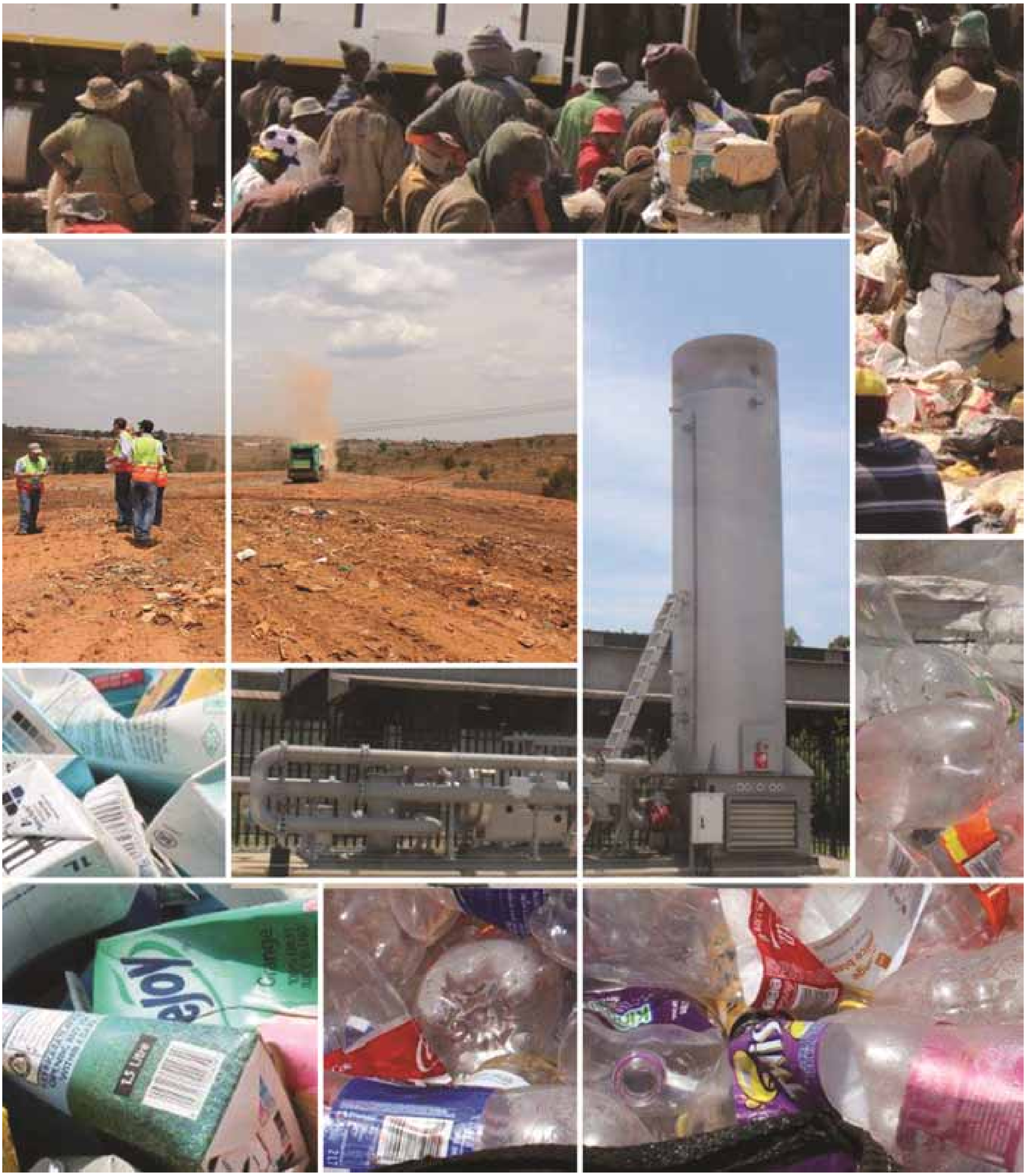

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Feasibility study for alternative waste treatment technology

Part 3: Waste characterisation study for September 2014 and November 2014 sampling

Gauteng Infrastructure Funding Agency on behalf of City of Johannesburg

GAUTENG Infrastructure Financing Agency

Joburg
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PIKI TUP JOHANNESBURG SOC Limited

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Abbreviations

- CoJ City of Johannesburg
- CV Calorific value
- FEL Front end loader
- MBT Mechanical-biological treatment
- MSW Municipal solid waste
- PPP Public-Private Partnership
- RCR Round collection refuse
- WCS Waste characterisation study
- WtE Waste-to-energy

Definitions

Definitions for the terms used are:

- The City: City of Johannesburg the Metropolitan Municipality
- The city: the geographic area that falls within the demarcated boundaries of the City of Johannesburg, and the area for which the City of Johannesburg is responsible in its role as local government

1 Executive summary

This document reports on the waste characterisation study (WCS) that was done for the City of Johannesburg (CoJ) to inform the feasibility study for the alternative waste treatment technology project.

The aim of the study is to capture seasonal and socio-economic variability in the composition and generation rates of municipal solid waste within the CoJ Metropolitan Municipality. The terms of reference for the study stipulates winter and summer sampling, but in order to fast track the project, the first round of sampling was done in September 2014, followed by a second round of sampling in November 2014. A comparison between these two samples provides evidence to support a decision as to whether a true winter sample is required for the purposes of the feasibility study.

Following is a summary of the September and November 2014 findings; more details can be found in the body of the report.

1.1 Sampling

A total of 54 purposive selected, random samples were collected and analysed during September 2014 and 74 samples during November 2014. This resulted in the inclusion of a total of 128 (i.e. 94%) out of the possible 136 collection routes as part of the sampling process in this characterisation study. A total of 18.4 tonnes of households waste was sorted and categorised for this study (7.8 tonnes during September 2014 and 10.6 tonnes during November 2014) (refer to section 5.1).

1.2 Household waste composition

The results of the September (8 September to 6 October 2014) and November (3 November to 12 December 2014) WCS, confirmed seasonal variability in the composition of the municipal solid waste in the City.

The month of September signifies the start of spring in Johannesburg and the September waste composition therefore needs to be confirmed as a true winter waste composition for the City. In the absence of a true winter WCS conducted, it was not possible to compare the characteristics of this study with that of a true winter sample.

Although the results of the study presented in this report provides useful insights that could be used to inform the feasibility study, lack of detail on the extent of seasonal variability pose a risk to the procurement processes.

Statistical analysis of the difference between the September and November results confirmed statistical significant differences in some waste streams. These differences can possibly be ascribed to seasonal variation (especially in garden waste) in the waste characteristics of round collection refuse (RCR) waste in the City.

Any flawed assumptions will have serious implications for the future success of the project as well as for the value for money of the investment.

It is the opinion of the project team that a true winter WCS is required to meet the objectives of the study and to provide evidence on which investment decisions can be based. The project team therefore recommends that another round of sampling should be done, no earlier than May 2015 but ideally in July 2015, to confirm the winter waste characteristics of the City.

1.2.1 Household waste composition by socio-economic category

Low income households contribute the majority (52%) of household waste in the City.

Comparing waste composition by income category it is apparent that:

- For both sampling periods high income households contributed the bulk of garden waste and miscellaneous non-combustible waste
- Low income households contributed the larger proportion of textiles and footwear waste
- A greater proportion of glass was disposed by high income households followed, by low and then medium income households

1.2.2 Low income waste composition by type of housing structure

There seems to be a correlation in waste composition and type of housing structure in low income households. The composition of garden waste is highest in formal houses followed, by low cost houses (RDP houses) with the lowest at informal houses. Food waste is highest at low cost housing, followed by informal housing.

1.2.3 Source separation of household waste

Inefficiencies in household waste separation at source were evident, especially in low income areas where garden and food waste were present in the source separated recyclables and glass in the residual waste. There is thus a need for training and education initiatives at households to improve source separation initiatives, especially in low income households.

The results indicate that sorting of plastics, paper and metals seem to be very effective, with only small amounts remaining in the residual waste of all income groups.

The miscellaneous non-combustible waste in residues is indicative of there being very little awareness of recycling opportunities for building rubble etc. This needs to be looked at by the City.

1.3 Special waste streams

Four categories of special waste were identified during the study, which included:

- Commercial waste
- Illegal dumping
- Builder's rubble
- Garden waste

Commercial waste analysed consisted of large amounts of glass, followed by textiles and footwear. There were also traces of metal, paper fractions, and plastics.

Builder's rubble analysed from garden waste sites was made up of e-waste, woody waste, fines, miscellaneous combustible and non-combustible waste.

Illegal dumping varies according to its source and location, although it is not possible to easily trace the source of the waste, and this was not the scope of this study. The general consensus when discussing illegal dumping of waste with Pikitup officials seems to be that in the built up areas this consists mostly of garden waste, while in the peripheral areas, this consists mostly of builder's rubble.

1.4 Waste generation estimates

The data collected through the actual sampling was used to estimate waste generation in the City. The September 2014 waste generation rates thus estimated indicate that between 1.3 and 2.6 million tonnes/annum (with a median value of 1.6 million tonnes) is generated in the City. This median estimate is on par with the City estimates. Based on the November 2014 data collected, the estimated annual household waste generation varies between 450 544 tonnes/annum (minimum) and 1 719 365 tonnes/annum (maximum).

The difference in the estimated waste generation between September and November can be attributed to the lower per capita waste generation rate in low income households observed during the November sampling as compared to September.

The variation in waste generation rates between September and November is a further indication that there may be seasonal variation not only in waste composition but also waste generation rates.

1.5 Household waste generation per income category

Low income households make up the bulk of the waste sample for both sampling periods (i.e. for September and November 2014, 52% and 52% respectively). High income households contributed relatively more waste in November compared to September 2014 (22% and 27% respectively).

Both the September and November 2014 data show that there was approximately one bin put out per household during the survey (i.e. bins/households). This is in agreement with Pikitup staff who confirmed that approximately one bin is usually collected per household during RCR collections.

1.6 Calorific values

Calorific values (CV) for the November 2014 samples were carried out by Talbot and Talbot laboratories.

The results of the laboratory tests are in line with generic published calorific values for the same waste streams. It can therefore be concluded that there is energy potential locked in the waste streams which could be extracted through waste-to-energy (WtE) technologies.

1.7 Findings and recommendations

Attention is drawn to the following findings:

- There is a seasonal and socio-economic variation in the waste generated within the CoJ[1]
- The difference in composition between September and November is statistically significant although the difference in composition is relatively small for most waste streams
- The project team is comfortable that a representative sample of RCR waste in the city was analysed during both sampling periods; the reader is cautioned that the full extent of seasonal variability has not been established due to the fact that no true winter sample was done
- The samples relating to special waste streams is however too small to generalise or extrapolate

It is recommended that:

- A true winter WCS must be done in the winter of 2015 to confirm the full extent of seasonal variability in the composition and generation of household waste in the CoJ
- More awareness creation and education on source separation of waste at households and garden waste sites are required

2 Background and purpose

Approximately 1.6 million tonnes of municipal solid waste is reportedly being generated annually in the City of Johannesburg Metropolitan Municipality. With limited landfill airspace remaining to dispose of the current and future waste generated the City has no choice other than to source alternative methods for managing its waste. Alternative treatment technologies should support diversion of waste from landfill, job creation and energy generation.

Therefore in order to understand what options are available to the City to manage its municipal solid waste and to propose alternative treatment technologies in terms of the waste hierarchy (NWMS, 2011), it is important to understand the nature and magnitude of the fractions comprising the waste stream. This waste characterisation study was conducted in response to the Terms of Reference (ToR) as specified in tender documents (Contract number - GT/GFA/50/2014) issued by the CoJ. Winter and summer sampling are required to account for seasonal variability in the waste composition.

To fast track the project which only started in August 2014, the Project Steering Committee (PSC) instructed the project team to commence sampling in September 2014 and again in November 2014. The purpose of the September to October 2014 and November to December 2014 sampling was to get a sense of the variation in waste characterisation in the CoJ during winter and summer months respectively.

It is acknowledged that sampling for a winter characterisation should ideally be undertaken during July, which is the heart of winter in Gauteng. According to the South African Weather Service[2], the midpoint of winter is assumed to be July. Similarly, January is to be considered the midpoint of summer.

