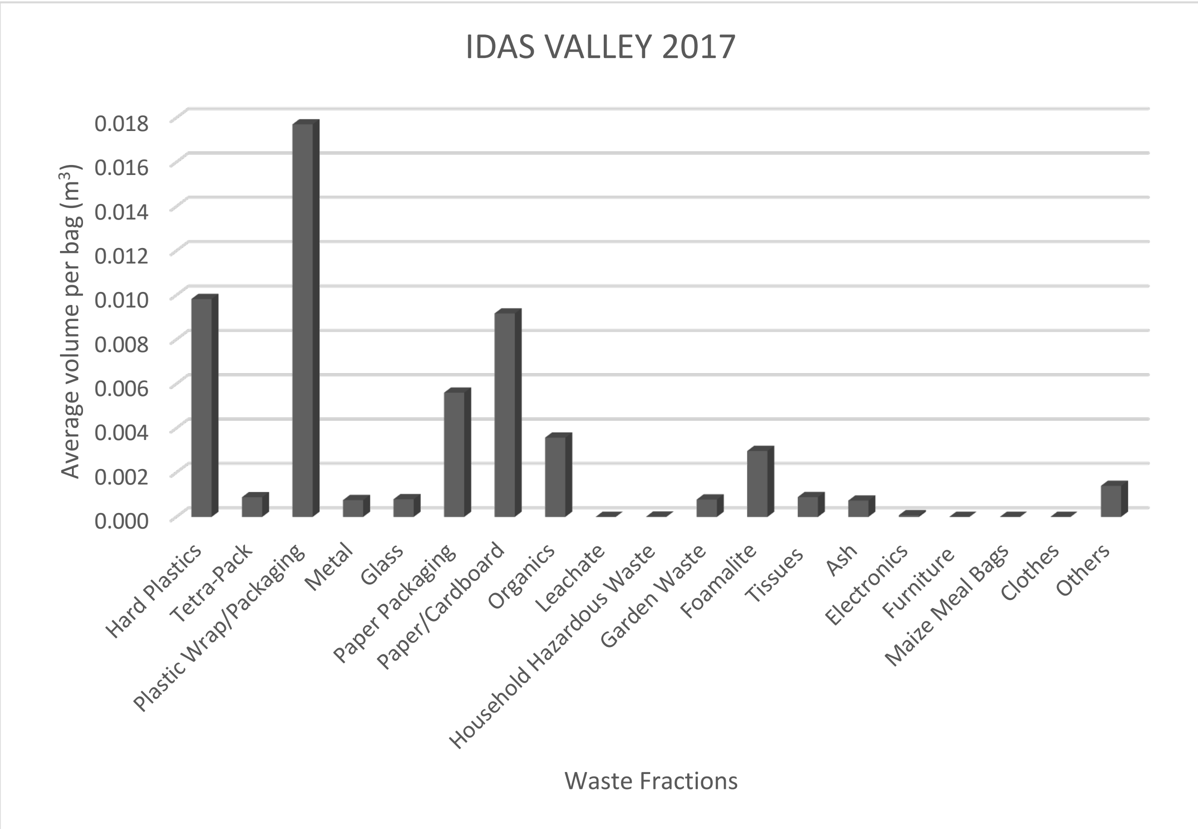

UNIEPARK 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


KAYAMANDI 2017
Average weight per bag (kg)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

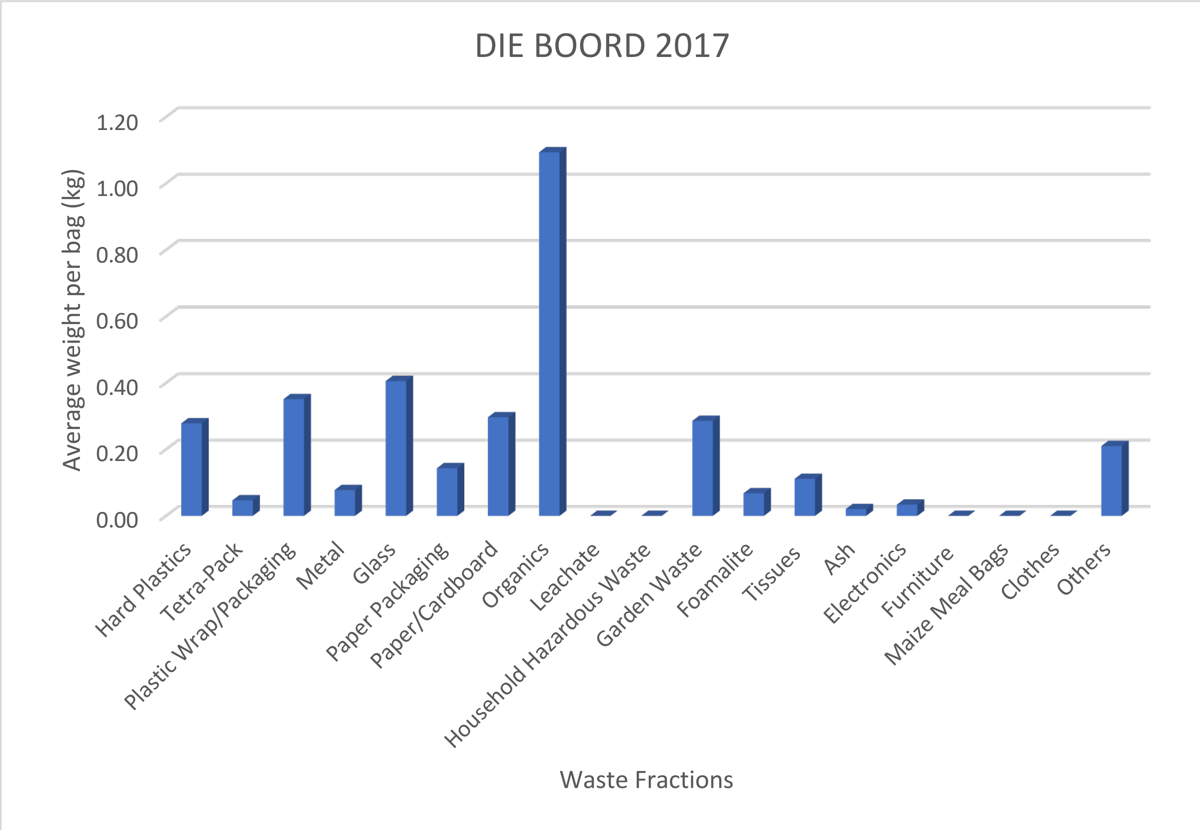

KAYAMANDI 2017
Average volume per bag (m³)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

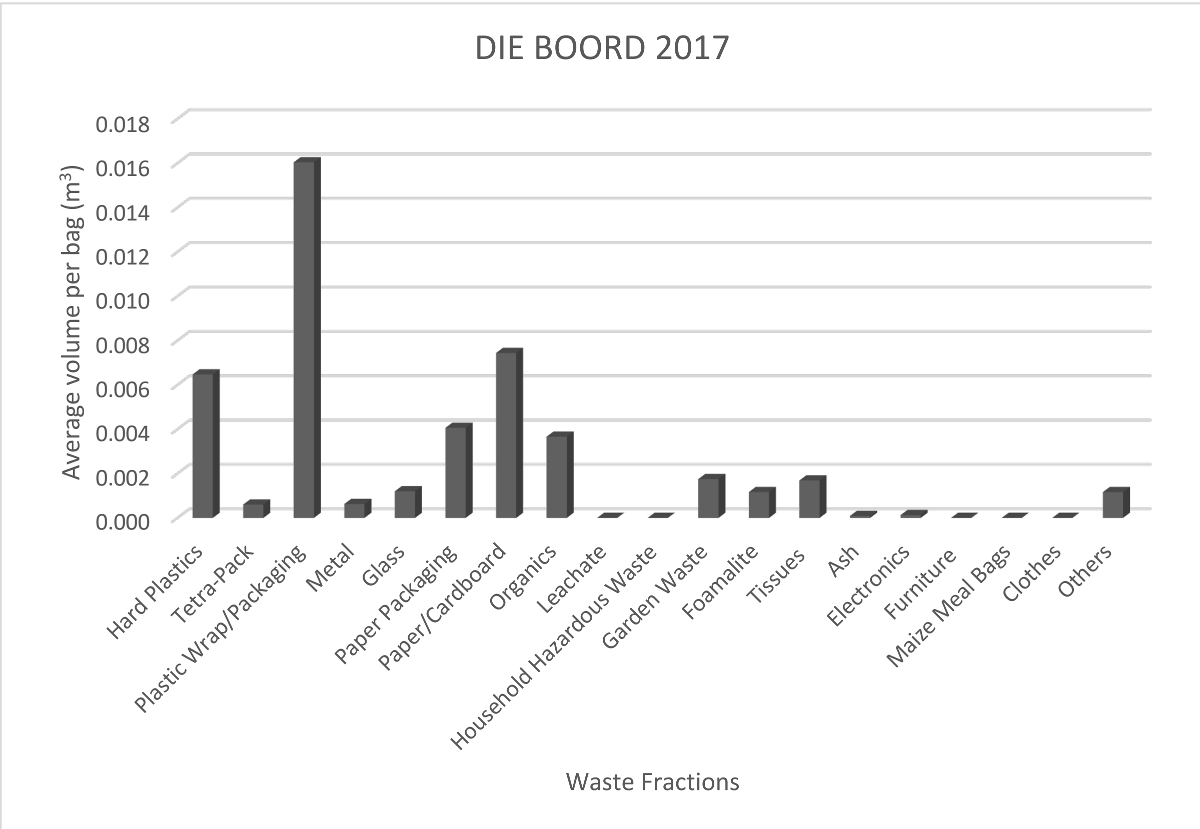


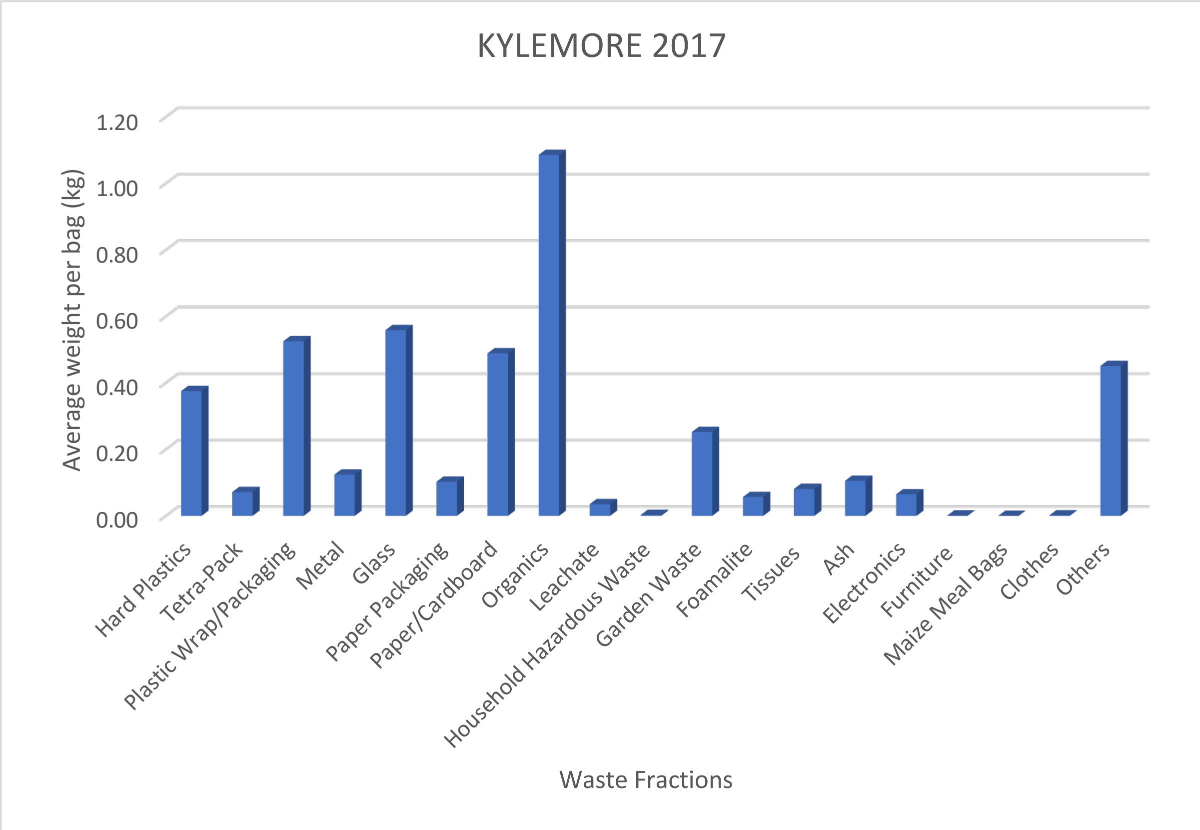
IDAS VALLEY 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

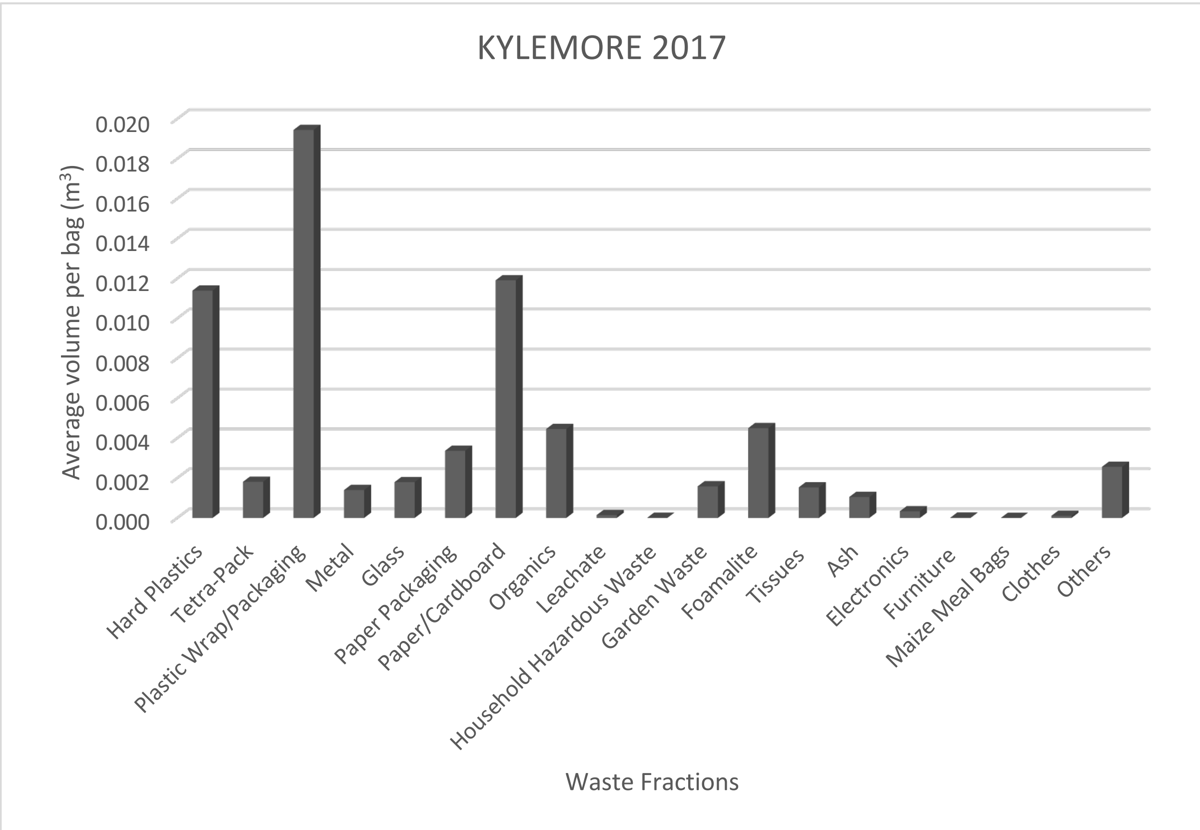


IDAS VALLEY 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


DIE BOORD 2017
Average weight per bag (kg)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


DIE BOORD 2017
Average volume per bag (m3)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


KYLEMORE 2017
Average weight per bag (kg)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