The 2001 waste characterisation (on which the methodology for this report is based) was done between 23 October 2000 and 15 December 2000, which was considered to be adequate for a representative summer sample. The 2001 study did not undertake a winter sampling but this was one of the recommendations put forward.

However, given the timing of this project, the results of the September 2014 round of sampling was compared to the November 2014 sampling. It has since been determined that there is a need to run a true winter sampling to conclude this study.

3 Aims and objectives

The aim of the WCS is to provide accurate information on waste stream composition and waste flows (which will be outlined in a separate report) within the City. This information is required to inform the technology choice and capacity requirements of the alternative waste treatment solution to be implemented by the City through a Public-Private Partnership (PPP).

The following objectives were specified in the tender documents:

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[1] This study represents a snap-shot in time and caution must be exercised when using the data for planning purposes
[2] http://www.weathersa.co.za/learning/weather-questions/82-how-arfe-the-dates-of-the-four-seasons-worked-out?recache=1

- Number of household serviced per sample vehicle as well as the waste compositions of the load
- The variation in the waste from each of the three socio-economic areas
- The total waste generated per household within each of the geographic zones that make up the three socio-economic areas of the city
- The categories of waste from each of the three socio-economic areas
- Physically count the number of households from which waste is collected in each of the three socio-economic areas and record the weight of the waste before disposal
- Determine the variability in waste categories from the three socio-economic areas by collecting separate samples from each of the waste collection vehicles
- The relevant statistical parameters (i.e. mean, standard deviation, etc.) for each sample in order to inform the sampling methodology in the next phase

Following is a description of the methodology and approach used to determine each of the above requirements as well as the necessary modifications that were required based on conditions on the ground during the September 2014 and November 2014 waste characterisation exercises.

4 Methodology

In preparing the sampling protocol for the waste characterisation, careful consideration has been given to the available options for achieving a balanced, cost-effective and sufficiently accurate waste characterisation for the City. A project like this could be delivered within an extremely high budget with a very high level of accuracy or within a rather limited budget resulting in a lower but still acceptable level of accuracy on which decisions can be based. Municipal waste generation varies on a daily, weekly and monthly basis and sampling provides only a snapshot in time. The approach followed was aimed at achieving a reasonably accurate result within the time and budget limitations of the project.

The methodology followed is described below.

4.1 Households serviced per collection vehicle and the composition of the load

The City reportedly services approximately 136 routes (once a week) using a fleet of collection vehicles, including mainly round collection vehicles. In order to get representative data reflecting the variation in waste generation and composition between the different socio-economic groups (high income, middle income and low income), it was decided to undertake purposeful, random sampling. The full 136 routes could not be studied due to practical, logistical and budget limitations. The samples were chosen purposefully to cover a range of socio-economic areas but the routes in the selected socio-economic areas were randomly chosen. It was confirmed that all trucks included in the sampling were empty at the start of the day (i.e. no residual waste remaining from the previous day).

Sampling teams comprised of one person accompanying the RCR vehicle to record data on the route, such as counting the number of households serviced (including the number of bins emptied into the RCR vehicle) and another four people to sort waste samples (100-200 kg/sample) into pre-determined waste categories. Three sampling teams were deployed daily (Monday to Friday, excluding public holidays) for a period of four weeks. The aim was to record data on the number of households serviced by the collection vehicle and sort waste from at least three RCR routes per day. Therefore during a four week period a total of 60 routes would have been studied.

The people accompanying the vehicles got into the cab of the vehicles at the allocated depot at the beginning of the rounds in the morning and following the normal routes scheduled for that vehicle for the particular day. The rest of the sorting team were deployed to the landfill site, where the truck was destined to dispose the waste, and awaited the arrival of the truck to start the waste characterisation exercise.

The individual in the truck recorded the route followed (i.e. manually recording the streets and also using a GPS device) while counting the number of households that put out bins, and also the number of bins (i.e. 240 litre) that were collected by the truck. The GPS data was used to confirm routes travelled for the RCR trucks during the sampling exercise.

The loaded truck would then return to the landfill, pass over a weighbridge, deposit its load and passed over the weighbridge again to determine the weight of the load. This load, instead of being disposed on the landfill, was deposited on an impermeable surface (tarpaulin used for this purpose), mixed using a front end loader (FEL), trackscavator (excavator on tracks) or manually using shovels.

A sample (one or two scoops of the bucket on the FEL) of the mixed load was then scooped up by the FEL and deposited into bags (one tonne capacity/bag). The sample thus collected was weighed, hauled away by the team and analysed for composition. Since the load was thoroughly mixed and random samples were taken from the mixed load, it would be possible to extrapolate the composition of each waste sample (i.e. the two bucket loads) to the waste in the corresponding truck, and thus meeting the requirements of the objective.

In some cases it was not possible to determine the number of households in a street. This may have been because, for example, the bins were put out on the street from a gated community of a townhouse complex, or a block of flats. In such instances the composition of the waste was used together with the other samples, but the waste generation per household could not be calculated and was therefore excluded from the statistical analysis.

Figure 1 (a to l) illustrates the procedure for collection of samples at the landfill site from the Pikitup trucks. The same procedure was followed for both sampling rounds.

Figure 1 | Illustration of the methodology followed to set up sorting operations at each landfill site (a - l)

a) Preparation of area where waste is to be off-loaded

Avoid areas with large boulders and rubble. These are to be removed, and preferably graded as smooth as possible.

b) $10m^2$ tarpaulin being spread on the levelled surface

$10m^2$ tarpaulin is arranged to be ready to accept the waste load.

c) Entire contents of truck to be emptied on to the tarpaulin

Waste that falls off the tarpaulin is to be brought back on to the centre of the tarpaulin using shovels (see bottom middle of the photo).

d) Waste body is being mixed

Operator needs to be under careful supervision to avoid the tarpaulin being pierced by the teeth of the bucket of the excavator

Operator is to simply mix the waste body with the bucket, and then take a scoop from the centre of the pile without piercing the tarpaulin.

e) Manually loading the scoop

Alternatively the scoop could take an initial scoop and the rest of the bucket filled in manually using spades.

Supervisor is to ensure that a representative sample of waste is loaded by staff.

f) Scoop will deposit waste sample in centre of the tarpaulin ($5m^2$)

Ensure that the tarpaulin is free of contamination (sand thrown up from the sides of the tarpaulin). Ensure brooms are on hand to sweep tarpaulin clean.

g) Deposited waste sample on to $5m^2$ tarpaulin

h) Small tarpaulin doubled on to itself

This is to prevent waste escaping and also prevent contaminants entering the waste sample.

i) Waste sample completed journey from offloading

The tarpaulin must be weighed at this stage on the scale provided, and this weight of the tarpaulin and waste body recorded in to datasheet.

The separate weight of the empty tarpaulin must also be taken to determine the weight of the waste body (see datasheet).

Waste offloading area just barely visible in the distance.

area to covered shed

The waste sample is transferred to the sorting table to be sorted. Ideally each person should be assigned a waste category to be sorted for.

j) Sorting waste sample

Show mass on the scale in the photos. A listing of all photos of waste streams to be seperated is included in the datasheet.

k) Waste fractions to be weighed

Tarpaulin to be offloaded by "capsizing" waste body, i.e. folding over the tarpaulin to eject the waste on to the floor.

Landfill manager is to be informed which waste pile is no longer required, in order for this to be landfilled.

l) Offloading large tarpaulin of waste

4.2 The variation in the waste from the three socio-economic areas

In order to understand the difference in waste generation rates and composition between the three socio-economic areas within the City, it was necessary to categorise each of the routes followed by the RCR trucks into high, medium and low income areas. This was determined visually using mapped information provided by the City, and cross-referencing the suburb on Google Earth as to compare with the classification in Appendix A, the socio-economic status of the suburb could therefore be accurately determined within reason.

In order to ensure spatially representative samples from households across the city were taken, routes ending at all operational landfills receiving waste from the CoJ RCR vehicles were included. In general the sampling teams spent approximately four days at each landfill site during the September sampling period, and then five days analysing special waste. For November, five days were spent at each landfill site, with one additional week (five days) looking at the special waste (refer to Table 1).

Table 1 | Summary of September 2014 and November 2014 sampling periods

Landfill site	September 2014 sampling (four days at each landfill)	November 2014 sampling (five days at each landfill site)
Marie Louise	8 to 11 September 2014	3 to 7 November 2014
Goudkoppies	12, 15, 16 and 17 September 2014	17 to 21 November 2014
Ennerdale	18, 19, 22 and 23 September 2014	24 to 28 November 2014[3]
Robinson Deep	25, 26, 29, 30 September (24 September 2014 being a public holiday is excluded)	10 to 14 November 2014 3 to 5 December 2014[4]
FG (Interwaste private landfill site)	1,2, 3 and 6 October 2014	11 to 12 December 2014[5]
Marie Louise (special waste)	13 to 17 October 2014[6]	8 to 10 December 2014[7]

4.3 Total waste generated per household within the City

Once the waste generated within the sample frame (i.e. the 60 routes out of the total possible 136 routes) was determined, the sample information could be extrapolated to the total population of households in the City utilising census household data by using a direct extrapolation based on socio-economic level for the purpose of this report.

4.4 Categories of waste from each of the three socio-economic areas

In order to provide some guidance to the team sorting and characterising waste at the landfill site it was necessary to pre-determine the categories of waste into which the waste needs to be sorted. These categories were informed by the need to provide guidance on technology choices for alternative treatment of waste.

The waste categories used for this purpose are provided in Table 2. Both the September 2014 and November 2014 samples were evaluated in terms of the criteria in Table 2 (i.e. level 1 and level 2).

Table 2 | Waste categories used when sorting the waste for categorisation purposes

Waste categories (level 1)	Detailed waste categories (level 2)
Glass	▪ Glass (i.e. specifically bottles) ▪ Non-packaging glass (i.e. shower doors, window panes)
Paper and cardboard	▪ Newspaper ▪ HL1 - all white office paper ▪ Non-recyclable paper (i.e. badly soiled, tissue paper, wax paper, laminated etc.) ▪ K4 ▪ Common mix ▪ Tetrapak (i.e. cardboard beverage packaging / cartons)
Metal: ferrous and non-ferrous	▪ Cans - steel (i.e. beans, tomato tins etc.)

[3] For the sampling of waste destined for Ennerdale Landfill, the landfill sampling team was stationed at Goudkoppies Landfill and the trucks were diverted to Goudkoppies because there was no functioning weighbridge at Ennerdale.
[4] This week was planned for sampling of waste at FG (Interwaste, a private landfill) site. However, it was not possible to obtain permission to sort RCR waste at FG. As a result no samples were sorted during first two days of the week. The remainder of this week was spent sampling high income areas in the Southdale deport area.
[5] The project team was not granted permission to sort RCR waste at FG. The trucks were therefore diverted to Marie Louise Landfill where the waste was sorted.
[6] Five days were allocated to the special waste sampling, which was undertaken at Robinson Deep Landfill. Special waste analysed included waste from the fresh produce market (three samples), dailies (one sample), source separated recycling rich waste (two samples), recycling residues (three samples), garden waste (three samples), and street sweepings (three samples).
[7] Only three days were allocated to this sampling (8 to 10 December 2014). During this time the special waste analysed included builder's rubble (three samples), illegal dumping (two samples), commercial waste (two samples), and garden waste (two samples).

Waste categories (level 1)	Detailed waste categories (level 2)
	▪ Cans - aluminium (i.e. beverage or Coke cans) ▪ Aluminium packaging (i.e. tin foil, foil trays etc.) ▪ Other scrap metal (i.e. engine block etc.) ▪ Aerosols - aluminium ▪ Aerosols - steel ▪ Copper (i.e. pipes or containers etc.)
Plastics	▪ HDPE drink bottles (i.e. milk or Sta-soft bottles) ▪ PET drink bottles (i.e. one litre or two litre beverage bottles) ▪ Polypropylene (i.e. PET bottle caps etc.) ▪ Polysterine ▪ Video tapes, DVDs and CDs ▪ LD - clear plastic ▪ LD - mix plastic ▪ LD - stretch (i.e. Chappies) ▪ All non-recyclable or not identified plastics
Garden waste	All garden waste
Food waste	▪ All food waste ▪ Cooking oil
Wood waste	All wood waste
E- waste	All electronic waste
Tyres	All types of tyres
Miscellaneous combustible	▪ Soft furniture (including cushions from sofas and mattresses) ▪ Crockery
Textiles and footwear	▪ Clothes, shoes, belts and bags ▪ Carpet ▪ Non-clothing textiles (i.e.. duvets and pillows)
Miscellaneous non-combustible	▪ Rubble ▪ Plasterboard, ceramics (i.e. ceiling or rhino light) ▪ Other non-combustible materials not otherwise specified
Hazardous wastes	▪ Fire extinguishers ▪ Gas bottles ▪ Ink and toner cartridges ▪ Paint ▪ Pesticides, varnish, inks and other chemicals ▪ WEEE (fluorescent tubes, low energy light bulbs and other light bulbs) ▪ Mineral oil (motor / machine oil) ▪ Automotive batteries (i.e. car batteries) ▪ Non-automotive batteries (i.e. torch batteries, etc.)
Healthcare waste	▪ Disposable nappies ▪ Other absorbent hygiene products (sanitary pads etc.) ▪ Potentially hazardous healthcare waste (sharps, needles etc.) ▪ Dead animals

Waste categories (level 1)	Detailed waste categories (level 2)
	▪ Pet excrement and pet bedding
Fines (<10 mm)	Not specified

4.5 Special waste streams

One week (five days), additional to the RCR waste, of sampling was set aside to sample and sort what was considered special waste streams not included in the RCR waste in both the September and November sampling sessions. These included:

- Bulk waste in containers (i.e. garden waste and commercial waste)
- Dailies from restaurants and food preparation clients
- Illegal dumping
- Recycling activities

Each of these special waste streams is discussed below.

4.5.1 Bulk waste in containers

The City operates various bulk container fleet, which includes:

- A single 80m^3 roll-on-roll-off container: Services the Johannesburg Fresh Produce Market (JFPM). Waste is disposed at Robinson Deep landfill site
- Two lift-on-containers: Both serving the JFPM. Waste is disposed at Robinson Deep landfill site
- Eight lift-on-containers: Servicing private customers
- Seven front-end-loaders: Servicing private customers
- Three rear-end-loaders: Servicing approximately 1 260 private customers

Due to time and budget limitations three samples of builder's rubble (November samples) from garden waste sites and two samples (November samples) of commercial waste were evaluated from the 1 260 private customers. However, based on landfill records it should be possible to determine large bulk sources of waste that may be suitable for individual exploitation.

Waste from the JFPM (three samples) was also analysed from three containers as mentioned above (during September sampling). Containers from a single day (three samples) were analysed for content using a similar procedure of waste characterisation as was used for the RCR waste during the preceding weeks.

4.5.2 'Dailies' from restaurants and food preparation clients

There are 12 trucks servicing restaurants and food establishments,(approximately 723 clients). A single truck hauling dailies was analysed and characterised (during September only). This was simply to get an understanding of what the dailies waste consists of. Since the waste composition turned out to be food waste mixed with packaging material, it was not deemed necessary to repeat the analysis in November as a similar composition is expected.

4.5.3 Illegal dumping

Illegal dumping is dealt with by the majority of depots in the city. Fleet (both Pikitup and private contractors) is reportedly rotated according to the needs at each depot / area. Illegal dumping composition reportedly varies according to the area in which it is found. It is however not possible to draw conclusions on the source and origin of illegal dumping purely based on the area from where it is collected.

Inner city illegal dumping reportedly consists of a mixture of concrete rubble and domestic waste. Illegal dumping from outlying areas, like Orange Farm, generally consists of a higher percentage or more of concrete and builders rubble.

Three truck loads, one each from Marlboro, Selby and Waterval depots, carrying illegally dumped waste were analysed during the September sample. During the November sample an additional two trucks were analysed. This was intended to provide an understanding of the composition of illegally dumped waste.

4.5.4 Recycling activities

A number of recycling initiatives are ongoing within the City. Routes were selected that had source separation within the suburbs or residential areas. The routes were analysed to determine the accuracy of source separation by households.

This was done from two perspectives.

- Firstly analysing the source separated materials to be sent for recycling (this was collected by Pikitup fleet which transported the source separated recyclables to groups of cooperatives supported by the City), i.e. sampled to determine if all the materials included in the recycling batch were suitable for recycling.
- Secondly, the residue waste from this process, which was collected by a separate RCR Pikitup truck, was characterised to determine how effective source separation by households currently is.

In the September sample, three routes were selected, i.e. one in high, medium and low economic areas. This was done to determine if there was any variation in the efficiency of sorting at household level based on the socio-economic area. The selected routes were as follows:

- West Turffontein (low income area),
- Crown Gardens (medium income area), and
- Winchester Hills and Mondeor (high income areas). The residues were also examined to see if there were any recyclables left in the residual waste from households.

During the November sampling, source separated recyclables from four low income routes were selected to be sampled and sorted. In addition, residual waste after source separation from five low income and nine high income routes were selected to be sampled during November 2014.

5 Results and discussion

5.1 Sampling

A total of 54 and 74samples (average 144 kg waste per sample) of RCR waste were sorted during September 2014 and November 2014 respectively, equating to the sampling of 40% of all the RCR routes in September and 54% in November.

The project therefore covered 128 out of 136 (94%) RCR routes in this WCS. A total of 18.4 tonnes of RCR waste was sorted (7.8 tonnes in September and 10.6 tonnes in November).

The detailed breakdown of number of routes and kilograms of waste sorted, grouped per landfill and socio-economic category, is provided in Table 3.

Table 3 | Number of samples and kilograms of RCR waste sorted for the purposes of the WCS in the CoJ Metropolitan Municipality

Income category	Marie Louise		Goudkoppies		Robinson Deep		Ennerdale		FG		Total	
	Sept	Nov	Sept	Nov	Sept	Nov	Sept	Nov	Sept	Nov	Sept	Nov
	Number of samples RCR waste sorted											
Low	4	8	1	9	6	4	10	15	8	0	29	36
Middle	4	3	3	3	0	8	0	0	2	0	9	14
High	4	4	7	3	3	11	0	0	2	6	16	24
Total	**12**	**15**	**11**	**15**	**9**	**23**	**10**	**15**	**12**	**6**	**54**	**74**
	Kg RCR waste sorted											
Low	486.5	1192.8	109.6	1127.4	898.1	610	1492.5	2167.6	1274.1	0	4260.8	5097.8
Middle	491.6	461.3	429.1	435	0	1142.7	0	0	300.2	0	1220.9	2039

High	515	630.3	1050.4	406.3	473.9	1602	0	0	310.6	819.9	2349.9	3458.5
Total	**1493.1**	**2284.4**	**1589.1**	**1968.7**	**1372**	**3354.7**	**1492.5**	**2167.6**	**1884.9**	**819.9**	**7831.6**	**10595.3**

The number of samples and kilograms of special waste streams that was sorted and categorised for the purposes of the WCS is summarised in Table 4.

Table 4 | Number of samples and kilograms of special waste streams sorted for the purposes of the WCS in the CoJ Metropolitan Municipality

Special waste stream	No of samples	Total kg sorted
Commercial waste (Nov)	2	208.5
Illegal dumping (Sept)	3	591.5
Illegal dumping (Nov)	2	377.7
Builder’s rubble (Nov)	3	309.9
Street sweepings (Sept)	3	601.1
Dailies (Sept)	4	584.6
Residues after source separation (Sept)	3	398.5
Residues after source separation (Nov)	14	2132.5
Source separated recyclables (Sept)	2	287.8
Source separated recyclables (Nov)	4	511.4
Total	**40**	**6003.5**

Comparatively more waste was sorted during the November 2014 period than during the September 2014. One week was initially set aside for training before the November sampling, but was insteadutilised to obtain additional samples since the same sorting teams as for September sampling was deployed. The time between the winter and summer sampling rounds was relatively short which negated the need for additional training to be conducted.

5.2 Household waste composition (RCR waste)

Household waste composition is directly affected by a variety of factors including socio-economic status of the households, food habits, season, geographical location, cultural conditions etc. (Ball, 2001, Aguilar-Virgen et al., 2013; Suthar and Singh, 2014).

A number of authors report significant seasonal variation in waste generation rate and composition (Koufodimos and Samaras, 2002; Yousaf and Rahman, 2007; Aguilar-Virgen et al., 2013). In particular, the changes in waste generation rate could be attributed to the amount of water associated with each season. With Johannesburg falling in the summer rainfall region, garden waste is expected to increase during the summer months, and be at its lowest during winter. Consumption of beverages increases during the summer months, hence cans (aluminium and steel) and PET (500 ml, 1 litre and 2 litre etc.) is likely to increase during this time. Construction activities are also expected to be higher during the winter months when the likelihood of rain is lower. Therefore builder’s rubble should decrease during summer periods.

A personal interview conducted with Mr Loggerenberg of Pikitup (Pers. Comm., 2014) confirmed these assumptions. It is therefore essential to confirm seasonal variation in the waste composition of the CoJ.

The results are presented in a format that allows for easy comparison between September and November characteristics.

The waste composition at level 1 (refer to Table 2) for September and November is presented in Figure 2. The amount of garden waste increased between the two sampling periods while the food waste decreased. This could be attributed to the spring season growth spurt of garden waste which will be discussed further below.

The waste categories were combined to allow a direct comparison with previous waste characterisation studies (Figure 3). If the combined information (Figure 3) is compared with the 2001 waste characterisation of the CoJ as illustrated in Figure 4 (Rod Ball and Associates, 2001), the overall composition seems very similar with only small differences in percentages between the three sampling periods (Figure 3 and Figure 4). The similarity in the overall waste composition in the City between 2001 and 2014 is indicative that no significant changes impacting on the waste generation and composition occurred in the City over this period.

Figure 2 | Comparing September 2014 to November 2014 RCR waste

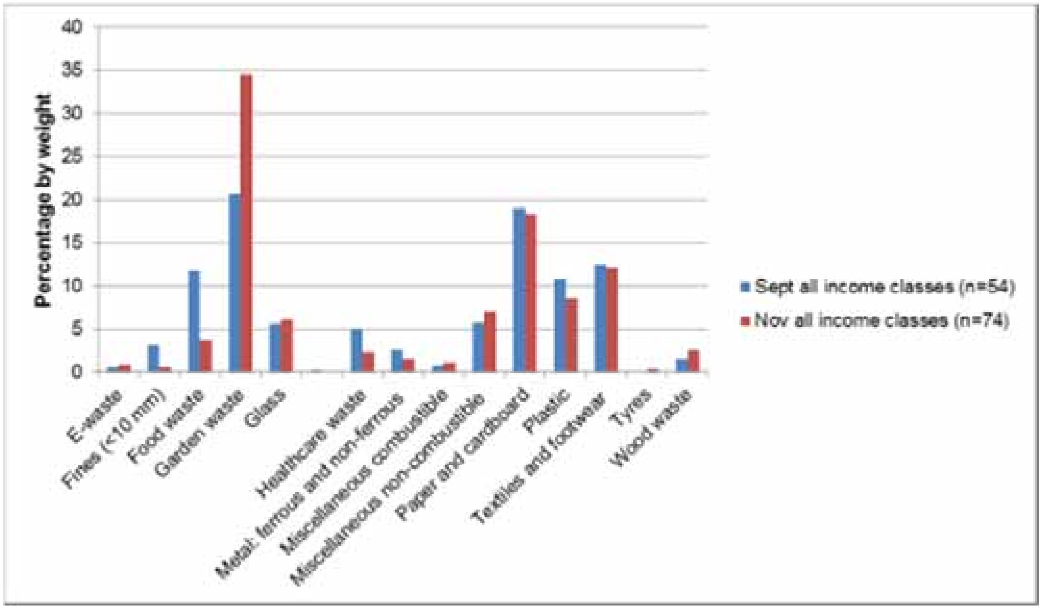
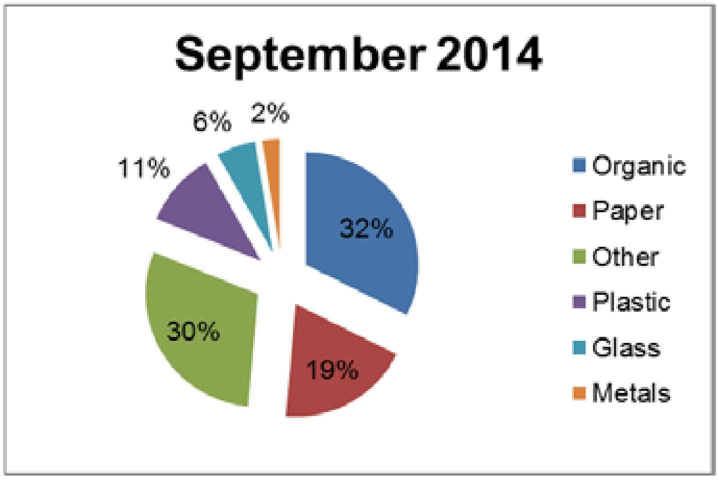