KYLEMORE 2017
Average volume per bag (m³)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
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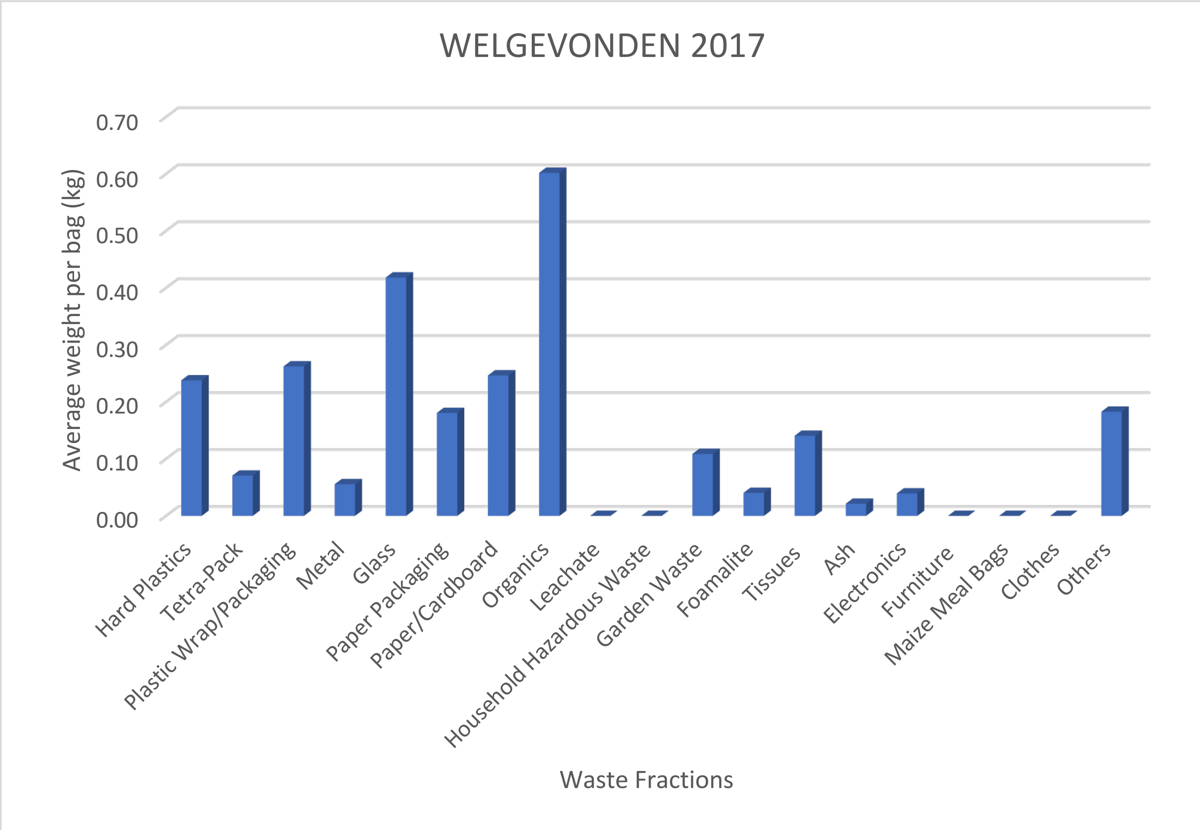
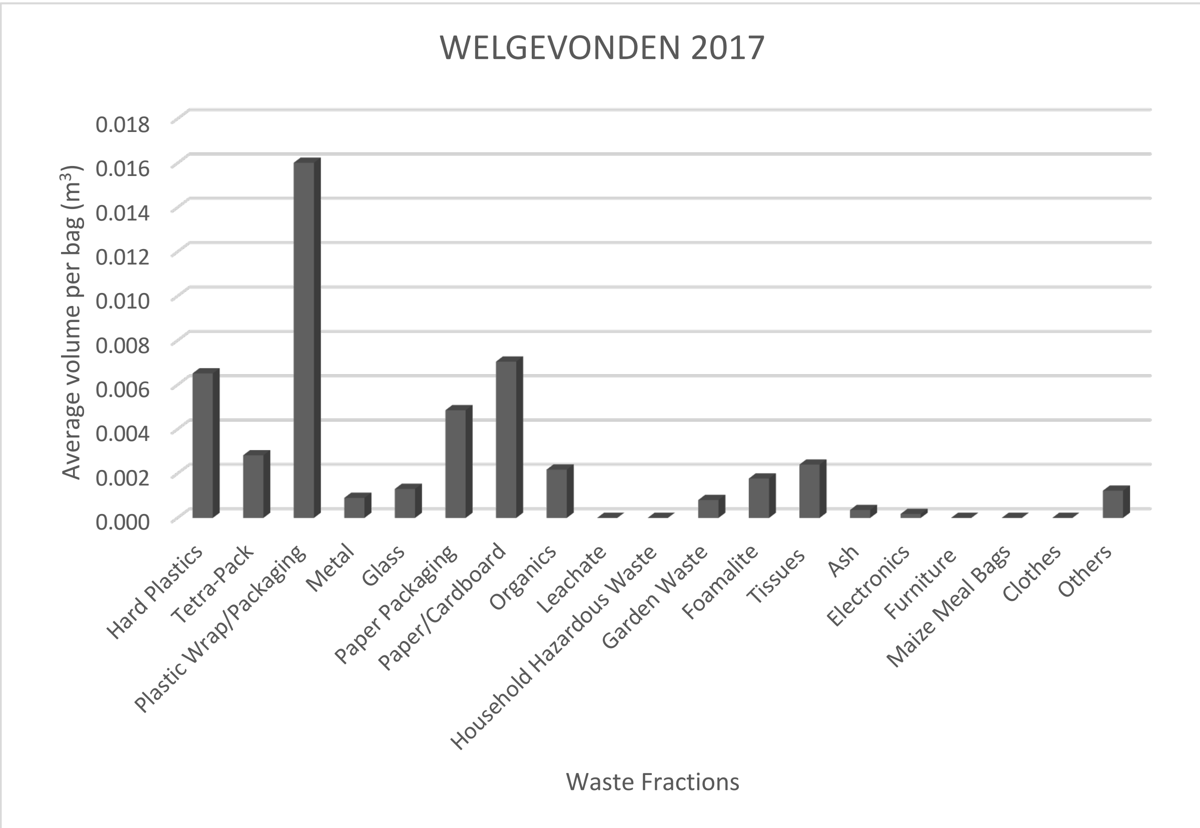
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


WELGEVONDEN 2017
Average weight per bag (kg)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


WELGEVONDEN 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
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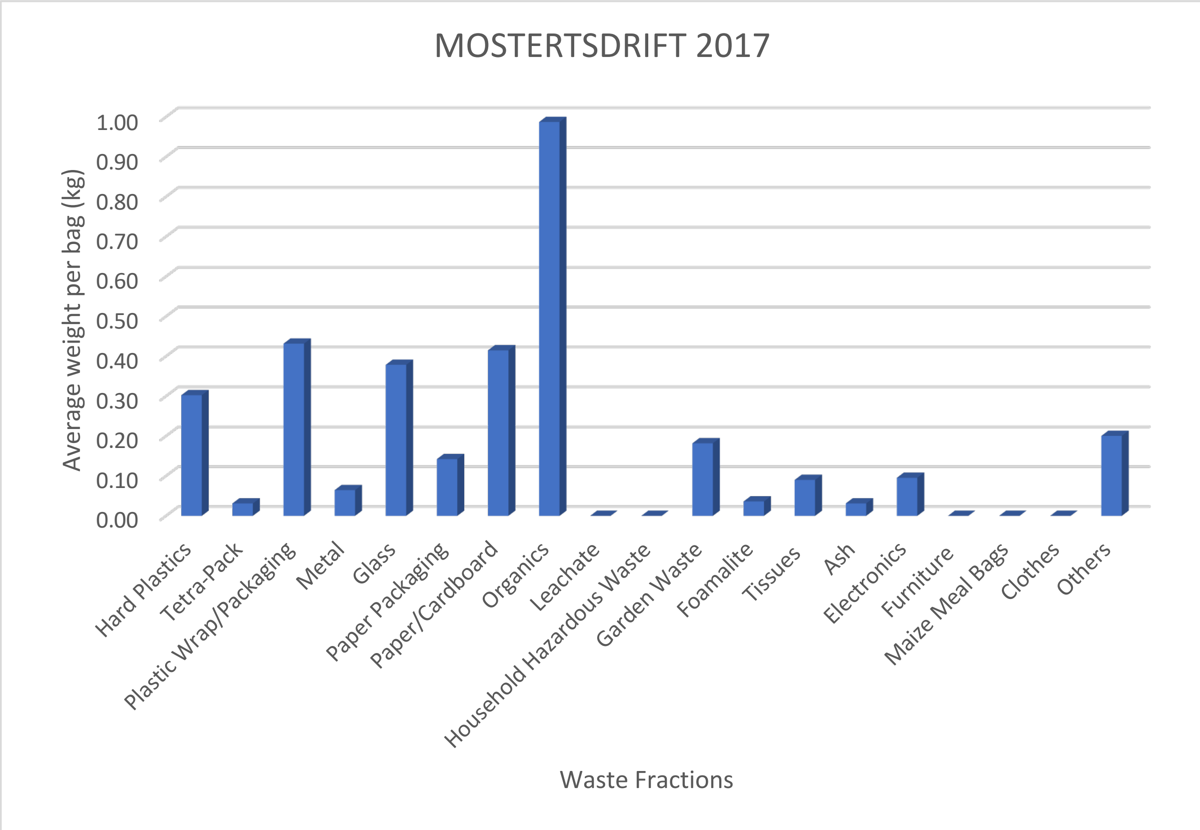
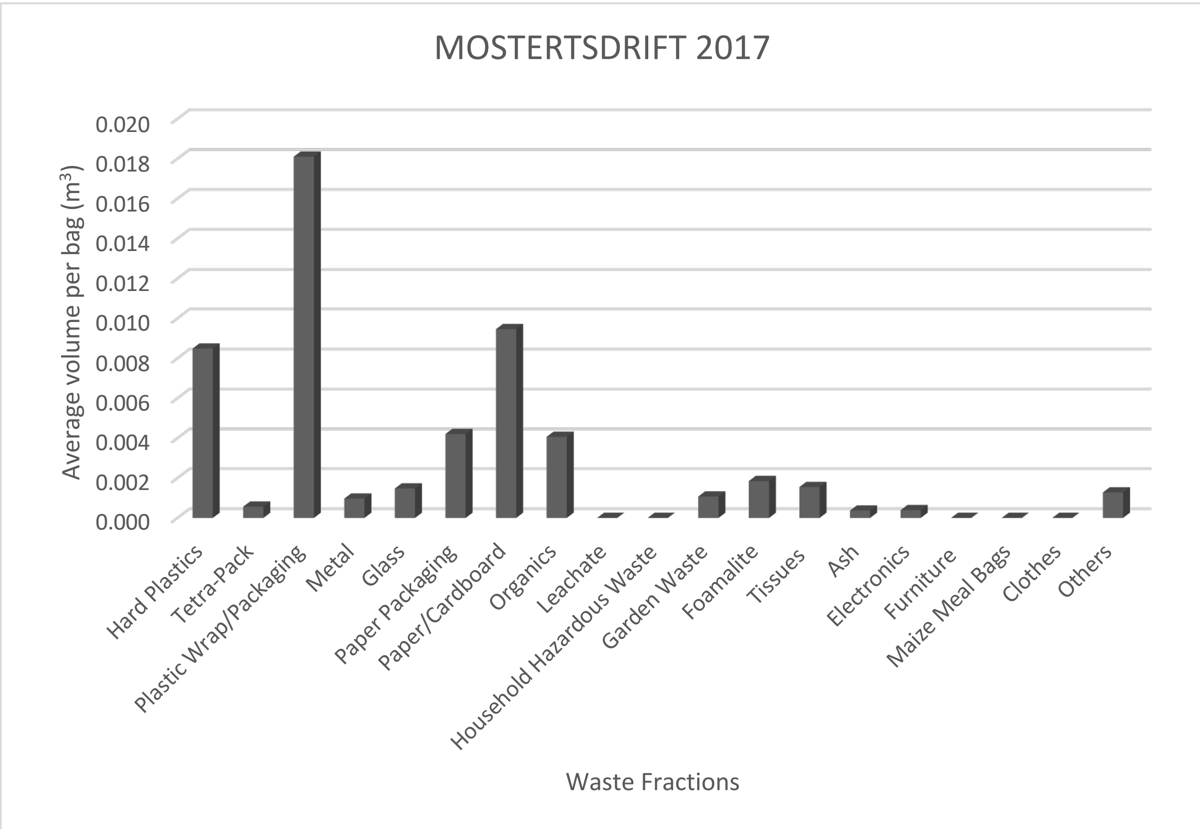
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