Figure 3 | Comparing RCR waste composition between September 2014 and November 2014 – all areas, all income categories



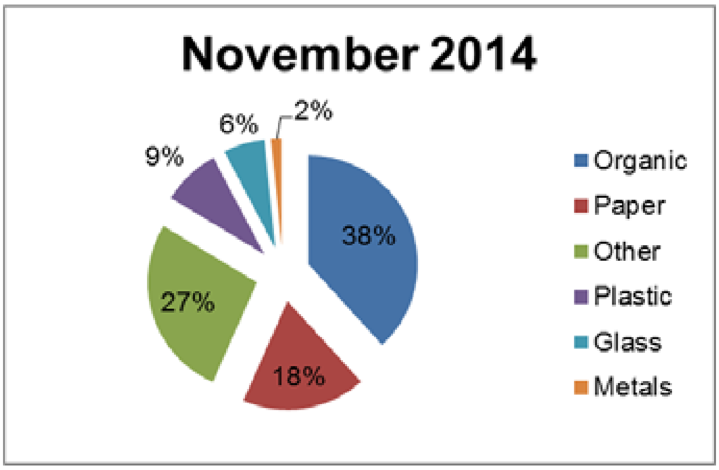
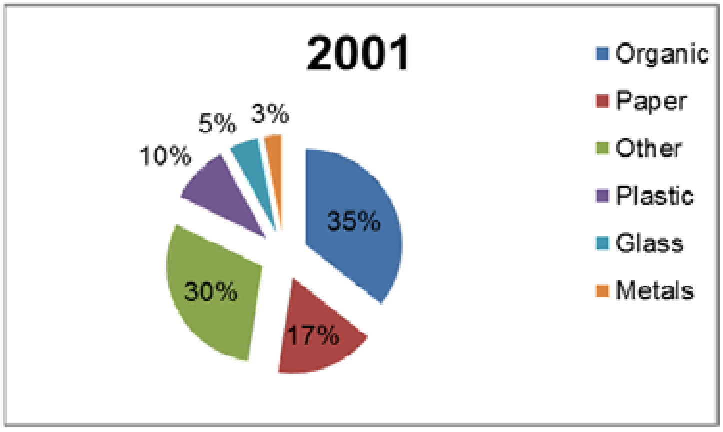


Figure 4 | Waste composition of the CoJ as determined in 2001 (Rod Ball and Associates, 2001)



The significance of the difference in composition of RCR waste between the two sampling periods (September and November 2014) was statistically determined by applying the Mann-Whitney[8] test (Table 5).

A statistically significant difference means a consistent difference, but the difference could be very small (e.g. a consistent 1% difference could be statistically significant).

Table 5 | Mann-Whitney test results for the comparison of waste percentages between September and November 2014 samples (p-value < 0.05 => significant)

p-value	Interpretation	Waste category
0.1026	No significant difference	E-waste
0.8759	No significant difference	Fines (<10 mm)
<.0001	Statistically significant difference	Food waste
0.0164	Statistically significant difference	Garden waste
0.9581	No significant difference	Glass
0.9917	No significant difference	Healthcare waste
0.3172	No significant difference	Metal: ferrous and non-ferrous
0.3079	No significant difference	Miscellaneous combustible
0.0011	Statistically significant difference	Miscellaneous non-combustible
0.6099	No significant difference	Paper and cardboard
0.5743	No significant difference	Plastic
0.3779	No significant difference	Textiles and footwear
0.24	No significant difference	Tyres
0.0015	Statistically significant difference	Wood waste

When considering the different waste categories for the RCR waste stream, there were statistically significant differences between food waste, garden waste, miscellaneous non-combustible waste (including builder's rubble) and wood waste. There were no statistically significant differences for the other categories of waste. Significant differences were established for those waste categories where one would expect there to be a seasonal difference (i.e. food waste, garden waste, miscellaneous non-combustible waste (i.e. builder's rubble), and wood waste). The full statistical analysis for all waste streams is provided in Appendix B.

The statistical test confirmed statistically significant differences between the September and November waste characteristics. Although statistically significant, the size (i.e. the practical significance) of the differences appears not to be very large. Secondly, the statistical tests did not pick up consistent differences within some of the waste

[8] The Mann-Whitney test and not the t-test was used because of the skewness of the data

categories such as plastic and paper, but in practice waste collection teams have reported that they observed some seasonal differences within these categories.

Differences in the presence of recyclables between the September and November samples could be explained by the fact that the November sample included routes where source separation initiatives are rolled-out, whereas the September sample purposefully avoided routes with source separation. The results confirmed seasonal variation in the waste characteristics of RCR waste in the CoJ. The project team is concerned that the September sample is not a true winter sample and therefore may not have shown all the differences the team would have expected to see between winter and summer samples.

5.2.1 Household waste composition by socio-economic category

Comparing the waste composition by income category (Figure 5 and Figure 6), it is apparent that for both sampling periods, high income household contributed the bulk of the garden waste and miscellaneous non-combustible waste. There are differences in the waste composition by socio-economic category for both sampling periods, but the differences are not consistent and therefore difficult to explain.

Figure 5 | Comparing waste composition between income classes (for September 2014)

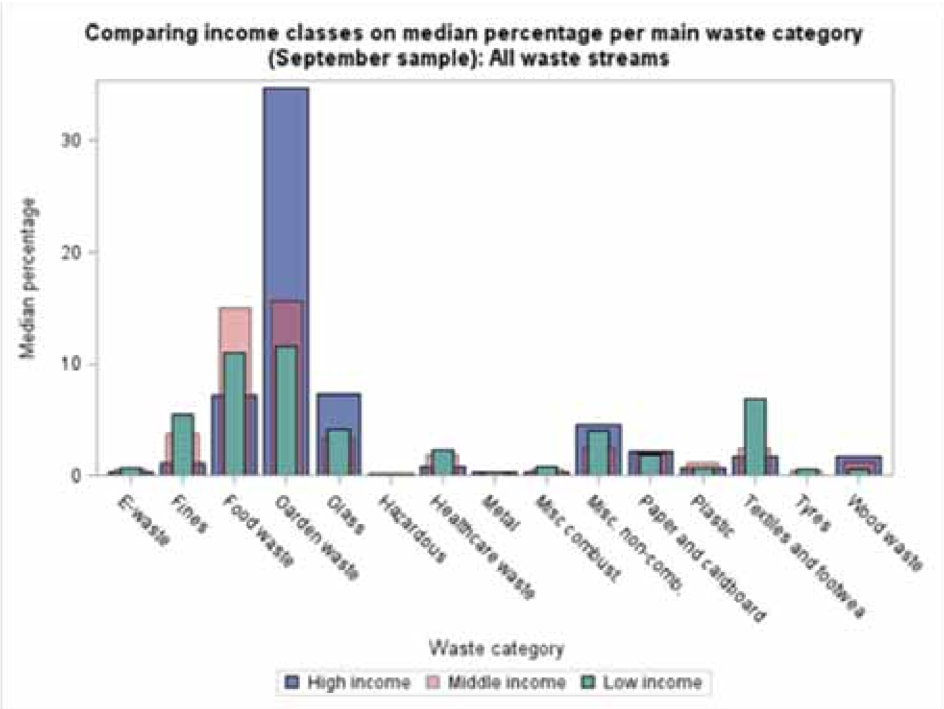
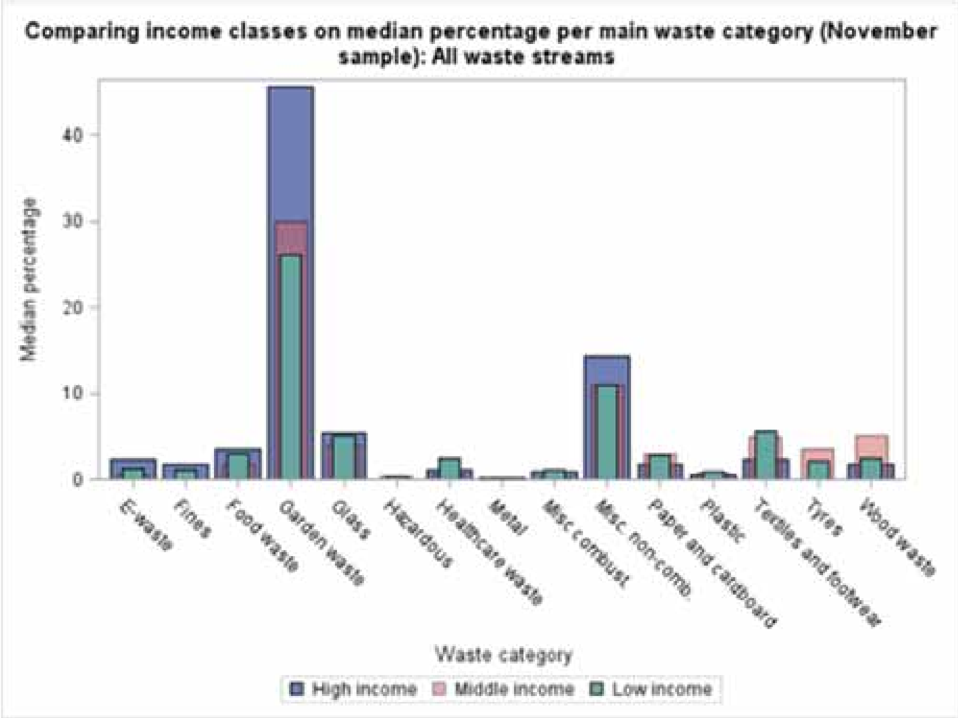


Figure 6 | Comparing waste composition between income classes (for November 2014)



In both sampling periods, low income households contributed the larger proportion of textiles and footwear waste, this finding can potentially be attributed to the fact that old or no longer wanted clothes and footwear are donated or sold to the poor by more affluent members of society. These items are then used and reused by the poor, until it reach the end of its useful life. Another possible explanation is the fact that poor people buy cheaper, often poorer quality items and hence the high turnover and increased disposal of these wastes by low income households.

Comparatively a greater proportion of glass was disposed of by high income households, followed by low and medium income households. This was only marginally the case for November 2014 results compared to September 2014 (which showed the greater spread). High and low income households produced more glass waste compared to medium income households over both sampling periods. The glass could potentially be as a result of consumption of alcoholic beverages by these income groups.

A high level breakdown of the waste proportions per income category for all landfills is provided in Table 6 and Table 7 with a detailed breakdown provided in Table 8 and Table 9.

Table 6 | Waste proportions per income category (all landfills) for September 2014

Waste category (grouped)	Income type			
	High income	Low income	Middle income	Total
	%	%	%	
E-waste	32.04	58.49	9.47	100%
Fines (<10 mm) not specified	15.74	65.05	19.21	100%
Food waste	19.01	62.24	18.75	100%
Garden waste	57.9	32.57	9.53	100%
Glass	42.02	47.9	10.08	100%
Hazardous waste	28.45	58.34	13.21	100%
Healthcare waste	26.95	60.05	13	100%
Metal: ferrous and non-ferrous	19.88	70.98	9.14	100%
Miscellaneous combustible	13.57	77.18	9.26	100%

Waste category (grouped)	Income type			
	High income	Low income	Middle income	Total
Miscellaneous non-combustible	10.22	78.07	11.71	100%
Paper and cardboard	38.56	44.32	17.12	100%
Plastic	27.07	54.25	18.68	100%
Textiles and footwear	11.38	77.37	11.25	100%
Tyres	.	72.57	27.43	100%
Wood waste	29.93	53.7	16.37	100%

Table 7 | Waste proportions per income category (all landfills) for November 2014

Waste category (grouped)	Income type			
	High	Low	Middle	Total
	%	%	%	
E-waste	41.9	46.2	11.9	100%
Fines (<10 mm) not specified	22.2	77.8	.	100%
Food waste	22.7	65.2	12.2	100%
Garden waste	34.7	43.0	22.3	100%
Glass	26.9	54.5	18.6	100%
Hazardous wastes (NB: each site	6.5	82.2	11.3	100%
Healthcare waste	17.7	69.3	13.0	100%
Metal: ferrous and non-ferrous	19.0	68.1	13.0	100%
Miscellaneous combustible	21.8	71.2	7.0	100%
Miscellaneous non-combustible	19.0	63.7	17.4	100%
Paper and cardboard	28.0	52.4	19.7	100%
Plastic	22.2	53.9	23.9	100%
Textiles and footwear	17.2	61.0	21.8	100%
Tyres	.	39.3	60.7	100%
Wood waste	14.8	49.4	35.8	100%

Table 8 | Waste proportions across detailed categories within income category (all landfills) for September 2014

Waste category (grouped)	Waste category (detailed)	Income category			
		High	Low	Middle	Total
		%	%	%	%
E-waste	All electronic waste	0.58	0.63	0.39	0.58
Fines (<10 mm) not specified	Fines (<10 mm) not specified	1.55	3.8	4.32	3.15

Waste category (grouped)	Waste category (detailed)	Income category			
		High	Low	Middle	Total
Food waste	All food waste	6.95	13.49	15.68	11.71
	Cooking oil	0.00	0.00	0.00	0.00
Garden waste	All garden waste	37.36	12.45	14.05	20.65
Glass	Glass (i.e. specifically bottles)	7.38	4.98	4.04	5.62
	Non-packaging glass (i.e. shower doors, window panes)	0.00	0.00	0.00	0.00
Hazardous waste	Automotive batteries (i.e. car batteries)	0.00	0.04	0.00	0.02
	Fire extinguishers	0.00	0.00	0.00	0.00
	Gas bottles	0.00	0.00	0.04	0.01
	Ink and toner cartridges	0.03	0.00	0.00	0.01
	Mineral oil (motor / machine oil)	0.01	0.12	0.04	0.07
	Non-automotive batteries (torch batteries, etc.)	0.05	0.03	0.04	0.04
	Paint	0.00	0.00	0.06	0.01
	Pesticides, varnish, inks and other chemicals	0.00	0.00	0.00	0.00
	WEEE - fluorescent tubes, low energy light bulbs and other light bulbs	0.11	0.05	0.04	0.07
Healthcare waste	Dead animals	0.08	0.37	.	0.23
	Disposable nappies	3.03	4.71	4.21	4.11
	Other absorbent hygiene products (sanitary pads etc.)	0.8	0.08	0.37	0.35
	Pet excrement and bedding	0.24	0.16	0.04	0.17
	Potentially hazardous healthcare waste (sharps, needles etc.)	0.04	0.2	0.00	0.12
Metal: ferrous and non-ferrous	Aerosols – aluminium	0.02	0.07	0.03	0.05
	Aerosols – steel	0.16	0.17	0.13	0.16
	Aluminium packaging (tin foil, foil trays etc.)	0.16	0.11	0.08	0.12
	Cans – aluminium (i.e. beverage or coke cans)	0.14	0.17	0.13	0.16
	Cans – steel (i.e. beans, tomato tins etc.)	0.94	1.22	1.02	1.1
	Copper – (i.e. pipes or containers etc.)	0.00	0.01	0.17	0.03
	Other scrap metal (i.e. engine block etc.)	0.16	1.59	0.09	0.92
Miscellaneous combustible	Crockery	0.22	0.54	0.16	0.38
	Soft furniture (including cushions from sofas and mattresses)	0.14	0.68	0.4	0.47

Waste category (grouped)	Waste category (detailed)	Income category			
		High	Low	Middle	Total
Miscellaneous non-combustible	Other non-combustible materials not otherwise specified	0.14	0.00	0.24	0.08
	Plasterboard, ceramics (i.e. ceiling or rhino light)	0.00	0.32	0.00	0.17
	Rubble	1.71	8.05	4.61	5.54
Paper and cardboard	Tetrapak - cardboard beverage packaging / cartons	0.38	0.67	0.58	0.56
	Common mix	7.46	6.3	10.7	7.29
	HL1 - all white office paper	1.73	1.34	1.54	1.49
	K4	6.39	4.41	5.21	5.16
	Newspaper	6.86	2.52	5.24	4.29
	Non-recyclable paper (i.e. badly soiled, tissue paper, wax paper, laminated etc.)	0.17	0.43	0.06	0.29
Plastic	All non-recyclable or not identified plastics	1.8	1.82	3.95	2.11
	HDPE drink bottles (i.e. milk or Sta-soft bottles)	0.65	0.56	1.27	0.69
	LD - clear plastic	0.7	0.96	1.03	0.88
	LD - mix plastic	2.3	3.48	3.81	3.15
	LD – stretch (Chappies)	0.15	0.1	0.15	0.13
	PET drink bottles (i.e. 1 litre or 2 litre beverage bottles)	1.6	1.14	1.92	1.4
	Polypropylene (i.e. PET bottle caps etc.)	1.11	1.95	1.7	1.65
	Polysterine	0.66	0.48	0.44	0.53
	Video tapes, DVDs and CDs	0.14	0.33	0.09	0.23
Textiles and footwear	Carpet	0.98	4.1	0.89	2.65
	Clothes, shoes, belts and bags	2.59	11.53	6.13	7.91
	Non-clothing textiles (e.g. duvets and pillows)	0.86	2.22	3	1.9
Tyres	All types of tyres	0.00	0.05	0.07	0.03
Wood waste	All wood waste	1.46	1.56	1.83	1.56
		100%	100%	100%	100%

Table 9 | Waste proportions across detailed categories within income category (all landfills) for November 2014

Waste category (grouped)	Waste category (detailed)	Income category			Total
		High	Low	Middle	
		%	%	%	%

Waste category (grouped)	Waste category (detailed)	Income category			Total
		High	Low	Middle	
E-waste	All electronic waste	1.84	0.87	0.54	1.15
Fines (<10 mm) not specified	Fines (<10 mm) not specified	2.25	0.85	0.47	1.27
Food waste	All food waste	2.63	4.76	2.19	3.52
	Cooking oil	0.00.	0.12	0.00.	0.05
Garden waste	All garden waste	43.11	25.97	32.33	33.25
Glass	Glass (i.e. specifically bottles)	6.09	6.49	5.3	6.12
	Non-packaging glass (i.e. shower doors, window panes)	0.00.	0.00.	0.00.	0.00.
Hazardous wastes (NB: each site	Automotive batteries (i.e. car batteries)	0.00.	0.00.	0.00.	0.00.
	Fire extinguishers	0.00.	0.00.	0.00.	0.00.
	Gas bottles	0.00.	0.00.	0.00.	0.00.
	Hazardous wastes	0.00.	0.00.	0.00.	0.00.
	Ink and toner cartridges	0.00.	0.00.	0.03	0.01
	Mineral oil (motor / machine oil)	0.00.	0.02	0.00.	0.01
	Non-automotive batteries (torch batteries, etc.)	0.00.	0.00.	0.00.	0.00.
	Paint	0.00.	0.06	0.00.	0.03
	Pesticides, varnish, inks and other chemicals	0.00.	0.00.	0.00.	0.00.
	WEEE - fluorescent tubes, low energy light bulbs and other light bulbs	0.01	0.00.	0.00.	0.00.
Healthcare waste	Dead animals	0.00.	0.56	0.00.	0.26
	Disposable nappies	1.3	2.64	1.33	1.92
	Other absorbent hygiene products (sanitary pads etc.)	0.01	0.01	0.03	0.02
	Pet excrement and bedding	0.02	0.01	0.00.	0.01
	Potentially hazardous healthcare waste (sharps, needles etc.)	0.00.	0.01	0.09	0.02
Metal: ferrous and non-ferrous	Aerosols – aluminium	0.07	0.04	0.05	0.05
	Aerosols – steel	0.14	0.15	0.12	0.14
	Aluminium packaging (tin foil, foil trays etc.)	0.00.	0.02	0.02	0.01
	Cans – aluminium (i.e. beverage or coke cans)	0.14	0.24	0.08	0.17
	Cans – steel (i.e. beans, tomato tins etc.)	0.71	0.82	0.83	0.78

Waste category (grouped)	Waste category (detailed)	Income category			Total
		High	Low	Middle	
	Copper (i.e. pipes or containers etc.)	0.00.	0.00.	0.00.	0.00.
	Other scrap metal (i.e. engine block etc.)	0.11	0.76	0.22	0.43
Miscellaneous combustible	Crockery	0.44	0.27	3.55	0.96
	Soft furniture (including cushions from sofas and mattresses)	0.57	1.38	0.36	0.9
Miscellaneous non-combustible	Other non-combustible materials not otherwise specified	0.53	0.41	1.23	0.61
	Plasterboard, ceramics (i.e. ceiling or rhino light)	0.77	0.32	0.12	0.44
	Rubble	4.73	8.13	5.78	6.48
Paper and cardboard	Tetrapak - cardboard beverage packaging / cartons	0.39	0.81	0.4	0.58
	Common mix	6.34	5.89	6.39	6.14
	HL1 - all white office paper	0.81	1.28	1.02	1.07
	K4	4.77	6.61	6.29	5.89
	Newspaper	5.14	3.92	2.78	4.14
	Non-recyclable paper (i.e. badly soiled, tissue paper, wax paper, laminated etc.)	0.01	0.05	0.14	0.06
Plastic	All non-recyclable or not identified plastics	1.46	0.69	0.72	0.97
	HDPE drink bottles (i.e. milk or Sta-soft bottles)	0.46	0.71	0.91	0.66
	LD - clear plastic	0.47	1.06	0.75	0.79
	LD - mix plastic	1.32	2.24	2.94	2.05
	LD – stretch (Chappies)	0.08	0.02	0.09	0.05
	PET drink bottles (i.e. 1 litre or 2 litre beverage bottles)	1.07	1.69	1.1	1.36
	Polypropylene (i.e. PET bottle caps etc.)	3.75	2.64	3.72	3.24
	Polysterine	0.23	0.31	0.28	0.28
	Video tapes, DVDs and CDs	0.01	0.02	0.04	0.02
Textiles and footwear	Carpet	1.41	1.65	3.95	2
	Clothes, shoes, belts and bags	3.95	11.6	7.06	8.03
	Non-clothing textiles (e.g. duvets and pillows)	1.17	1.11	1.37	1.18
Tyres	All types of tyres	0.00.	0.26	0.95	0.3
Wood waste	All wood waste	1.67	2.54	4.42	2.59

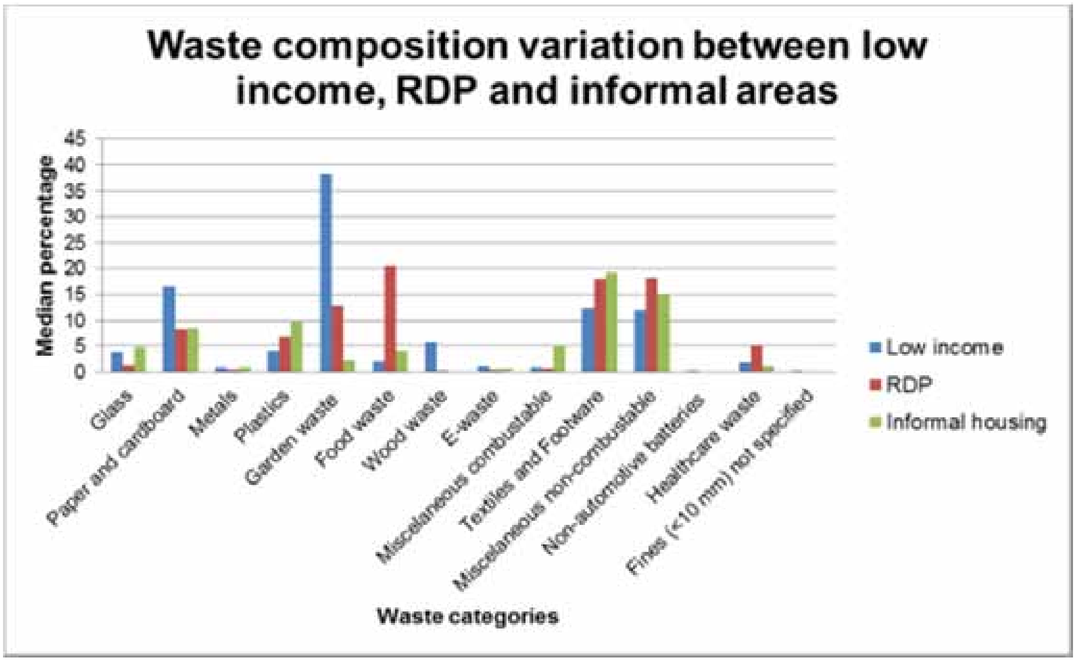
Waste category (grouped)	Waste category (detailed)	Income category			Total
		High	Low	Middle	
		99.98	100.01	99.99	100.01

5.2.2 Low income waste composition by type of housing structure

The samples taken during September in the Ivory Park area allows for comparing the waste composition in low income households based on the housing type. Three samples each were taken from informal housing structures, low cost government houses (RDP houses), and other formal houses. The results of this comparison are illustrated in Figure 7. The most obvious difference is in the composition of garden waste which is highest in formal houses followed by RDP homes with the lowest at informal houses. This could be attributed to the more established housing top structures, and planning for a yard or garden (which is prevalent in more formal and planned housing systems).