MOSTERTSDRIFT 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


MOSTERTSDRIFT 2017
Average volume per bag (m3)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
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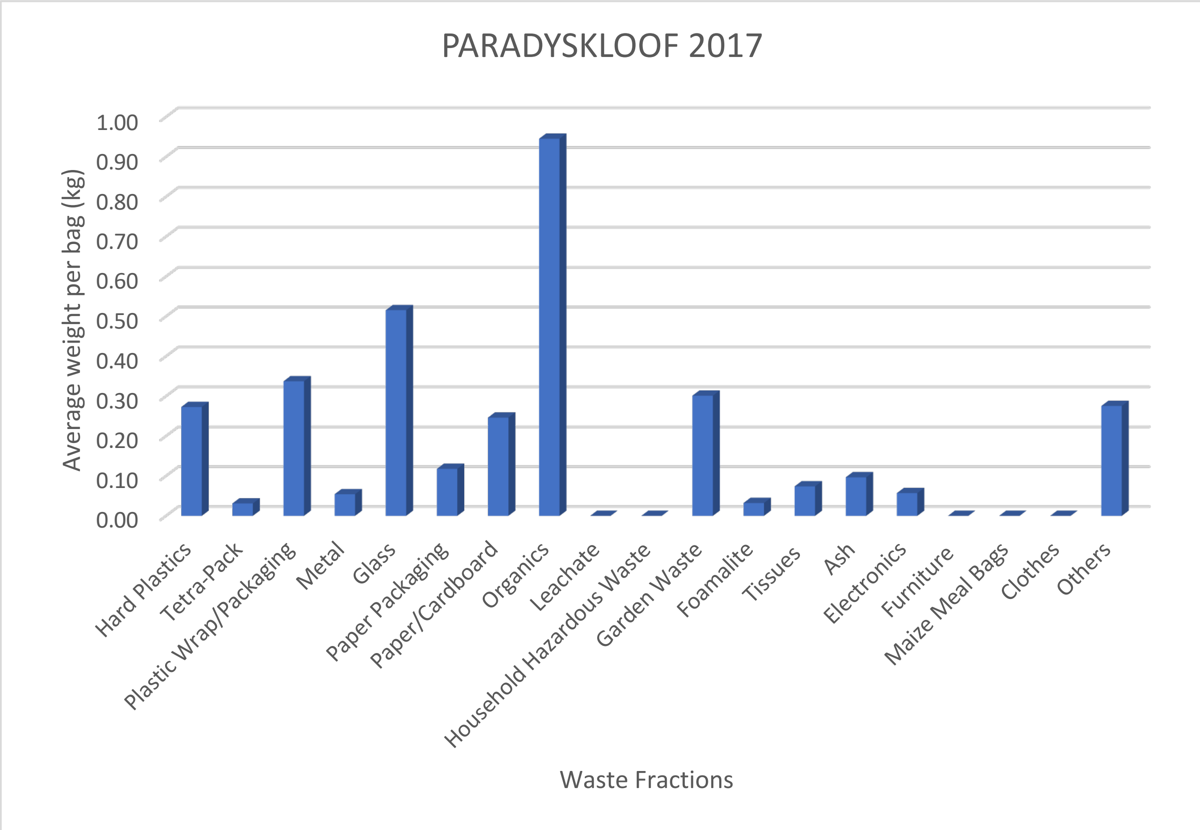
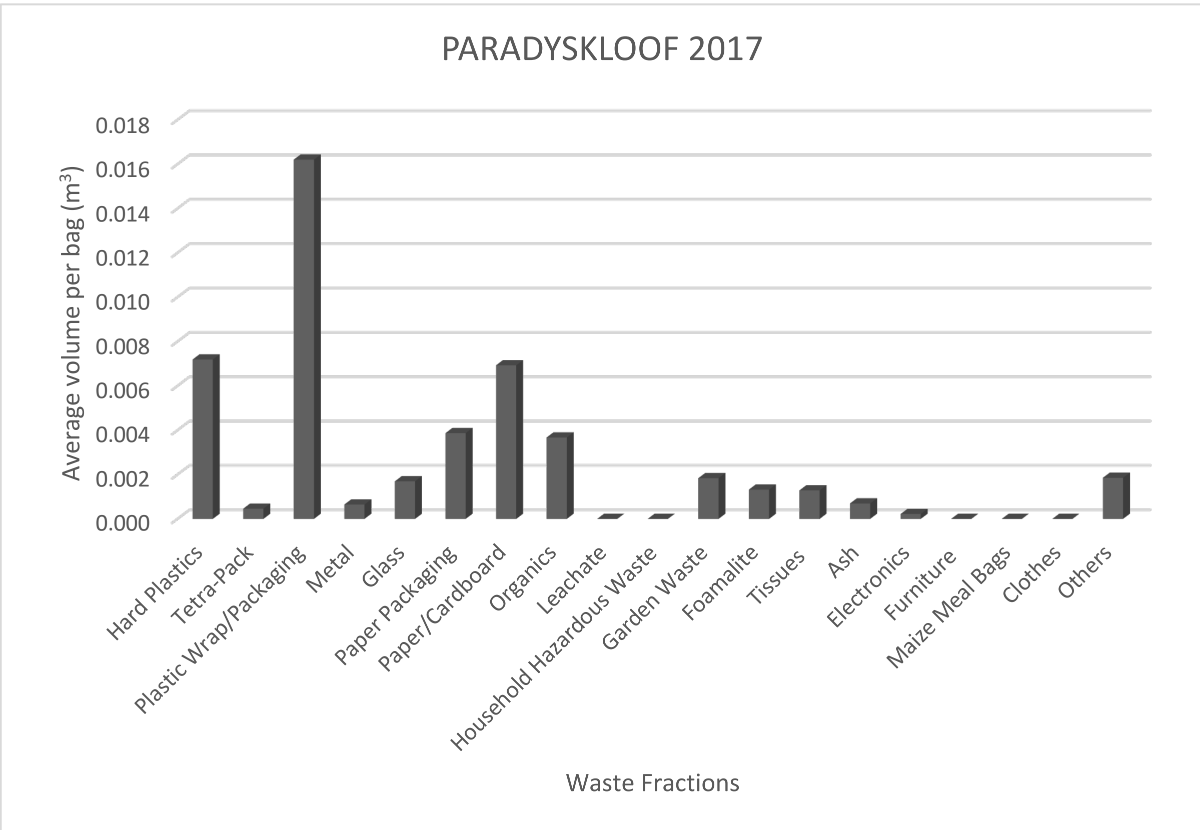
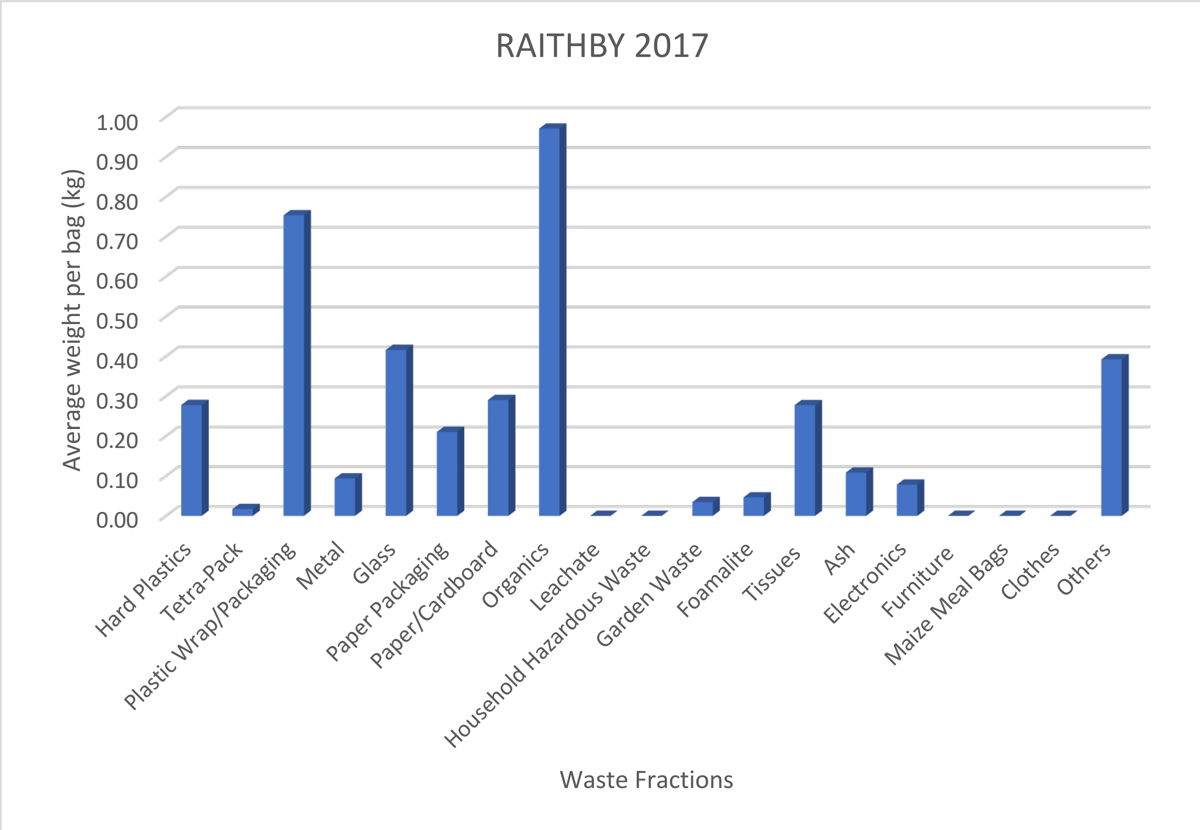
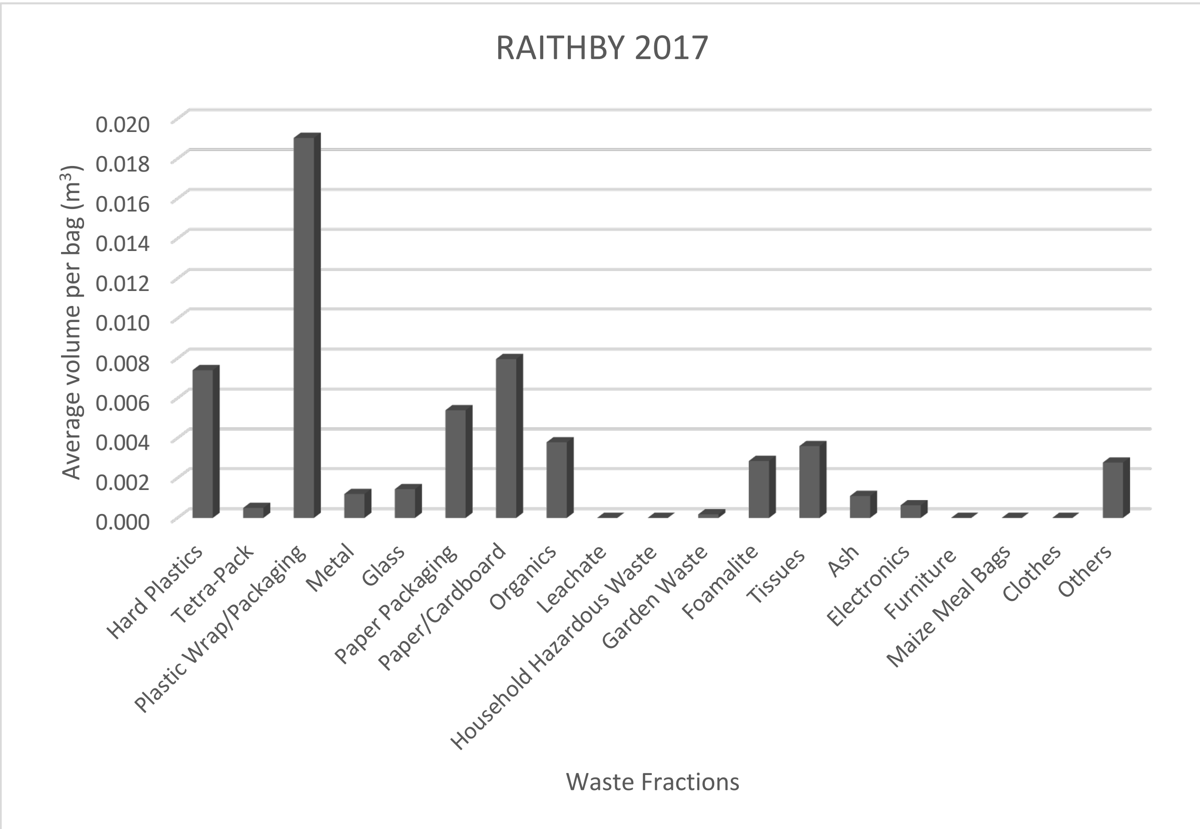
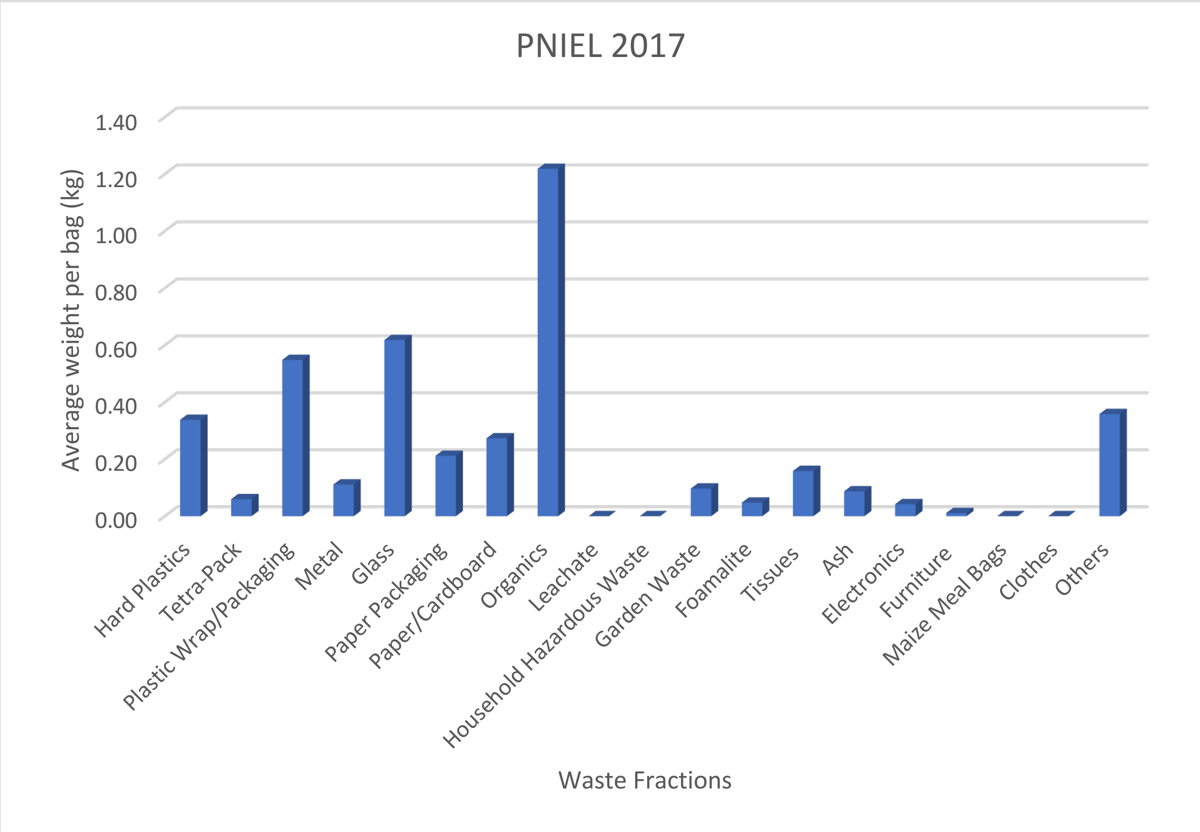
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