The food waste component is highest at low cost housing followed by informal housing. There seems to be a correlation between textile and footwear waste and the type of housing with informal households having the highest contribution of this waste type followed by low cost housing and other formal housing. This may be an indication of even low income households donating clothes and footwear to the less fortunate.

Figure 7 | Comparing low income waste composition between different types of housing structures



5.2.3 Source separation of household waste

Waste separation at source initiatives are being rolled out in the City. For the September 2014 data, samples of the recyclable waste sorted at source by the high income households served by the Southdale depot area were sorted into the different waste streams. The results therefore provide an indication of the accuracy of the sorting done at household level as well as the composition of the recyclable waste from this area. The recyclable composition by weight from this area comprised of 22.9% glass, 7.15% paper and cardboard, 1.32% textiles and footwear, and 1.01% plastics amongst other (Figure 8).

Low and medium income households were included in the November 2014 sample (Figure 9). Contrary to expectation, the November 2014 sample from low income households contained portions of fines, food waste, hazardous and health care waste. This is indicative of the need for more training and awareness creation on the recyclables to be separated at source.

The composition of residual waste from areas with a kerbside collection service for source separated recyclables was also determined. One sample from each of the socio-economic areas (low, middle and high income) was taken and analysed. The results (Figure 9) indicate that sorting of plastics, paper and metals seem to be very effective with only small amounts remaining in the residual waste of all income groups. Low income households are not effective in sorting out glass with 21.85% of the residual waste being glass. This trend was not repeated in the November 2014 sample however, there was still some glass found in the November 2014 sample from low income areas. The high proportion of miscellaneous non-combustible waste in residues is indicative of there being very little awareness of recycling opportunities for building rubble etc. This needs to be looked at by the City. It should however be noted that the results for the residual waste is based on a very small sample which should be confirmed.

Figure 8 | Composition of the recycled waste portion from high income households in the Southdale depot area (September 2014)

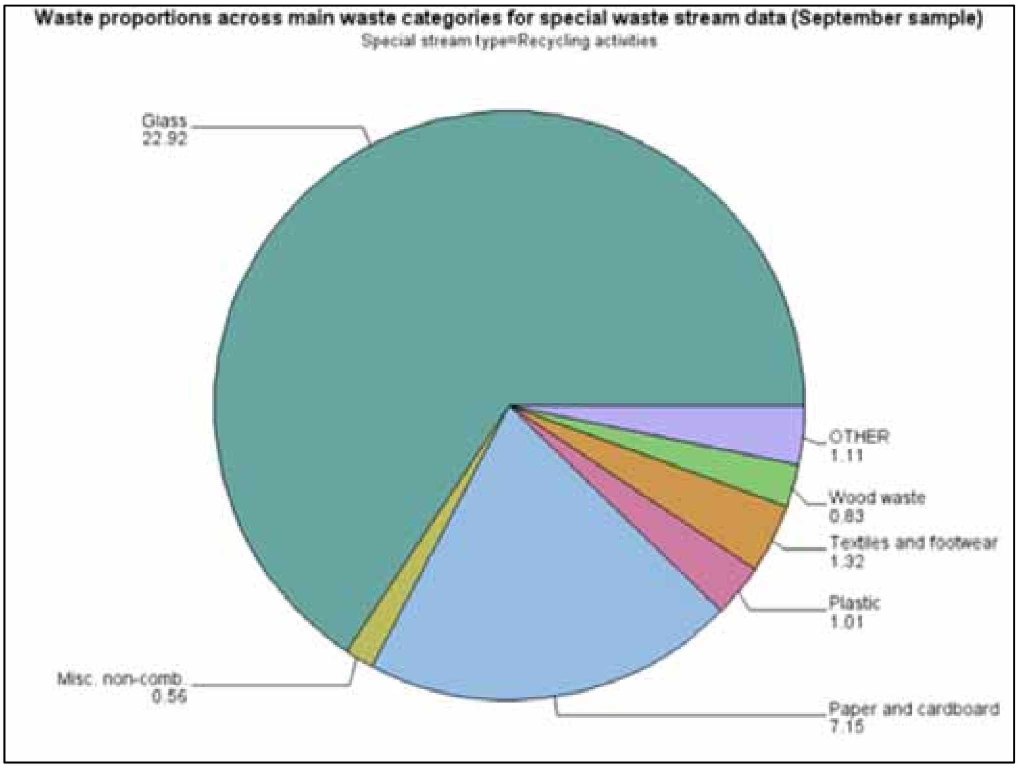


Figure 9 | Comparing composition of recyclables from low income areas (November 2014)

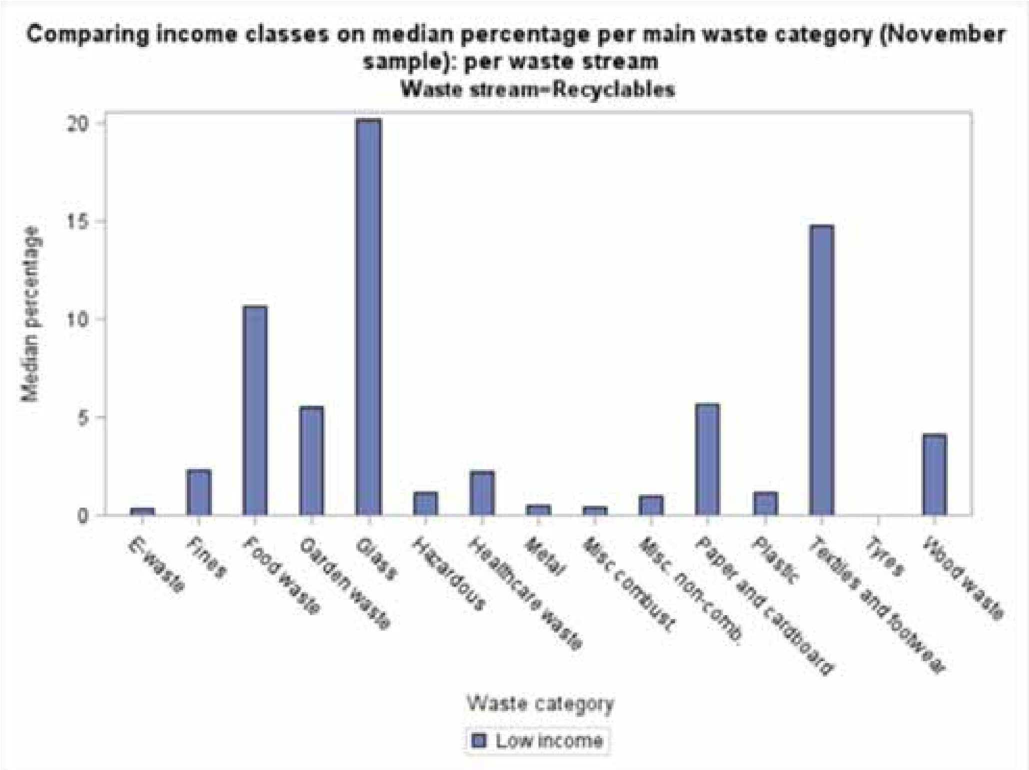


Figure 10 | Residual waste per income group from households with kerbside collection of source separated waste (September 2014)

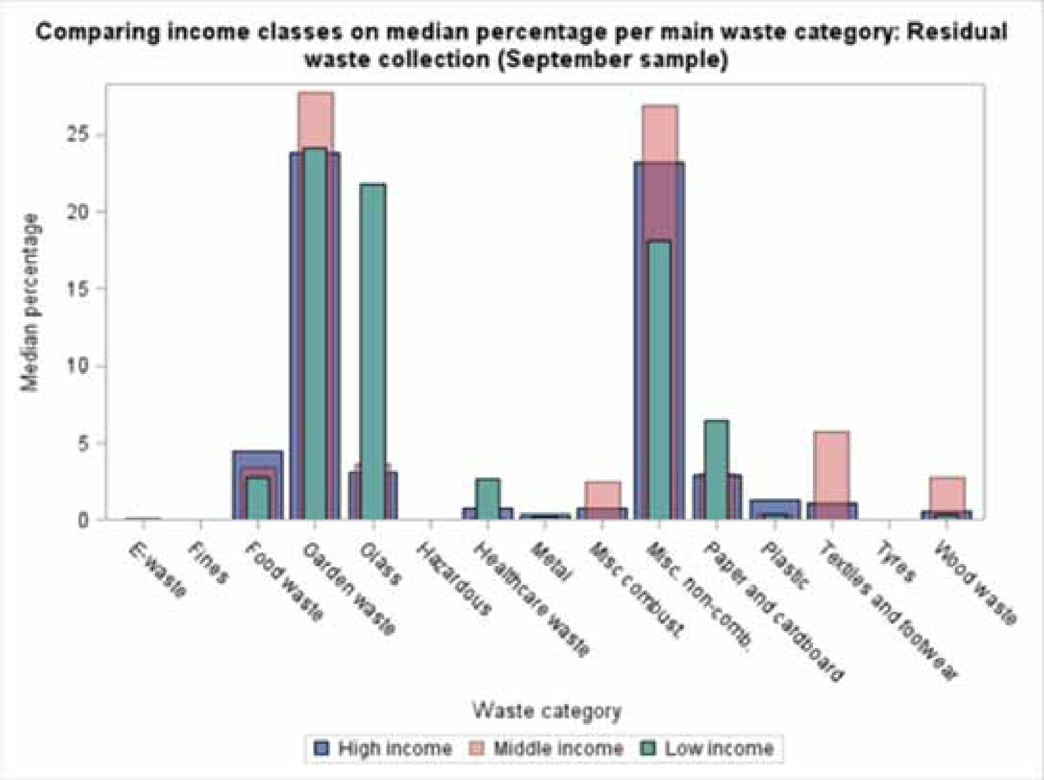
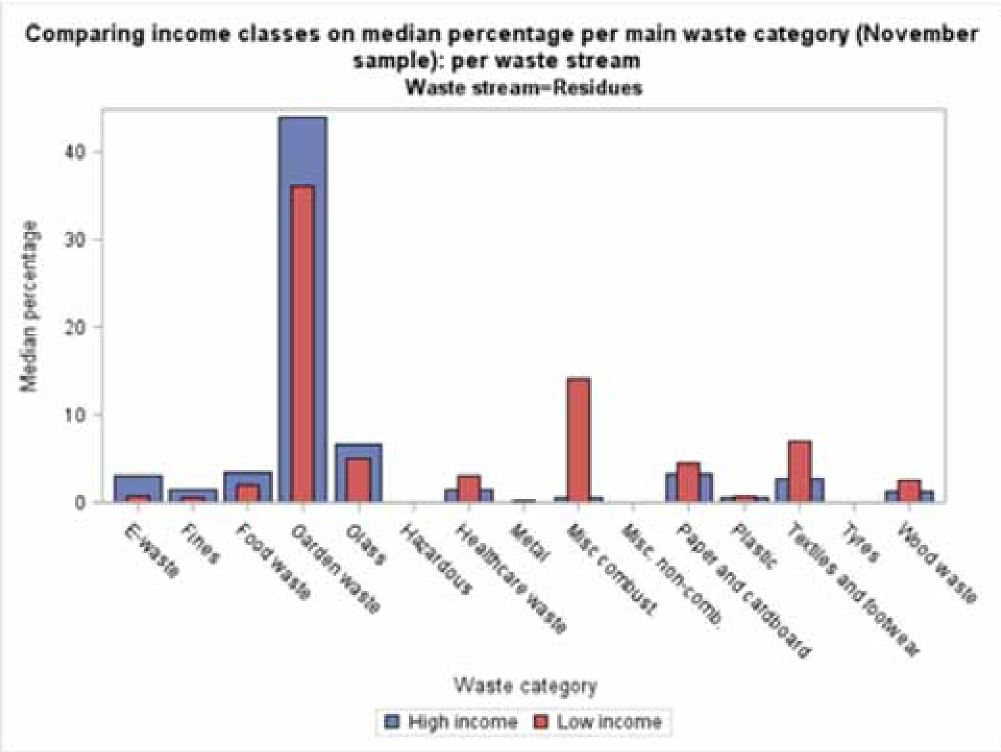