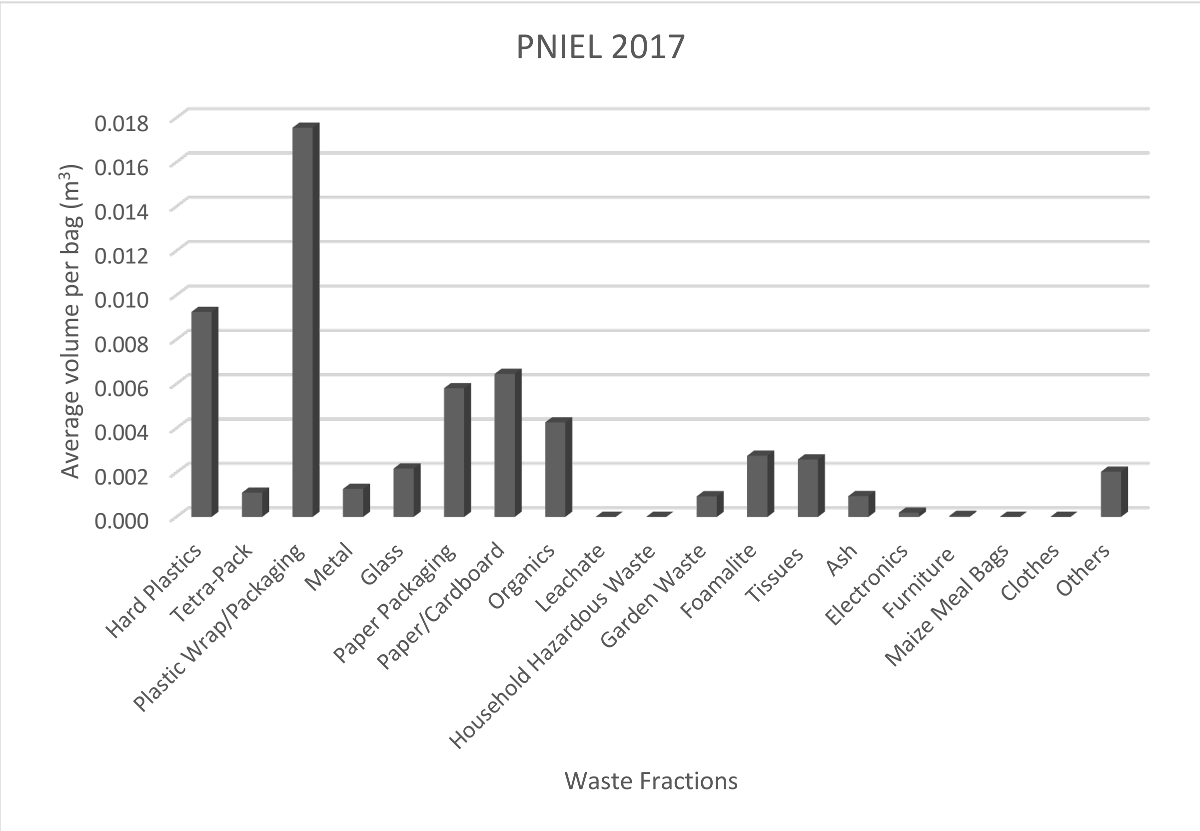

PARADYSKLOOF 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

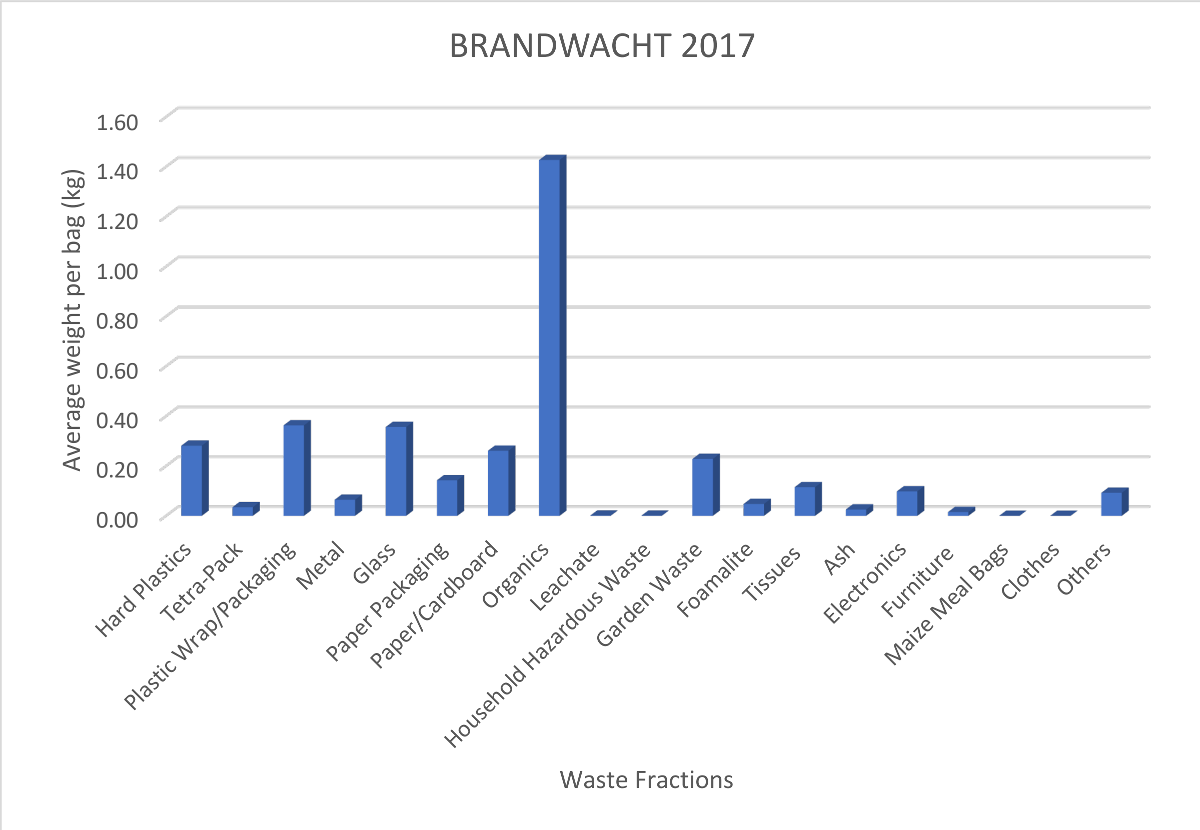

PARADYSKLOOF 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

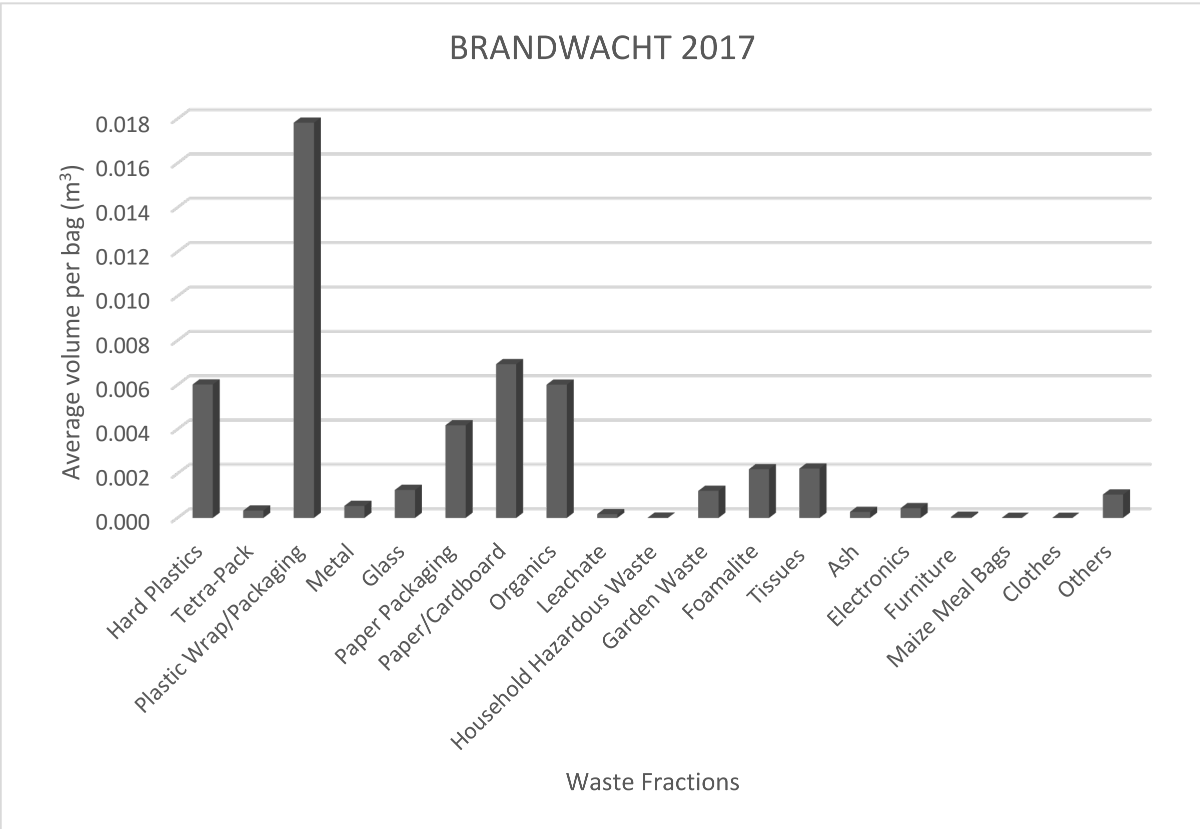

RAITHBY 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

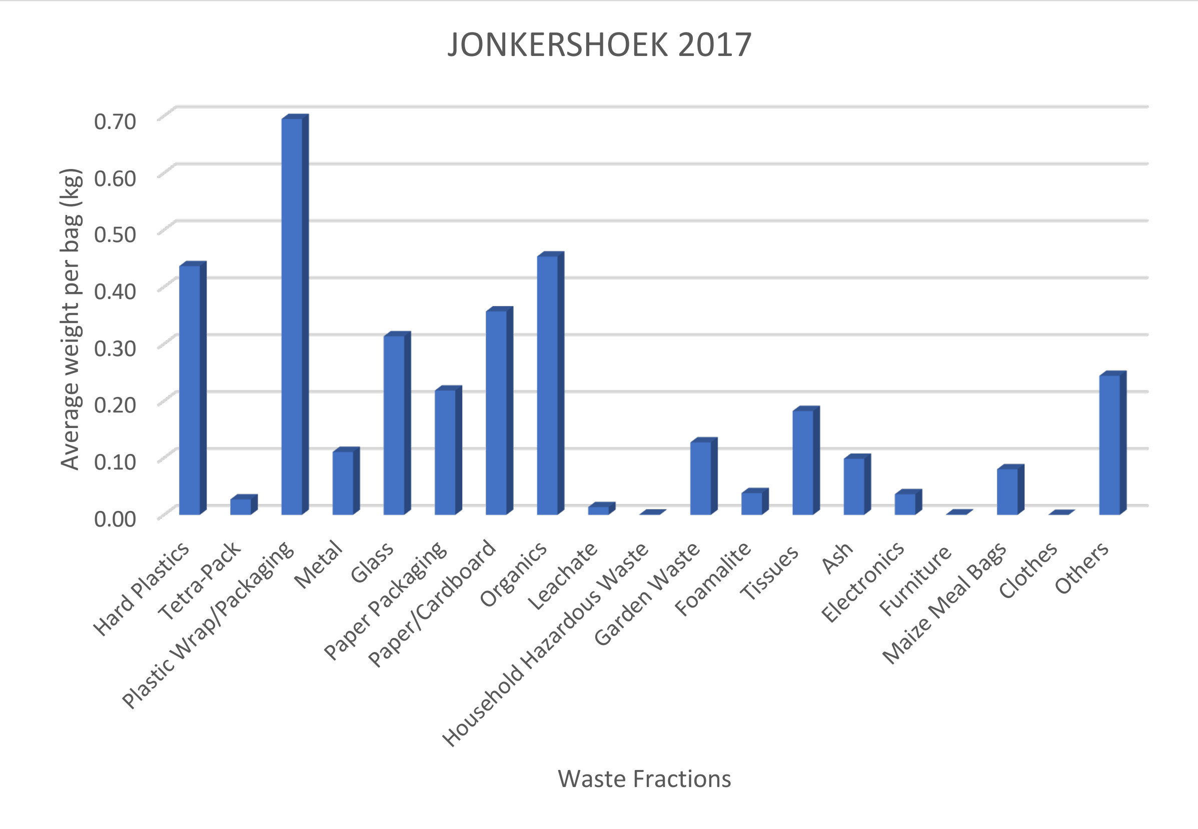

RAITHBY 2017
Average volume per bag (m³)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

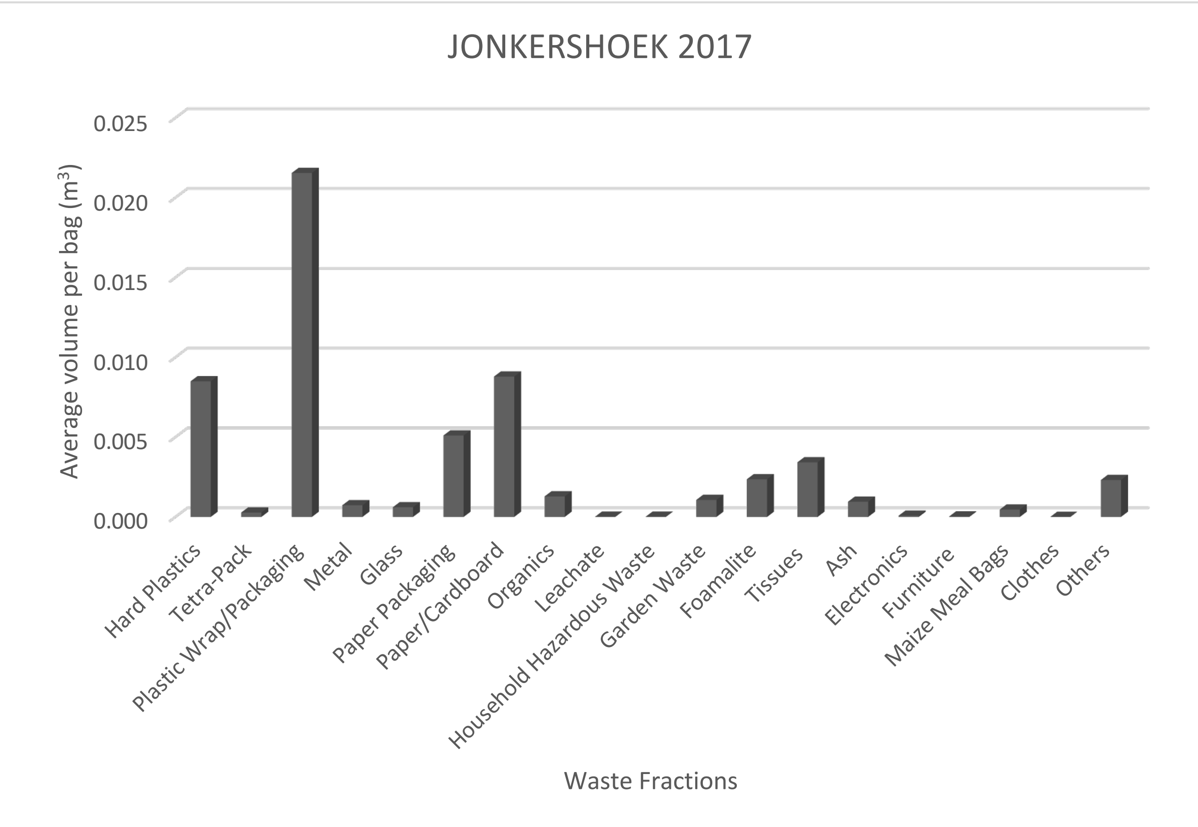

PNIEL 2017
Average weight per bag (kg)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

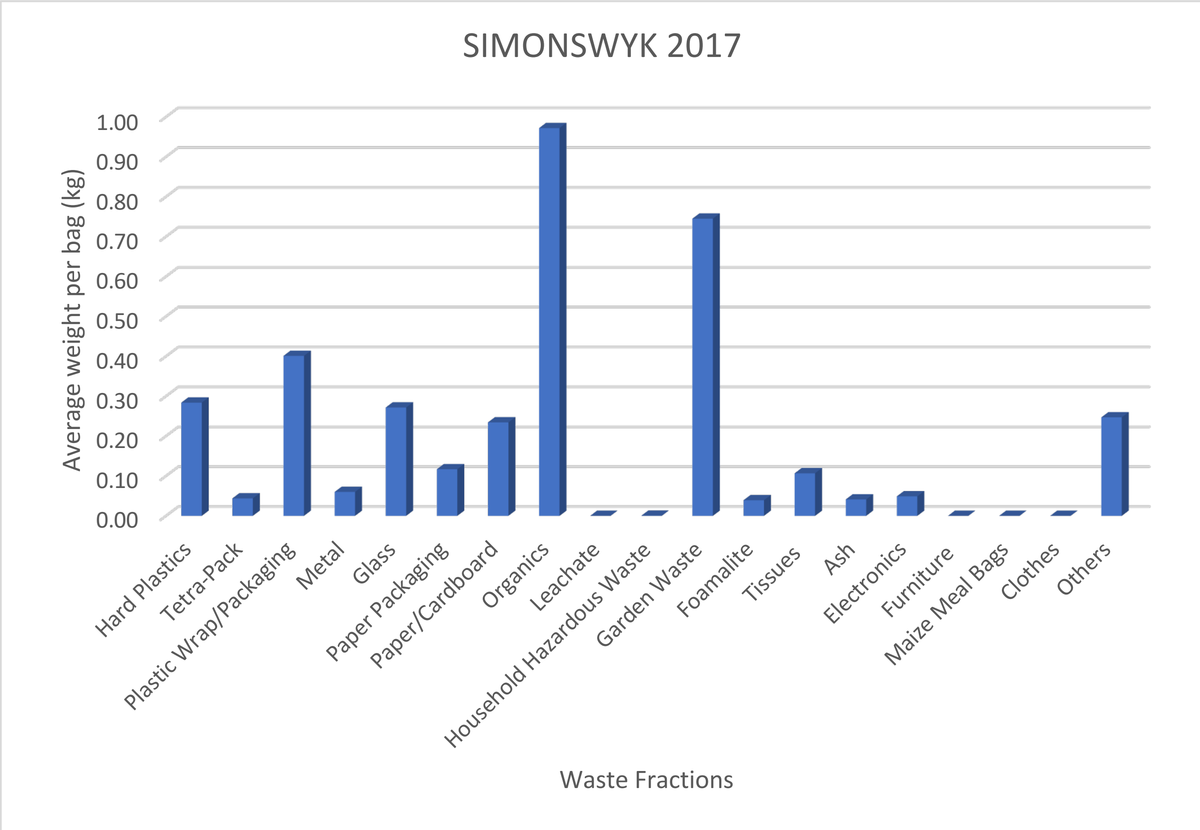

PNIEL 2017
Average volume per bag (m3)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

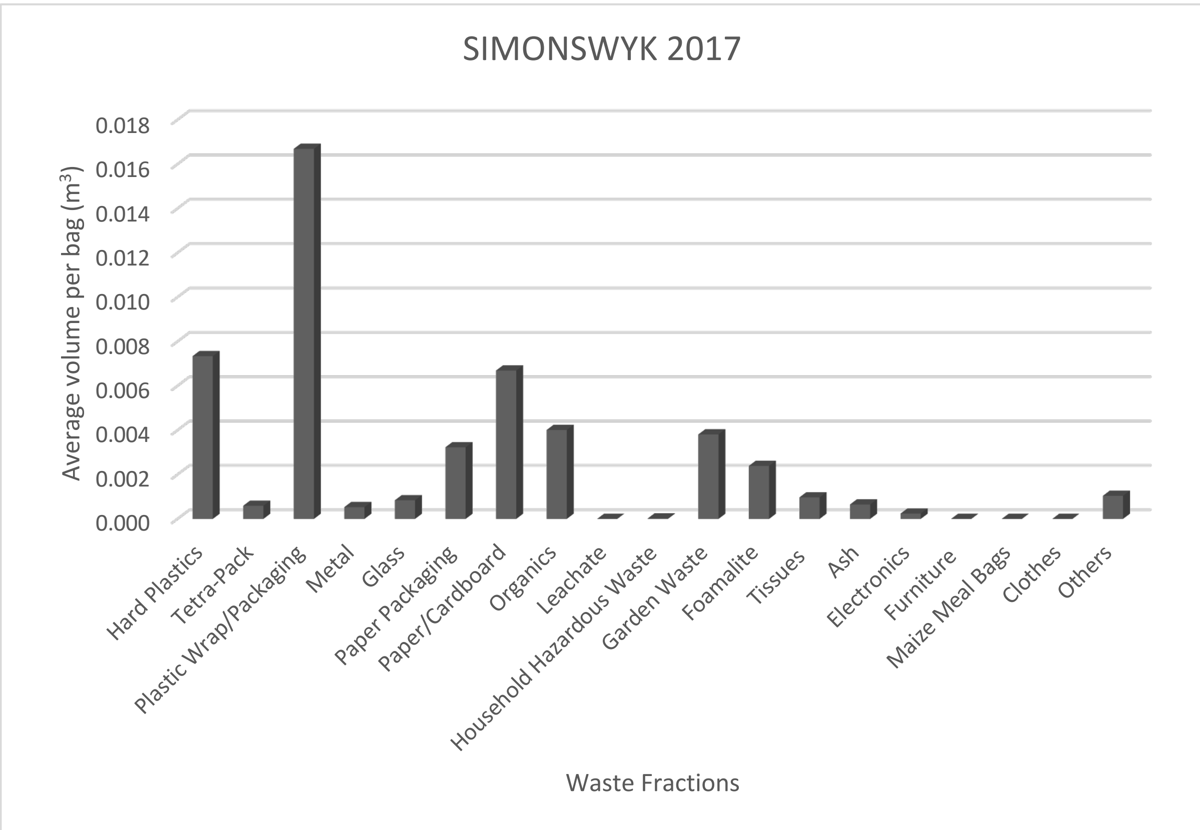

BRANDWACHT 2017
Average weight per bag (kg)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

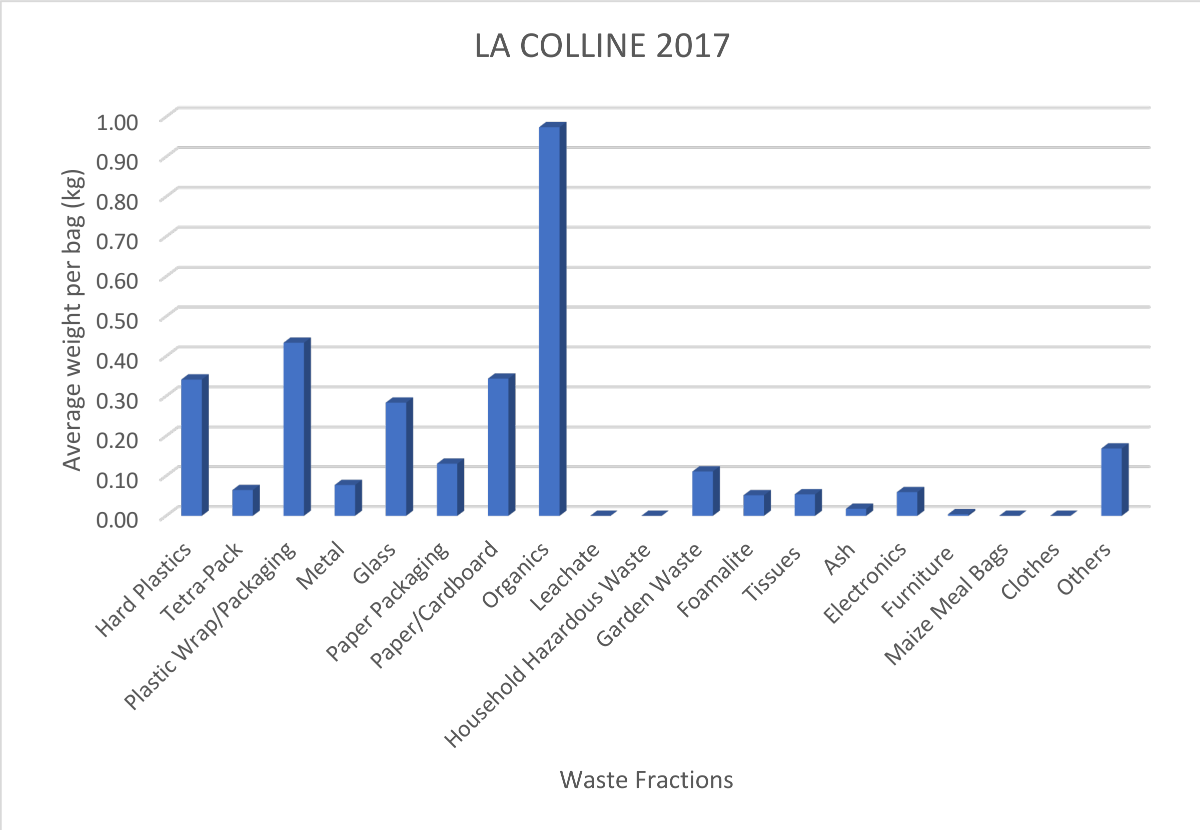

BRANDWACHT 2017
Average volume per bag (m3)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