Figure 11 | Residual waste per income group from households with kerbside collection of source separated waste (November 2014)



5.3 Special waste streams

Four categories of special waste were examined during the November sampling period. This includes commercial waste from two commercial clients, illegal dumping, builder's rubble and garden waste. The following should be noted:

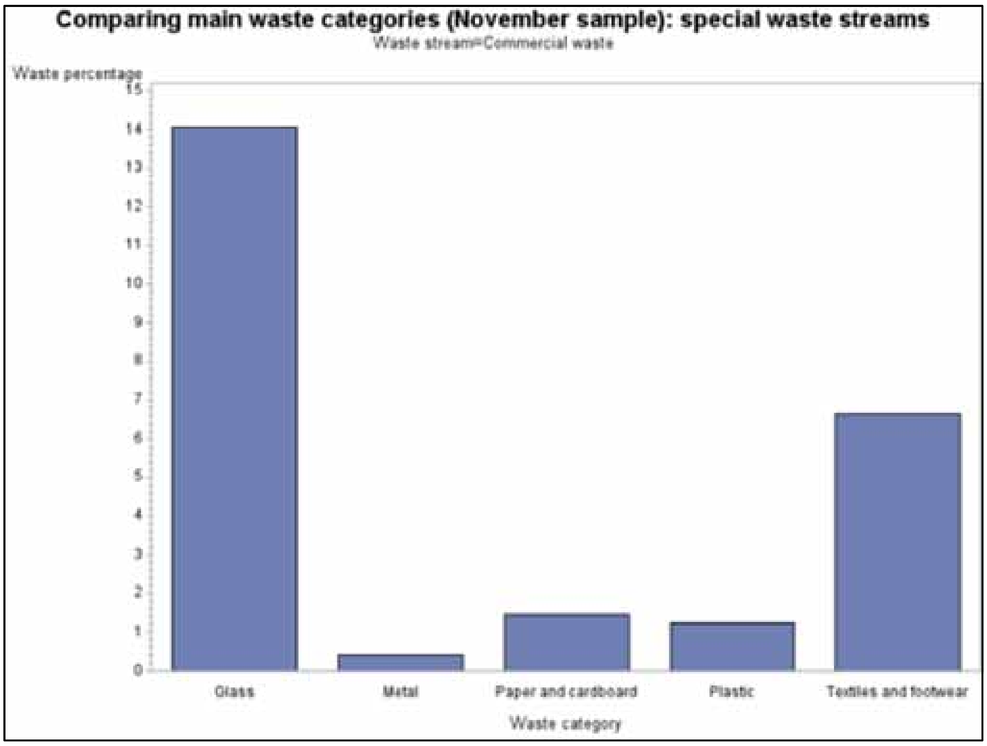
- The results present a snapshot in time
- The one sample of illegal dumping is from a high income area but could originated from anywhere or have been dumped by any income group
- The two samples of builder's rubble is from a high income and a middle income area respectively

- Garden waste appears as zero in the table because the two samples obtained by the team in the Pikitup truck were diverted to the landfill working face before these could be weighed and sorted. This was attributed to the new Pikitup staff working on the landfill site (see note on 10th December 2014 in Table 21).

5.3.1 Commercial waste

The commercial waste was collected from an area serviced by the Roodepoort depot. It should be noted that commercial waste will vary according to the type of industry collected from. The composition of this sample consisted mainly of glass and textiles (Figure 12). There were also traces of metal, paper and cardboard, and plastics in the waste sorted. This composition confirmed the assumption that commercial waste consists largely of recyclable materials.

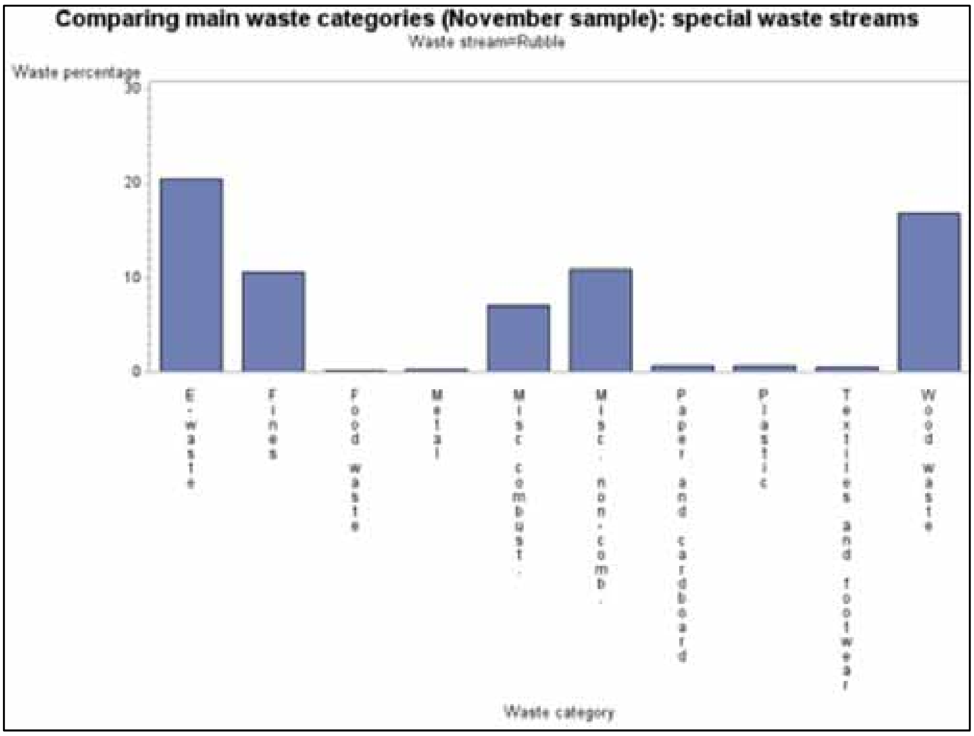
Figure 12 | Breakdown of waste from commercial clients (November 2014)



5.3.2 Builder's rubble from garden waste sites

The composition of builder's rubble from garden waste sites is detailed in Figure 13 below. The bulk of this was identified as e-waste, and wood waste. Fines and rubble formed the bulk of the remaining waste deposited in the builder's rubble skips sampled. It is concerning that e-waste finds its way into the builder's rubble waste stream. This does seem to point to a possible need for greater education and awareness at the garden waste sites.

Figure 13 | Composition of builder's rubble collected in bulk containers from drop off sites



5.3.3 Illegal dumping

Illegal dumping is the waste dumped illegally by the public and cleared by Pikitup or its appointed contractors. The composition of this waste stream is variable depending on the area from which the sample is collected and the season. The general consensus when discussing illegal waste with Pikitup officials (Pers. Comm., Komane and Loggerenburg, 2014) seems to be that in the built up areas this consists mostly of garden waste, while in the peripheral areas, this consists mostly of builder's rubble. For the purposes of this report, the illegal dumping for the September 2014 samples were taken from the Johannesburg CBD (served by Selby depot), Alexandra Township (served by Marlboro depot) and Bosmont (served by Waterval depot). The waste composition of the illegally dumped waste were largely miscellaneous non-combustible waste (28.25%), wood waste (11.27%), and textiles and footwear waste (8.95%) (Figure 14). This waste was found in primarily medium to low income areas.

Figure 14 | Composition of illegally dumped waste in the CoJ (for September 2014)

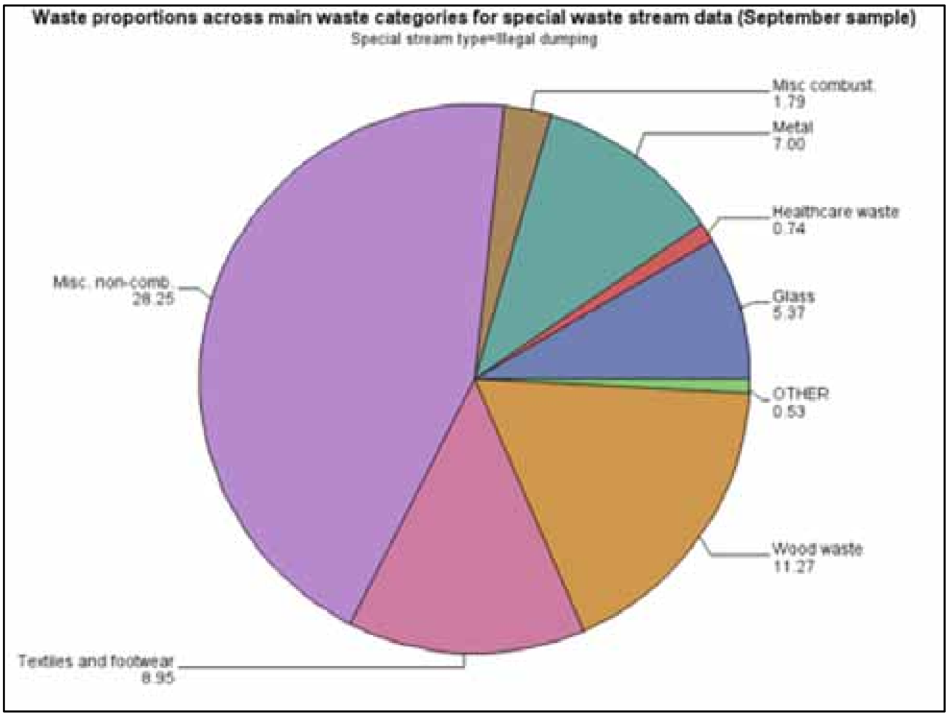
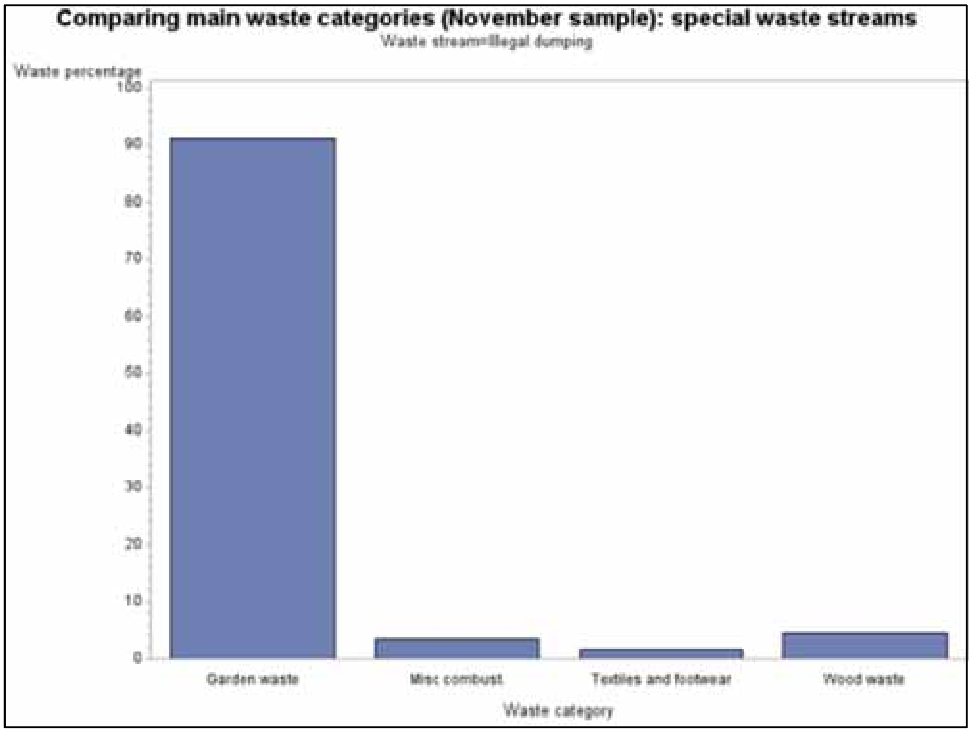


Figure 15 illustrates the composition of illegal dumping sampled during the November 2014 period. Although one needs to be careful to not ascribe the source of the waste to the area in which it was found (because the waste could have come from anywhere in the city), it is interesting to note that the bulk of this sample contained garden waste, and was cleared from a high income area. The origin of the waste may be from the high income household gardens but it is possible that third parties, such as garden services, may be responsible for the illegal dumping. The above findings appear to corroborate the impressions of Pikitup staff as to how the character varies over the city.