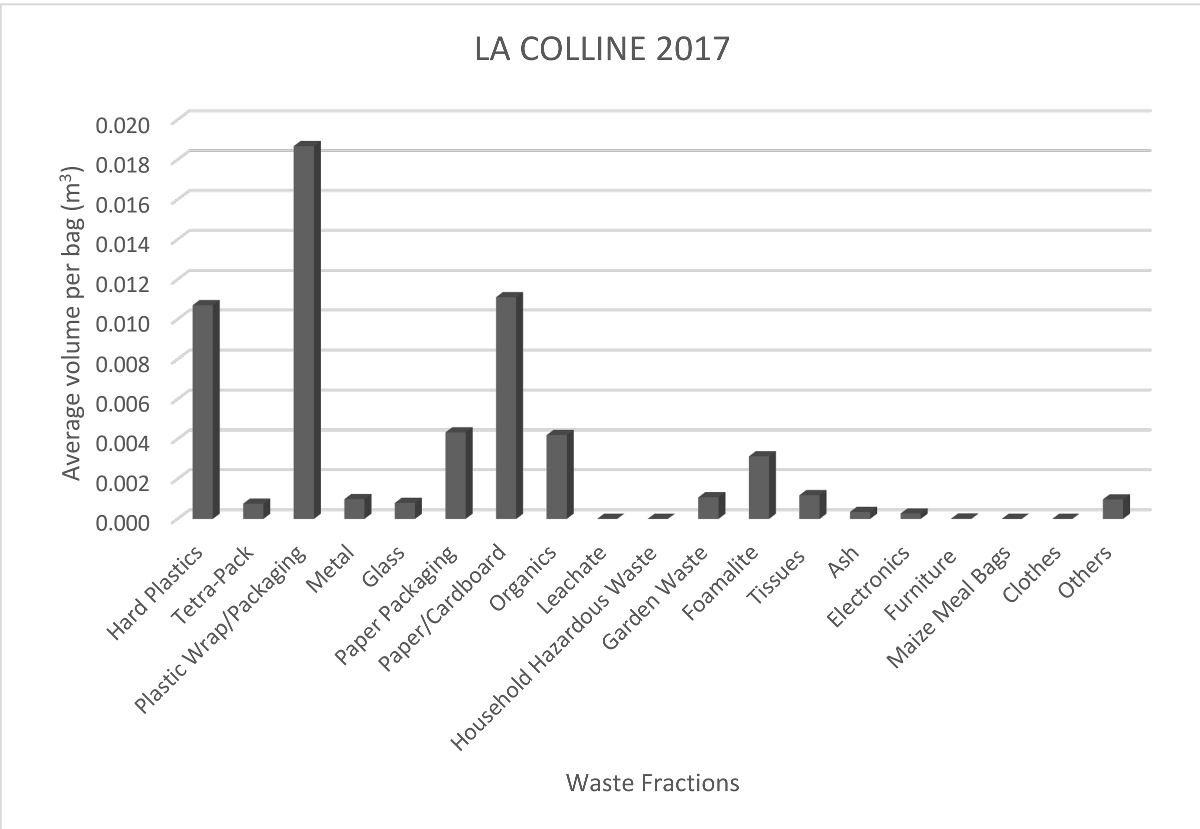

JONKERSHOEK 2017
Average weight per bag (kg)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

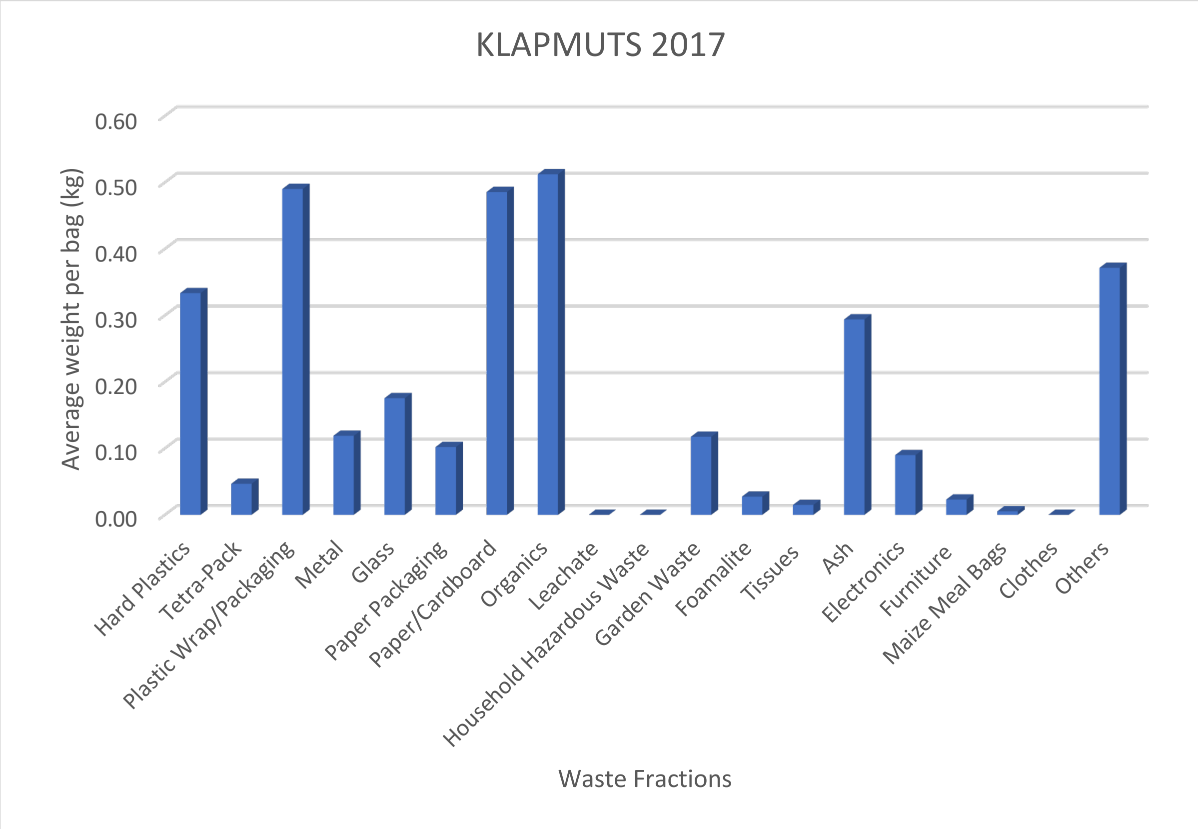

JONKERSHOEK 2017
Average volume per bag (m3)
0.025
0.020
0.015
0.010
0.005
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


SIMONSWYK 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

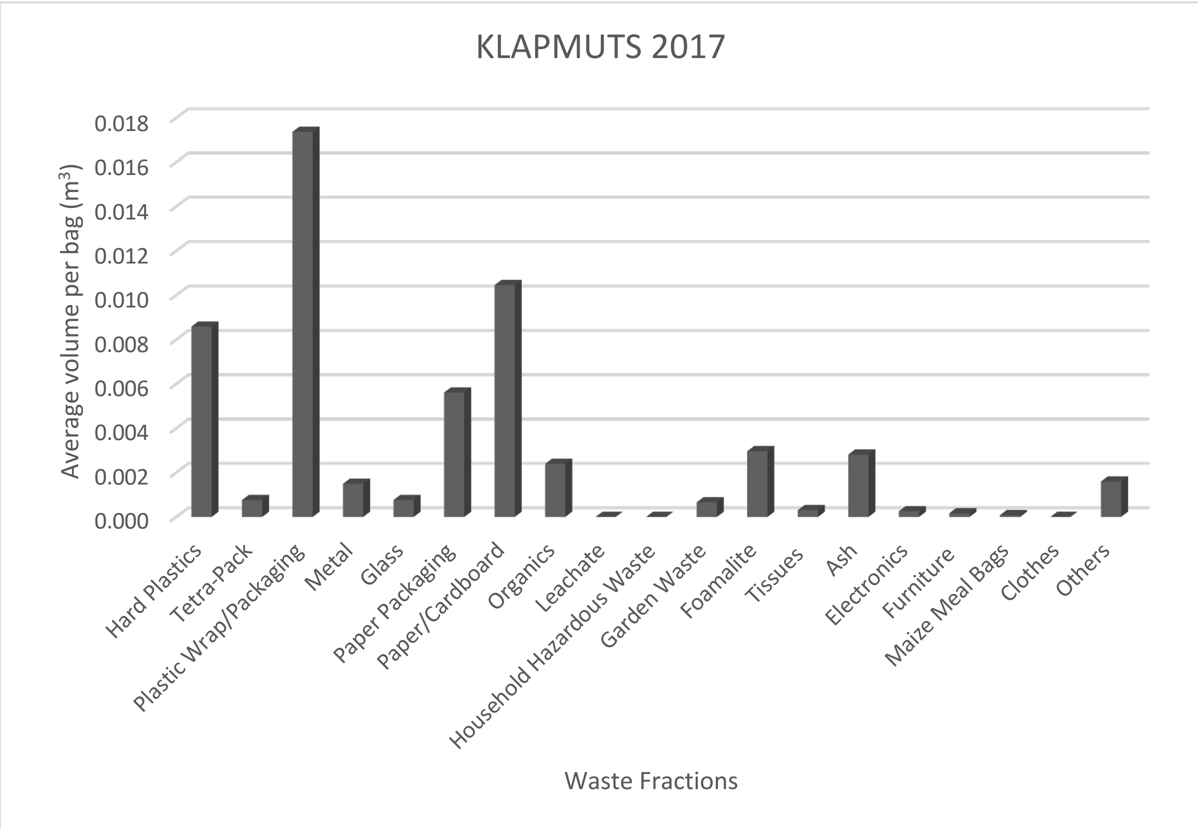

SIMONSWYK 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


LA COLLINE 2017
Average weight per bag (kg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

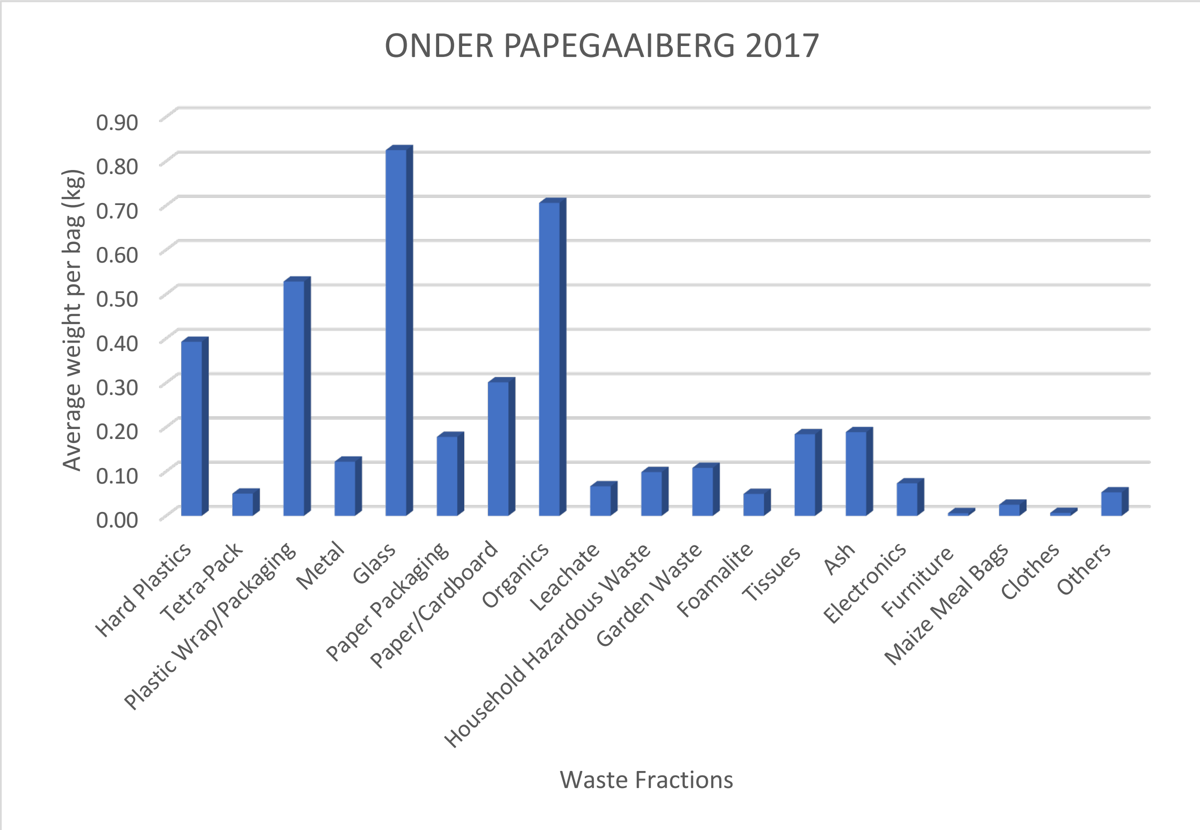

LA COLLINE 2017
Average volume per bag (m³)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

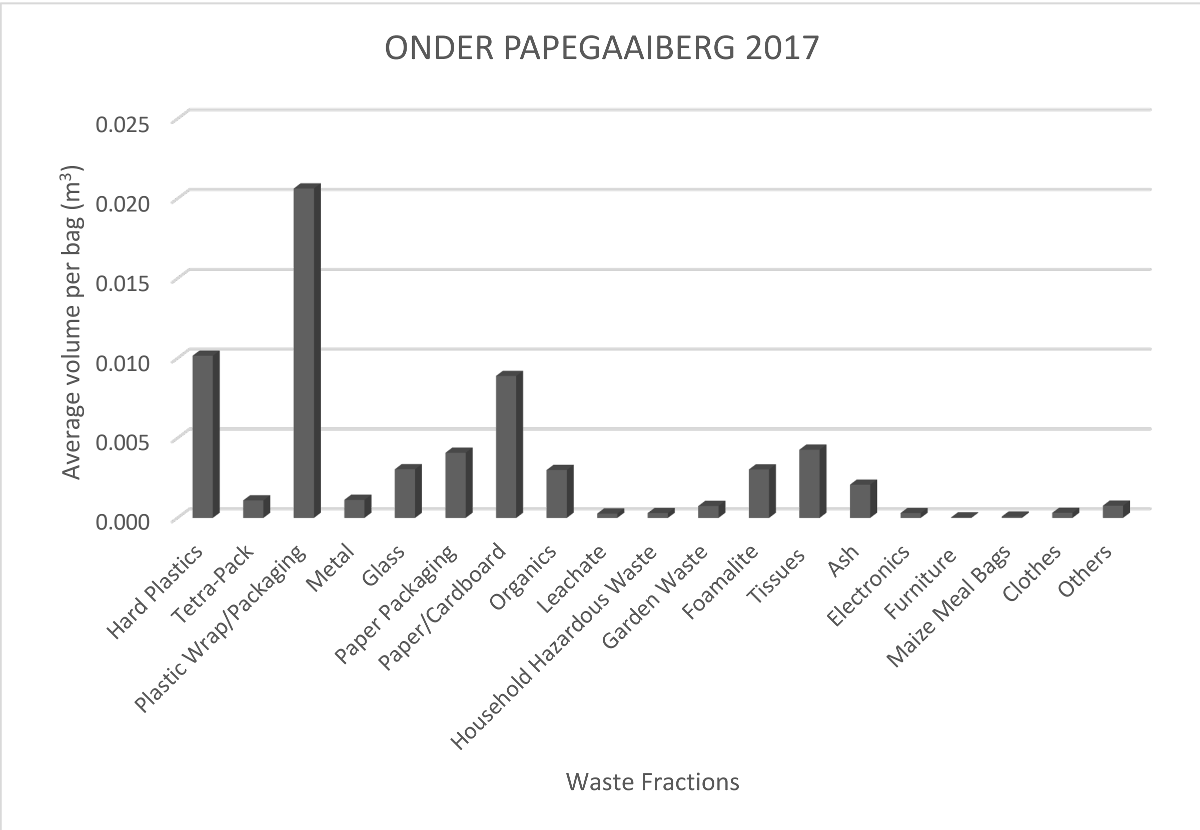


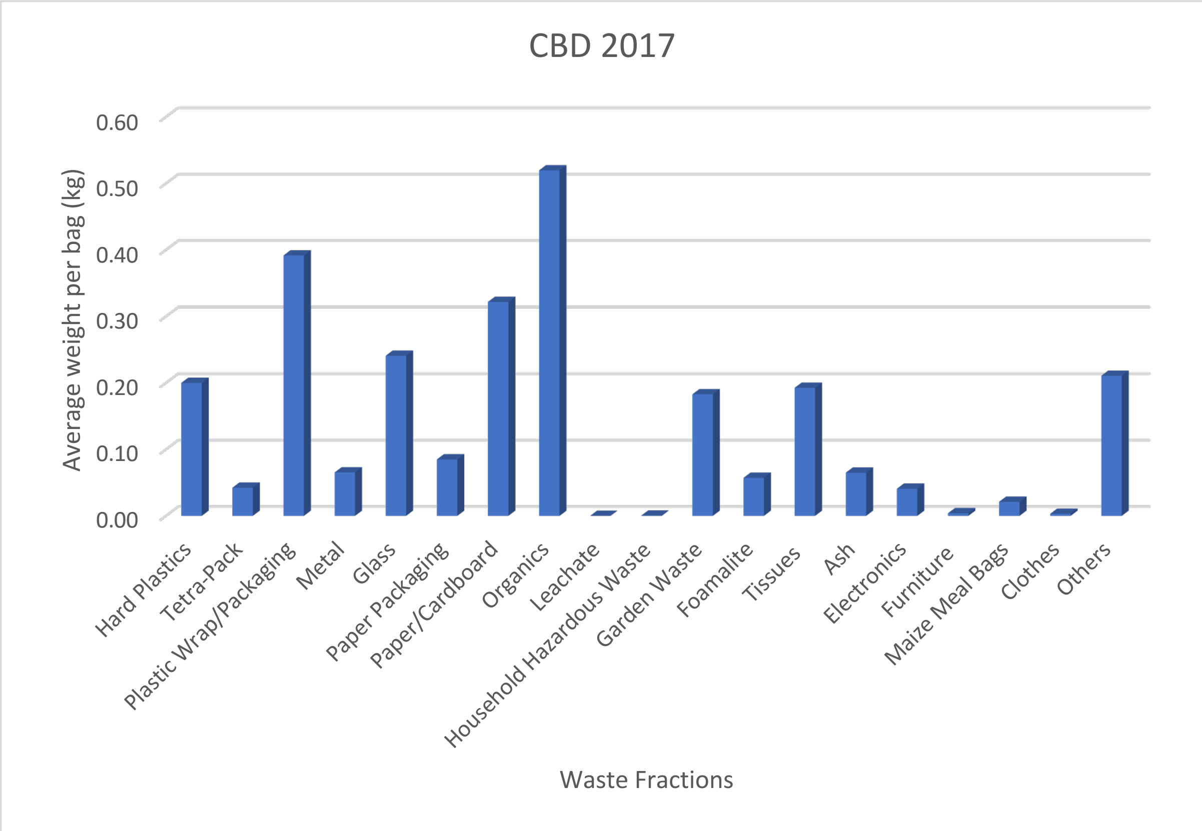
KLAPMUTS 2017
Average weight per bag (kg)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

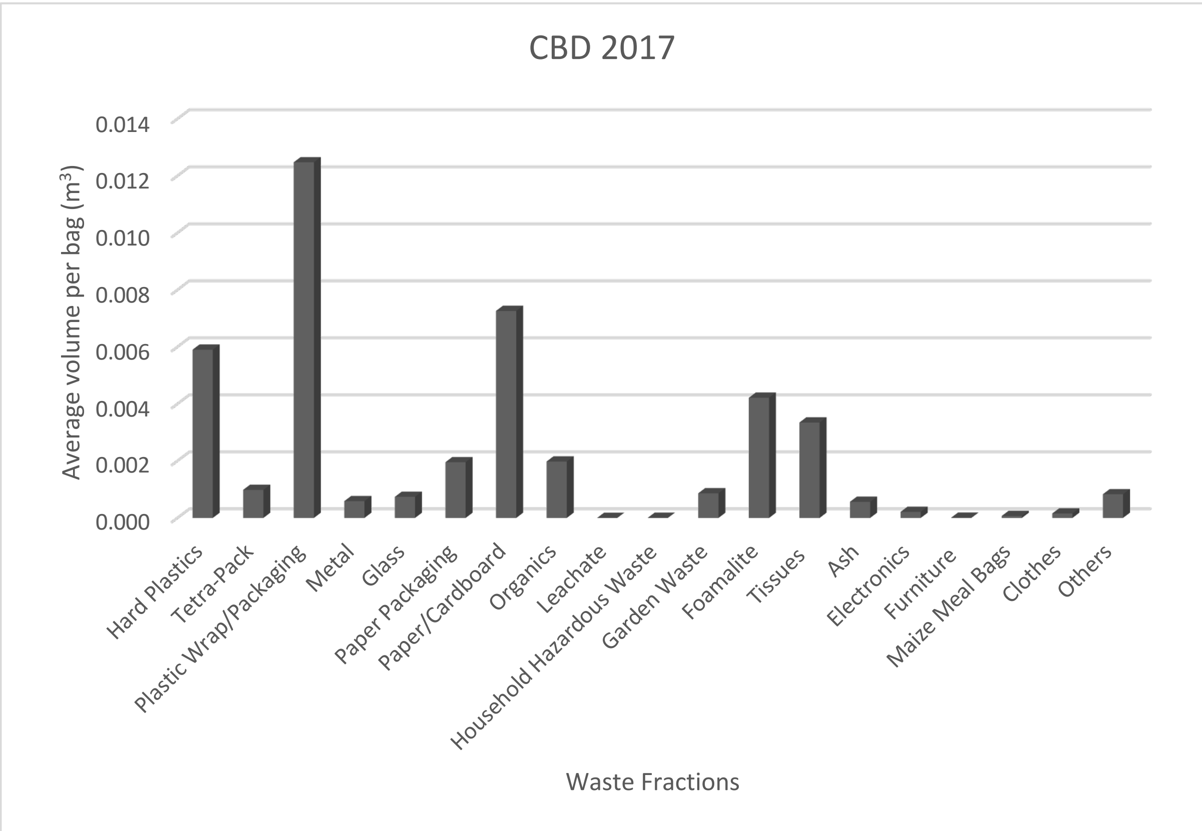


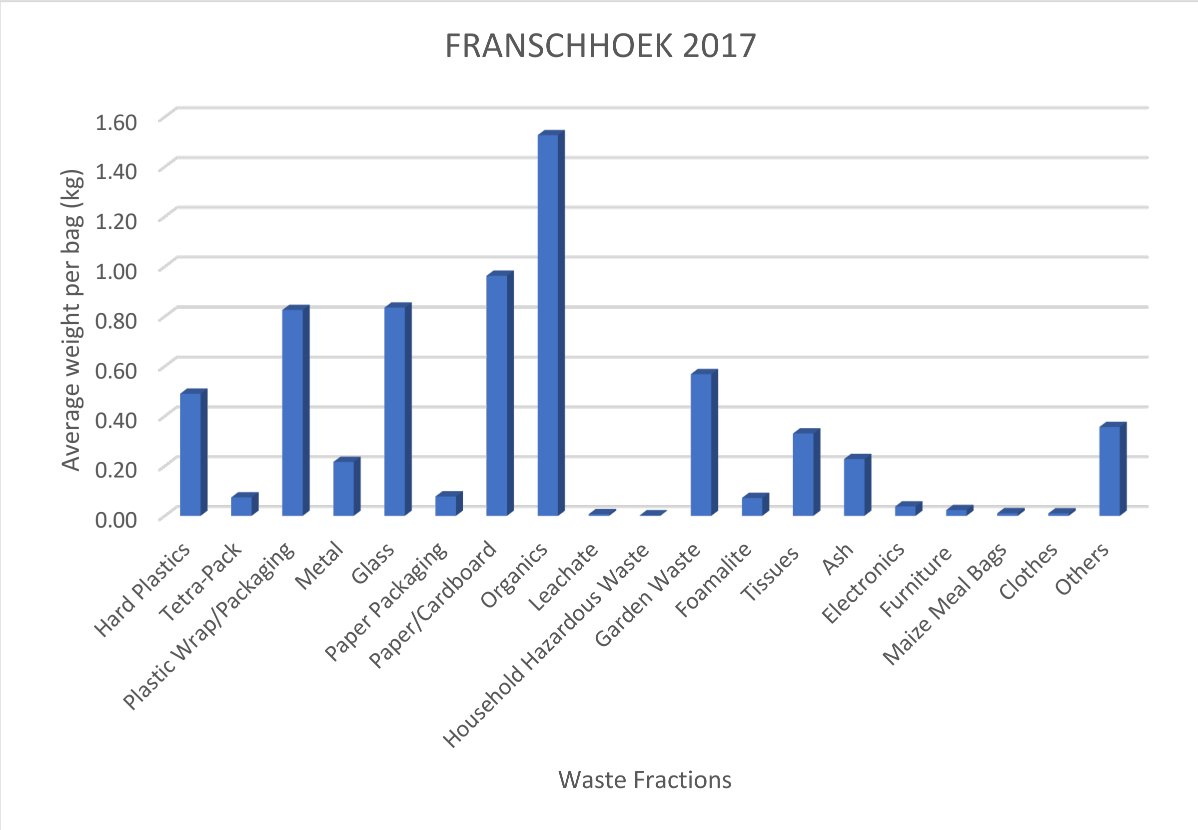
KLAPMUTS 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

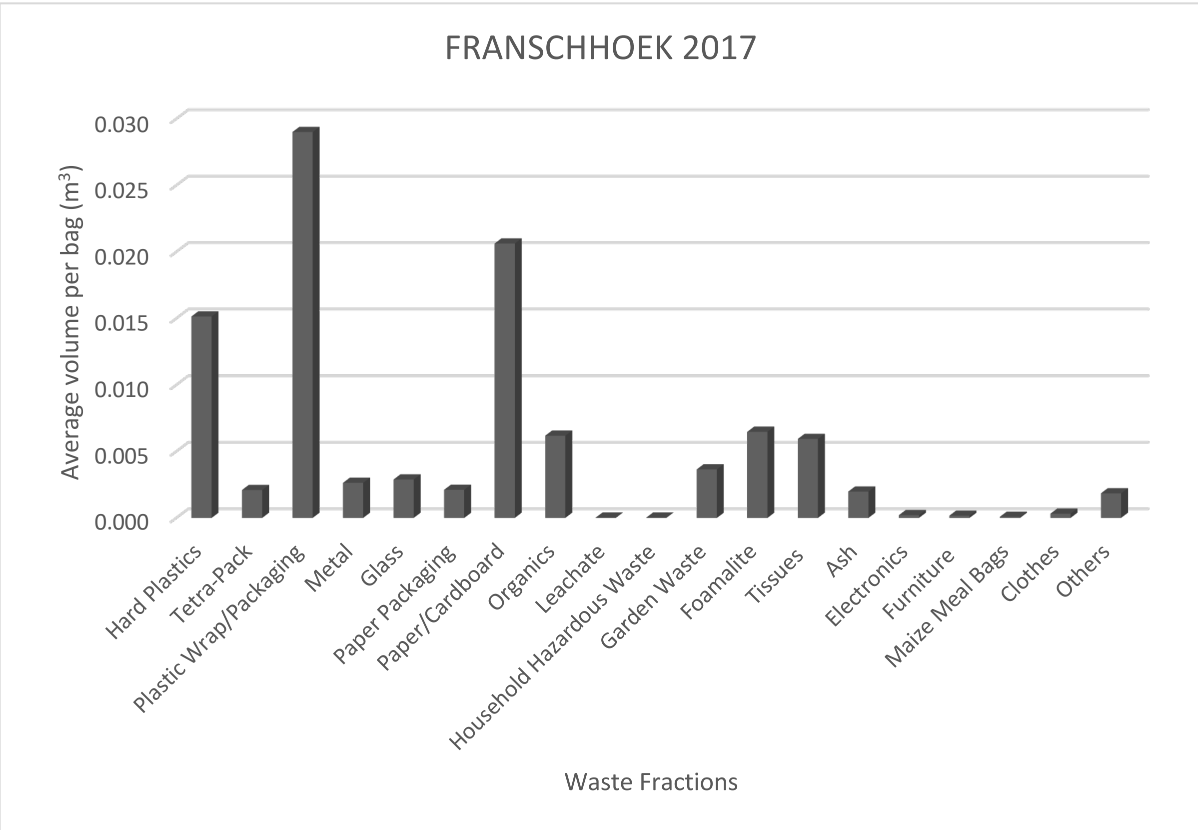

ONDER PAPEGAAIBERG 2017
Average weight per bag (kg)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

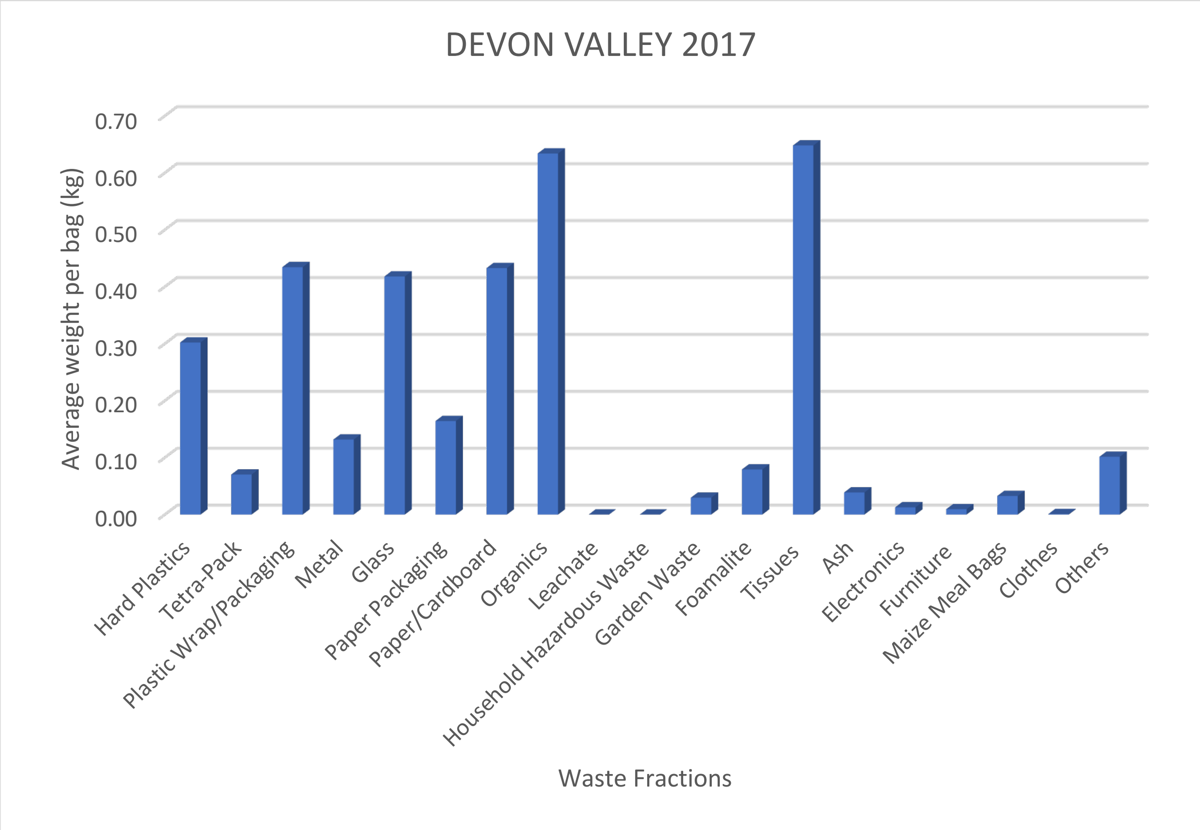

ONDER PAPEGAAIBERG 2017
Average volume per bag (m³)
0.025
0.020
0.015
0.010
0.005
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

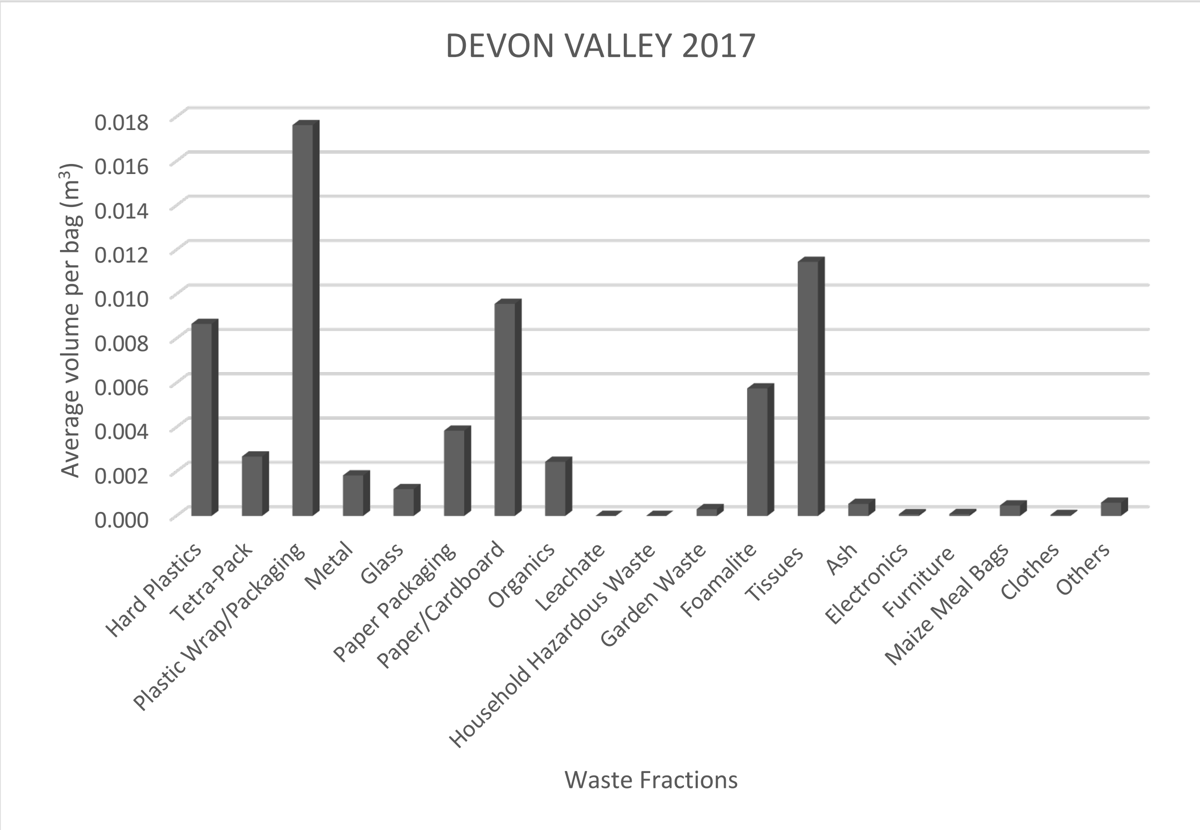

CBD 2017
Average weight per bag (kg)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

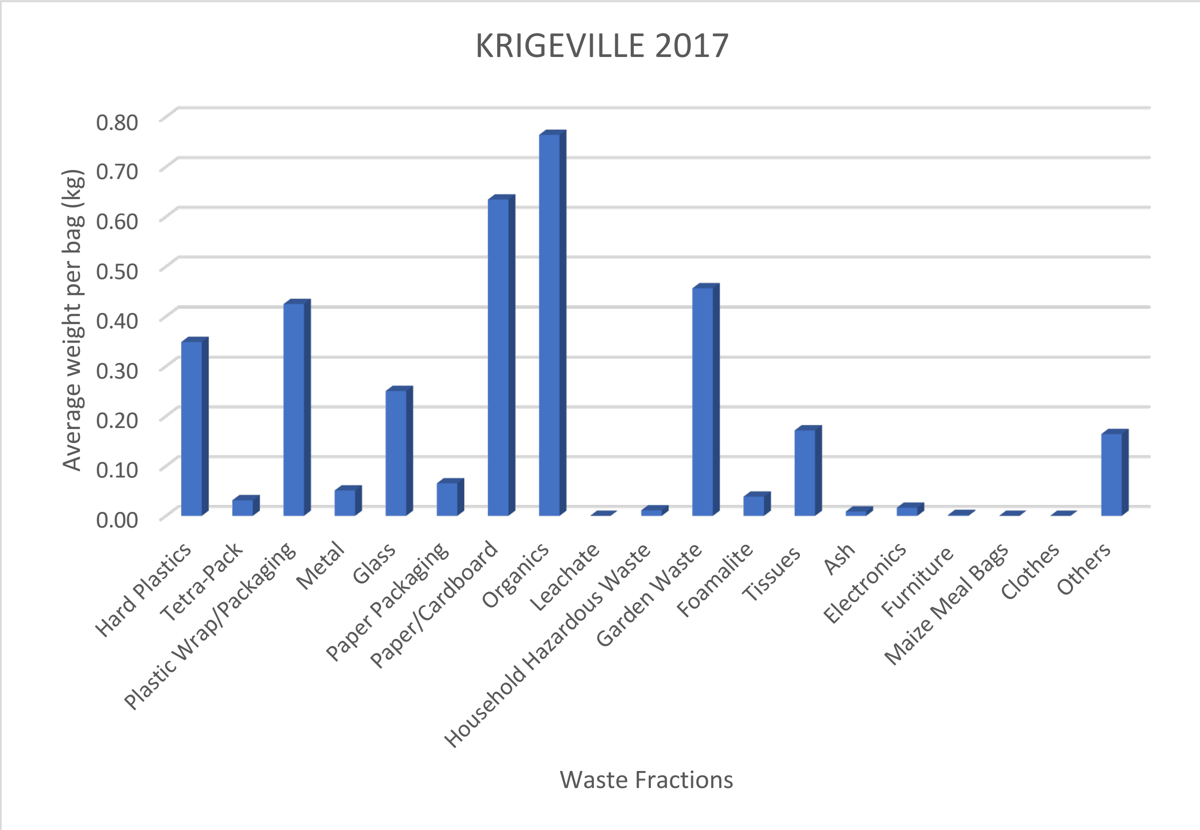

CBD 2017
Average volume per bag (m3)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

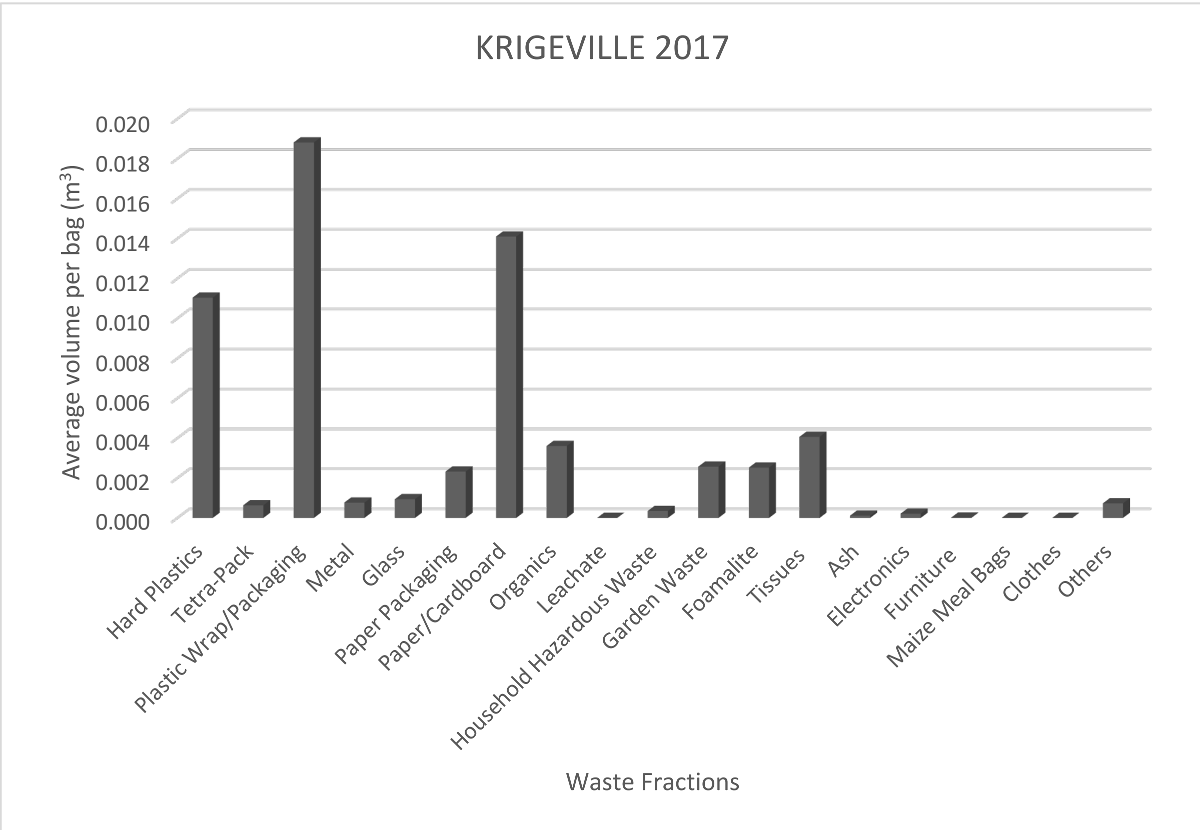

FRANSCHHOEK 2017
Average weight per bag (kg)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

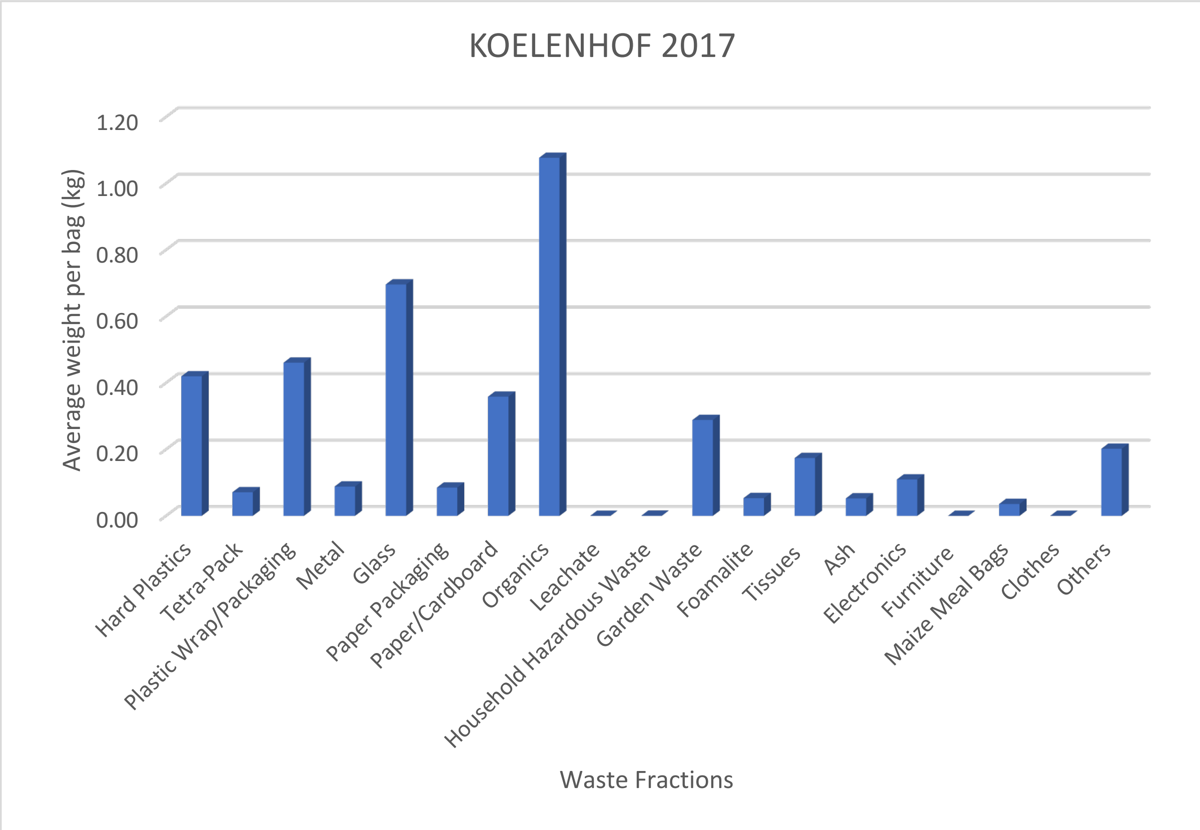

FRANSCHHOEK 2017
Average volume per bag (m³)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

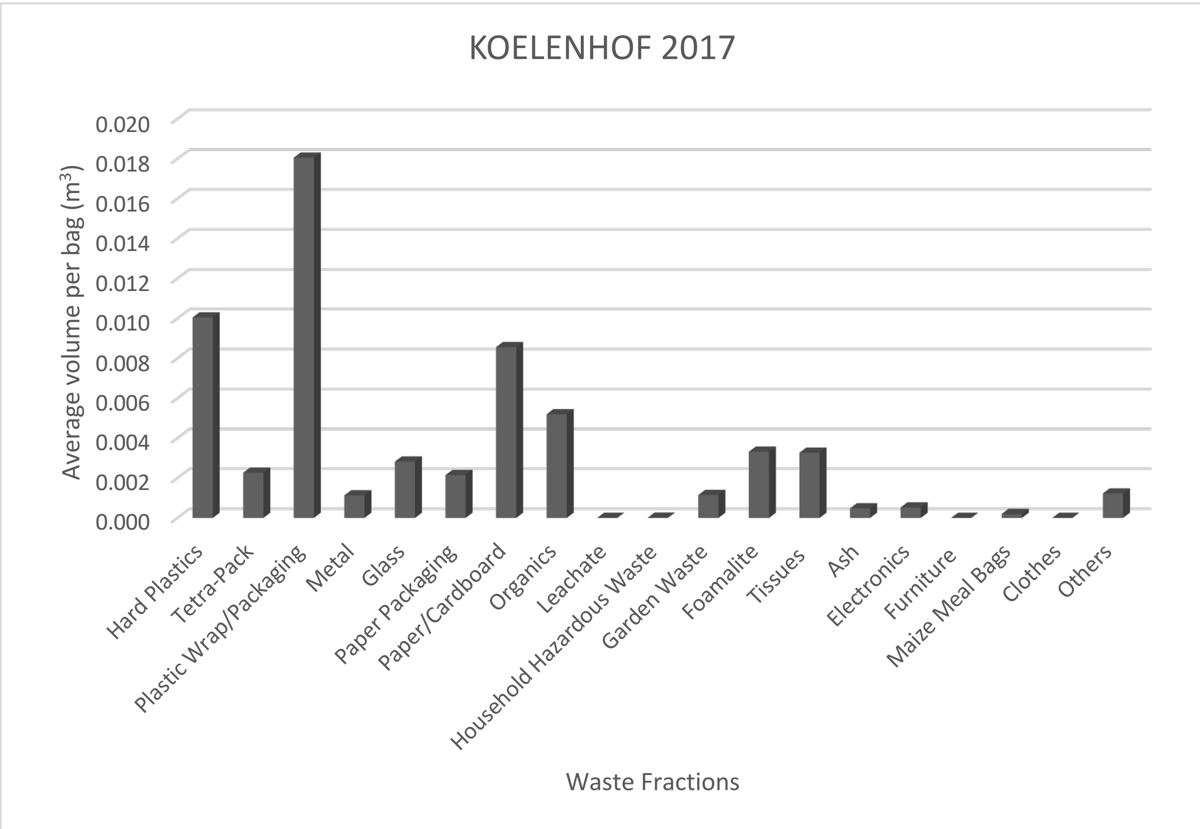

DEVON VALLEY 2017
Average weight per bag (kg)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions


DEVON VALLEY 2017
Average volume per bag (m³)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

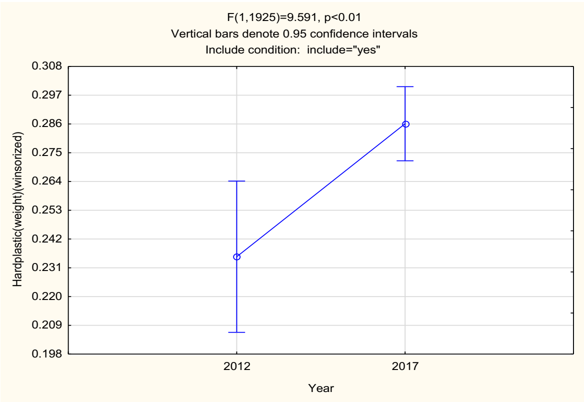

KRIGEVILLE 2017
Average weight per bag (kg)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

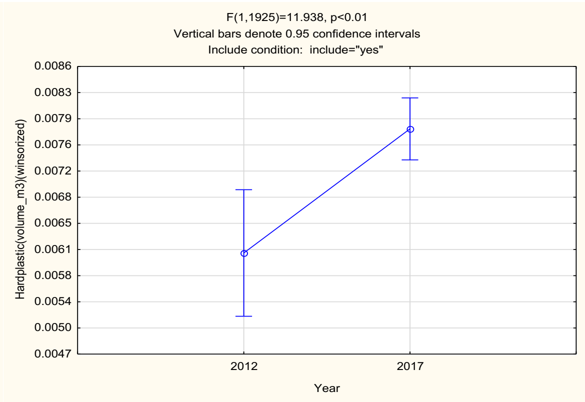

KRIGEVILLE 2017
Average volume per bag (m3)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

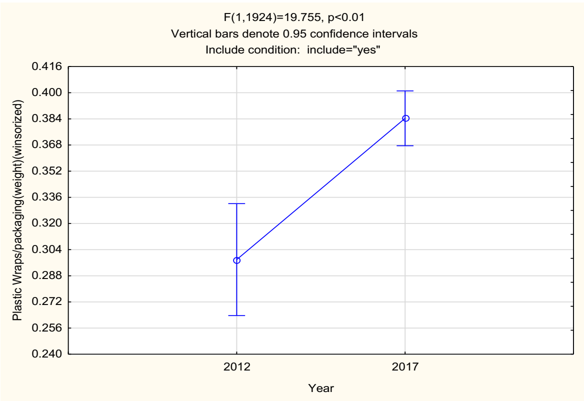

KOELENHOF 2017
Average weight per bag (kg)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

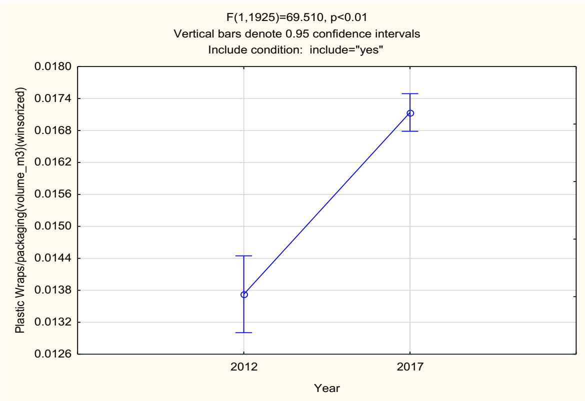

KOELENHOF 2017
Average volume per bag (m³)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Hard Plastics
Tetra-Pack
Plastic Wrap/Packaging
Metal
Glass
Paper Packaging
Paper/Cardboard
Organics
Leachate
Household Hazardous Waste
Garden Waste
Foamalite
Tissues
Ash
Electronics
Furniture
Maize Meal Bags
Clothes
Others
Waste Fractions

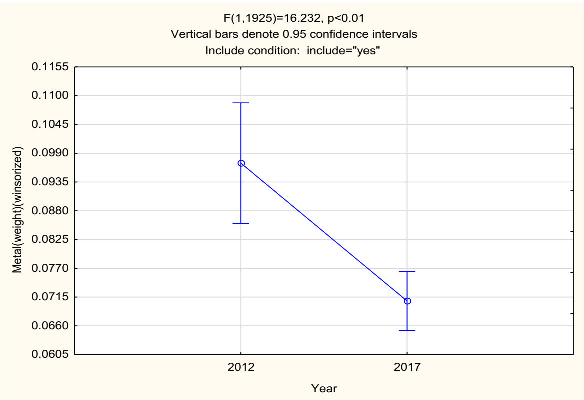
APPENDIX 2.1

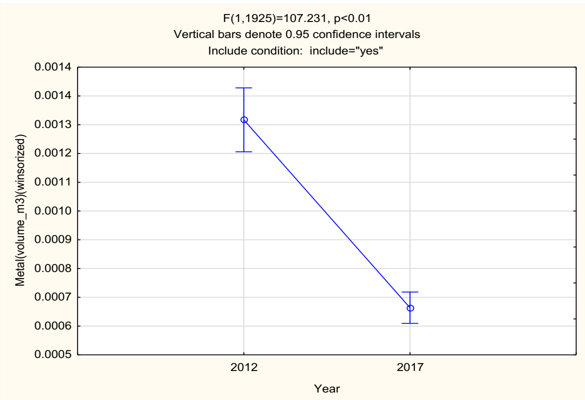

F(1,1925)=9.591, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Hardplastic(weight)(winsorized)
0.308
0.297
0.286
0.275
0.264
0.253
0.242
0.231
0.220
0.209
0.198
2012
2017
Year

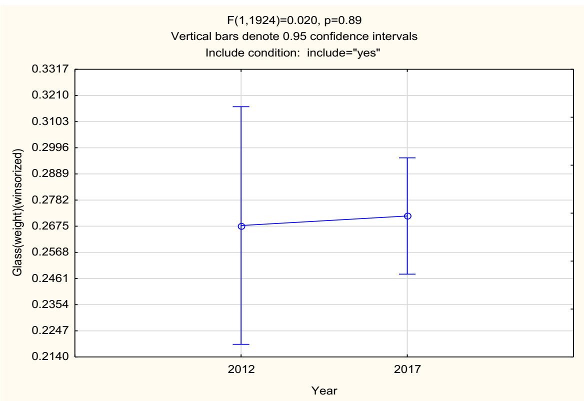

F(1,1925)=11.938, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Hardplastic(volume_m3)(winsorized)
0.0086
0.0083
0.0079
0.0076
0.0072
0.0068
0.0065
0.0061
0.0058
0.0054
0.0050
0.0047
2012
2017
Year

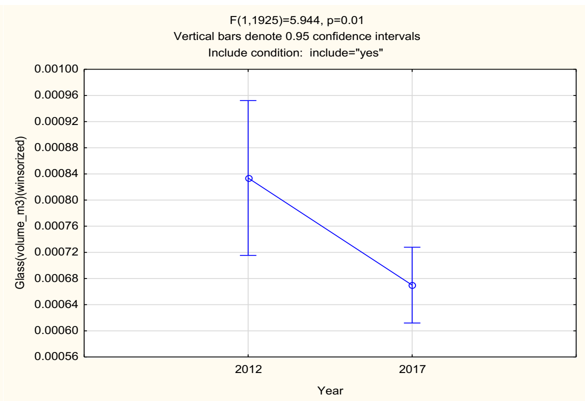

F(1,1924)=19.755, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Plastic Wraps/packaging(weight)(winsorized)
0.416
0.400
0.384
0.368
0.352
0.336
0.320
0.304
0.288
0.272
0.256
0.240
2012
2017
Year

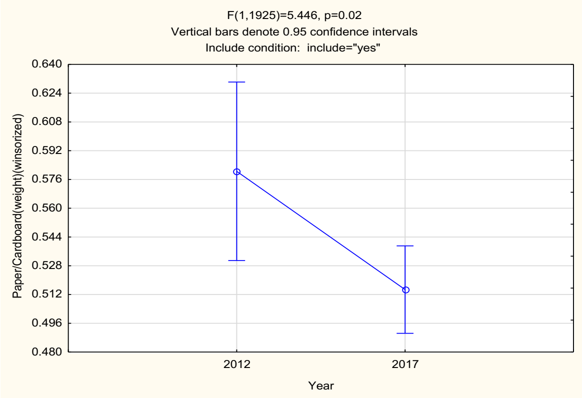

F(1,1925)=69.510, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Plastic Wraps/packaging(volume_m3)(winsorized)
0.0180
0.0174
0.0168
0.0162
0.0156
0.0150
0.0144
0.0138
0.0132
0.0126
2012
2017
Year

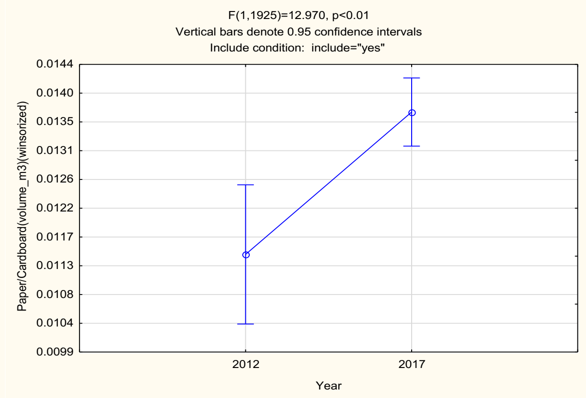

F(1,1925)=16.232, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Metal(weight)(winsorized)
0.1155
0.1100
0.1045
0.0990
0.0935
0.0880
0.0825
0.0770
0.0715
0.0660
0.0605
2012
2017
Year

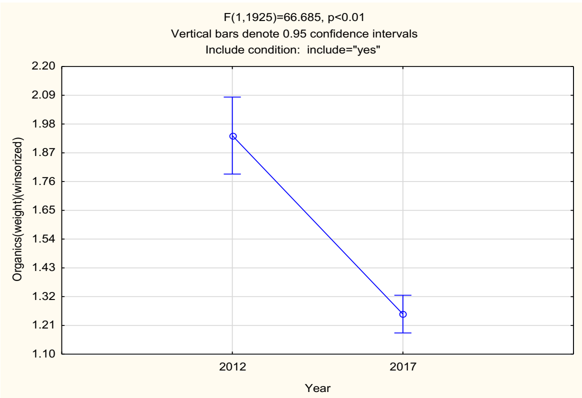

F(1,1925)=107.231, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Metal(volume_m3)(winsorized)
0.0014
0.0014
0.0013
0.0012
0.0011
0.0010
0.0009
0.0008
0.0007
0.0006
0.0005
2012
2017
Year

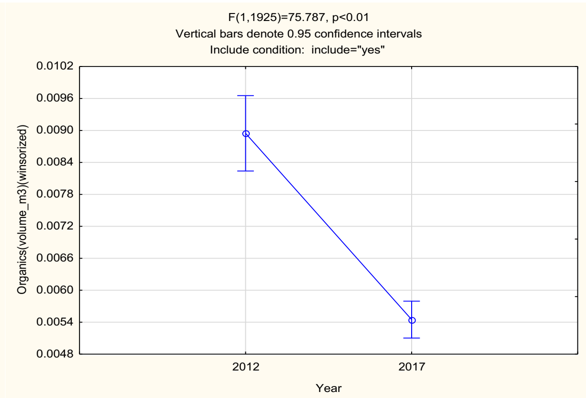

F(1,1924)=0.020, p=0.89
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Glass(weight)(winsorized)
0.3317
0.3210
0.3103
0.2996
0.2889
0.2782
0.2675
0.2568
0.2461
0.2354
0.2247
0.2140
2012
2017
Year

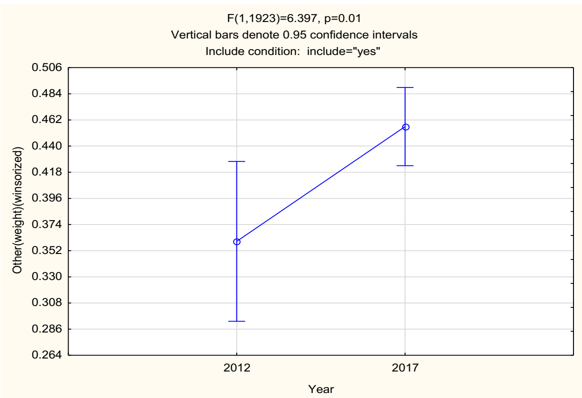

F(1,1925)=5.944, p=0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Glass(volume_m3)(winsorized)
0.00100
0.00096
0.00092
0.00088
0.00084
0.00080
0.00076
0.00072
0.00068
0.00064
0.00060
0.00056
2012
2017
Year

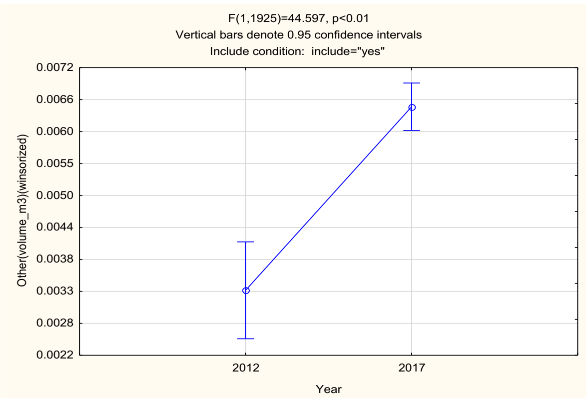

F(1,1925)=5.446, p=0.02
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Paper/Cardboard(weight)(winsorized)
0.640
0.624
0.608
0.592
0.576
0.560
0.544
0.528
0.512
0.496
0.480
2012
2017
Year


F(1,1925)=12.970, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Paper/Cardboard(volume_m3)(winsorized)
0.0144
0.0140
0.0135
0.0131
0.0126
0.0122
0.0117
0.0113
0.0108
0.0104
0.0099
2012
2017
Year


F(1,1925)=66.685, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Organics(weight)(winsorized)
2.20
2.09
1.98
1.87
1.76
1.65
1.54
1.43
1.32
1.21
1.10
2012
2017
Year


F(1,1925)=75.787, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Organics(volume_m3)(winsorized)
0.0102
0.0096
0.0090
0.0084
0.0078
0.0072
0.0066
0.0060
0.0054
0.0048
2012
2017
Year


F(1,1923)=6.397, p=0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Other(weight)(winsorized)
0.506
0.484
0.462
0.440
0.418
0.396
0.374
0.352
0.330
0.308
0.286
0.264
2012
2017
Year


F(1,1925)=44.597, p<0.01
Vertical bars denote 0.95 confidence intervals
Include condition: include="yes"
Other(volume_m3)(winsorized)
0.0072
0.0066
0.0060
0.0055
0.0050
0.0044
0.0038
0.0033
0.0028
0.0022
2012
2017
Year

APPENDIX 2.2

Name of area	Change over time (2012 to 2017)					
Fraction	**Mass 2012***	**Mass 2017 ***	**% change**	**Volume 2012 ****	**Volume 2017****	**% change**
Cloetesville	5.25	4.13	-21%	0.05	0.06	+20%
Jamestown	4.71	3.71	-21%	0.05	0.06	+20%
Uniepark	3.70	3.85	+4%	0.04	0.06	+50%
Kayamandi	6.06	4.18	-31%	0.05	0.06	+20%
Idas Valley	5.14	3.29	-36%	0.05	0.06	+20%
Die Boord	3.67	3.42	-7%	0.05	0.05	0%
Welgevonden	4.07	2.61	-36%	0.04	0.05	+25%
Paradyskloof	4.06	3.36	-17%	0.05	0.05	0%
Brandwacht	5.07	3.55	-30%	0.04	0.05	+25%
Simonswyk	3.62	3.61	0%	0.05	0.05	0%

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

APPENDIX 2.3

HARD PLASTICS	Change over time (2012 to 2017)			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	+65%	**0.01**	+50%	**0.02**
Jamestown	-9%	0.25	-13%	0.51
Uniepark	+14%	0.6	+13%	0.56
Kayamandi	+19%	0.34	+50%	**0.02**
Idas Valley	+14%	0.15	+43%	**<0.01**
Die Boord	+17%	0.19	0%	0.75
Welgevonden	-4%	0.92	+17%	0.55
Paradyskloof	+12%	0.17	+33%	0.13
Brandwacht	+81%	0.19	+40%	0.58
Simonswyk	+45%	0.15	+60%	0.09

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

PLASTIC WRAP / PACKAGING	**Change over time (2012 to 2017)**			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	+8%	0.79	+18%	**<0.01**
Jamestown	+41%	**0.01**	+23%	**<0.01**
Uniepark	+88%	**<0.01**	+39%	**<0.01**
Kayamandi	+0%	0.33	+19%	**<0.01**
Idas Valley	+29%	0.13	+29%	**<0.01**
Die Boord	+90%	**0.01**	+42%	**<0.01**
Welgevonden	-10%	0.62	+21%	**0.02**
Paradyskloof	+17%	0.44	+6%	0.23
Brandwacht	+48%	0.26	+29%	**0.03**
Simonswyk	+64%	**0.05**	+13%	**0.05**

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

METALS	Change over time (2012 to 2017)			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	-14%	0.28	0%	**<0.01**
Jamestown	-38%	**<0.01**	-67%	**<0.01**
Uniepark	+43%	0.54	+0%	0.18
Kayamandi	-9%	0.57	+100%	0.31
Idas Valley	-36%	**<0.01**	-50%	**<0.01**
Die Boord	0%	0.85	-50%	**0.02**
Welgevonden	-54%	**<0.01**	-50%	**<0.01**
Paradyskloof	-33%	0.17	-50%	**<0.01**
Brandwacht	+17%	0.99	-50%	0.11
Simonswyk	-54%	**0.03**	-50%	**<0.01**

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

GLASS	Change over time (2012 to 2017)			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	-31%	0.35	-33%	**0.01**
Jamestown	-76%	**<0.01**	-67%	**<0.01**
Uniepark	-38%	0.31	-33%	0.27
Kayamandi	+21%	0.14	+0%	0.75
Idas Valley	+8%	0.97	-50%	**0.05**
Die Boord	+52%	**0.03**	+100%	0.34
Welgevonden	+45%	0.45	0%	0.74
Paradyskloof	+6%	0.96	0%	0.29
Brandwacht	+64%	0.51	+100%	0.28
Simonswyk	+87%	0.28	0%	0.46

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

PAPER/CARDBOARD	Change over time (2012 to 2017)			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	-14%	0.39	+29%	**0.02**
Jamestown	3%	0.83	+23%	0.12
Uniepark	-43%	0.65	+27%	0.15
Kayamandi	-8%	0.25	+36%	**0.01**
Idas Valley	+7%	0.42	+33%	**<0.01**
Die Boord	+11%	0.57	+30%	0.16
Welgevonden	-4%	0.91	+36%	**0.03**
Paradyskloof	-32%	**<0.01**	0%	1.00
Brandwacht	-24%	0.36	0%	0.86
Simonswyk	-42%	**0.01**	-15%	0.42

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

ORGANICS	Change over time (2012 to 2017)			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	-46%	**<0.01**	-33%	**<0.01**
Jamestown	-34%	**<0.01**	-40%	**<0.01**
Uniepark	+18%	0.27	+60%	0.14
Kayamandi	-55%	**<0.01**	-46%	**<0.01**
Idas Valley	-66%	**<0.01**	-55%	**<0.01**
Die Boord	-38%	**0.01**	-60%	**<0.01**
Welgevonden	-65%	**<0.01**	-67%	**<0.01**
Paradyskloof	-44%	**<0.01**	-33%	**<0.01**
Brandwacht	-55%	0.16	-20%	0.20
Simonswyk	+1%	0.50	-20%	0.55

* Average total mass per bag (kg)

** Average total volume per bag (m^3)

OTHERS	**Change over time (2012 to 2017)**			
Area	**Mass***	**p-value**	**Volume****	**p-value**
Cloetesville	+25%	0.07	+80%	**0.01**
Jamestown	+10%	**0.03**	+200%	**<0.01**
Uniepark	+132%	0.18	+100%	**0.04**
Kayamandi	-30%	**0.01**	+33%	0.11
Idas Valley	+11%	0.23	+75%	**0.04**
Die Boord	+73%	0.10	+25%	0.65
Welgevonden	-20%	0.92	+50%	**0.05**
Paradyskloof	+218%	**0.02**	+200%	**<0.01**
Brandwacht	+150%	0.30	+250%	**0.05**
Simonswyk	-9%	0.65	+50%	0.30

* Average total mass per bag (kg)

** Average total volume per bag (m^3)