Figure 15 | Comparing main waste categories (November 2014) for illegal dumping



5.4 Waste generation estimates

The project team is able to estimate the per capita and annual waste generation based on the data collected during the sampling combined with the population and households estimates for the City. The lack of accurate landfill records (weighbridges at landfills are not in proper working condition) is a concern as it is not possible to confirm the estimates based on the actual waste disposal figures.

5.4.1 Estimate based on September 2014 data

The project team calculated waste generation per capita for each socio-economic group in the City (Table 10) based on 2011 data taken from the demographic growth projection report prepared by Kayamandi in 2013, and the actual data collected during the September sampling.

It should be noted that this calculation is a preliminary estimate based on limited data.

A summary of the data used in the calculations, also indicating the areas and economic classes covered in the samples, are provided in Appendix C.

Table 10 | Estimated waste generation (kg/capita/week) for low, middle and high income areas (for September 2014)

	Minimum	Maximum	Median
High income	7.27	15.43	8.59
Middle income	6.35	10.42	6.36
Low income	4.78	10.76	6.93

The median value rather than the average is provided since it is statistically more accurate to use median values due to the fact that this first sample still contained a low number of repetitions within each region and income class. Extrapolating this per capita waste generation to the socio-economic status of the population across the City results in a preliminary estimated 31 396 696.60 kilogram of household waste generated in the City on a weekly basis (Table 11).

Table 11 | Estimate household waste generation (kg/week) for the CoJ (for September 2014)

	Minimum	Maximum	Median
High income	5 901 029.92	12 524 469.28	6 972 468.64
Middle income	8 016 411.45	13 154 489.34	8029035.72
Low income	11 308 849.04	25 456 739.68	16 395 465.24
Total waste generation	25 226 290.41	51 135 698.30	31 396 696.60

Annual household waste generation based on the data collected during sampling in the City is therefore at this stage estimated to be between 1.3 and 2.6 million tonnes/annum with a median value of 1.6 million tonnes, which is on par with the CoJ estimates (Table 12).

Table 12 | Estimated annual household waste generation in the CoJ (tonnes/annum) (for September 2014)

	Minimum	Maximum	Median
High income	306 853.56	651 272.40	362 568.37
Middle income	416 853.40	684 033.45	417 509.86
Low income	588 060.15	1 323 750.46	852 564.19
Total	1 311 767.10	2 659 056.31	1 632 642.42

5.4.2 Estimate based on November 2014 data

In determining the per capita waste generation and ultimately the estimated annual household waste generation in the CoJ, a similar methodology was followed for the November sampling (Table 13, Table 14, and Table 15).

Table 13 | Estimated waste generation (kg/capita/week) for low, middle and high income areas (for November 2014)

	Minimum	Maximum	Median
High income	8.62	9.37	8.85
Middle income	5.84	6.52	6.44
Low income	0.57	7.80	4.88

Table 14 | Estimate household waste generation (kg/week) for the CoJ (for November 2014)

	Minimum	Maximum	Median
High income	3 462 869	9 484 524	6 423 027
Middle income	4 742 633	16 176 093	8 465 131
Low income	458 812	7 404 090	4 243 529
Total	8 664 314	33 064 707	19 131 687

Table 15 | Estimated annual household waste generation in the CoJ (tonnes/annum) (for November 2014)

	Minimum	Maximum	Median
High income	180 069	493 195	333 997
Middle income	246 617	841 157	440 187
Low income	23 858	385 013	220 664
Total	450 544	1 719 365	994 848

Based on the November 2014 data collected, the estimated annual household waste generation varies between 450 544 tonnes/annum (minimum) and 1 719 365 tonnes/annum (maximum).

The difference in the estimated waste generation between September and November can be attributed to the lower per capita waste generation in low income households observed during the November sampling, as compared to September. The variation in waste generation rates between September and November is a further indication that there may be seasonal variation, not only in waste composition but also waste generation rates.

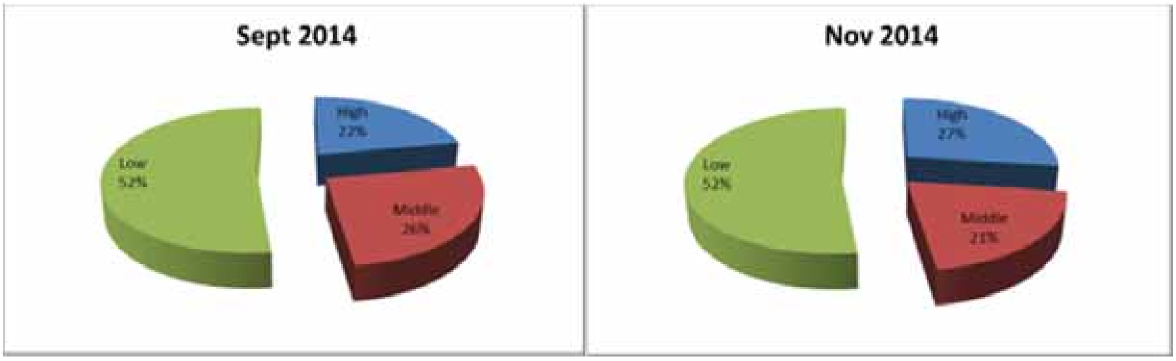
5.5 Contribution to household waste generation per income category

The September 2014 results indicate that the low income areas contribute 52% of the household waste generation in the City, followed by middle income (26%) and high income (22%) (Figure 16).

For November 2014 data the results are very similar: low income households contributing 52% of the waste again, middle income households contributing 21% and high income households contributing 27% of the waste.

High income households contribute more waste in November as compared to September. This can possibly be attributed to the increase in garden waste which increased significantly between September and November, especially from high income households.

Figure 16 | Relative contribution of each socio-economic group to household waste sample for September and November 2014



Based on 2013 data of Pikitup, the categories of waste in Table 16 are believed to be generated within the City (Pers. Comm. Komane, 2014). This information excludes commercial waste streams which are dumped at the landfill sites. Landfill data as provided by Pikitup is summarised in Table 17.

The accuracy of the data presented in Table 16 and Table 17 is questionable since at the start of the project, only one landfill (Marie-Louise) had a fully functional weighbridge. Subsequently the weighbridges for Marie Louise and Goudkoppies were repaired. The project team made use of the weighbridge at the materials recovery facility at Robinson Deep landfill for the purposes of this study (both September 2014 and November 2014), but the waste disposed of at the landfill is not weighed at present. Ennerdale landfill is also a matter of concern, since the weighbridge there was also not functional and the waste samples included in this project was diverted to Goudkoppies where the weighbridge was working.

Table 16 | Waste disposed of within the City of Johannesburg (Pikitup, 2014)

Waste type	Tonnes / annum
Round collected refuse from households	646 000
Illegal dumping	229 000
Garden waste	132 000
Street sweeping	87 000
Bulk containers	52 000
Informal areas	29 000
Dailies	17 000
Total	963 000

Table 17 | Waste disposed reflected by landfill site (Pikitup, 2014)

Landfill	Number of loads / transactions per landfill	Tonnes / annum
Ennerdale	14 620	94 788.613
Goudkoppies	49 262	312 586.588
Marie Louise	76 989	355 981.757
Robinson Deep	70 862	468 903.287
FG* (Interwaste)		180 864.000

Note*: The data for FG was provided by Interwaste and is based on the average over 9 months, extrapolated to 12 months.

Data on number of households and bins/bags serviced per RCR vehicle was also collected during the September 2014 and November 2014 sampling period. In instances where it was not possible to count the number of households (for example gated communities and blocks of flats), the data was excluded from the calculations. Although in some instances bags filled with waste were set out together with the bins, the calculations did not account for the bags. The findings of the observations are presented in Table 18 and Table 19. It will be statistically more correct to use the median rather than the average at this stage of the project.

Table 18 | Comparison between households serviced and bins collected per socio-economic group (for September 2014)

	Number of households	Number of bins
High income (n=14)		
Ave	389.64	422.79
Median	379.00	422.50
Max	798.00	803.00
Min	103.00	140.00
Middle income (n=6)		
Ave	514.67	664.33
Median	600.50	689.50
Max	720.00	869.00
Min	81.00	411.00

	Number of households	Number of bins
Low income (excl. RDP and informal) (n=15)		
Ave	586.40	584.86
Median	611.00	637.00
Max	1096.00	970.00
Min	112.00	112.00
Low income RDP (n=3)		
Ave	406.00	386.67
Median	430.00	403.00
Max	456.00	432.00
Min	332.00	325.00
Low income informal (n=3)		
Ave	491.00	461.00
Median	511.00	468.00
Max	592.00	511.00
Min	370.00	404.00

Table 19 | Comparison between households serviced and bins collected per socio-economic group (for November 2014)

Income type	Number of households	Number of Bins
High income (N = 25)		
Average	501.0	555.9
Median	447.0	578.0
Minimum	286.0	274.0
Maximum	866.0	887.0
Low income (N = 34)		
Average	676.8	713.1
Median	685.5	696.0
Minimum	90.0	289.0
Maximum	1242.0	1242.0
Middle income (N = 14)		
Average	467.0	515.9
Median	431.0	482.0
Minimum	104.0	309.0
Maximum	839.0	839.0

Both the September 2014 and November 2014 data show that there was approximately one bin put out per household during the survey (i.e. bins/households). This is in agreement with Mr Loggerenberg of Pikitup (Pers.

Comm., 2014) who confirmed that approximately one bin is usually collected per household during RCR collections.

The per capita waste generation per depot areas and income type was also calculated based on the actual waste collected during the sampling period. The results indicate geographical differences in per capita waste generation between income groups in the CoJ (Table 20).

Table 20 | Per capita waste generation per depot area and income type (November 2014)

Depot	Income type	Number of observations	Minimum	Average	Median	Maximum
Avalon	Low	10	3.45	5.39	5.31	9.12
Central Camp	Low	5	2.11	5.65	7.52	8.57
Norwood	High	1	10.25	10.25	10.25	10.25
	Low	2	6.65	7.43	7.43	8.20
	Middle	4	8.75	10.22	10.01	12.14
Orange Farm	Low	6	4.02	4.46	4.49	5.18
Randburg	High	3	9.22	10.61	10.92	11.68
	Middle	3	10.66	15.44	15.98	19.67
Roodepoort	High	3	8.62	8.95	8.85	9.37
	Low	6	3.35	5.33	5.39	7.80
	Middle	3	5.84	6.27	6.44	6.52
Selby	High	1	7.20	7.20	7.20	7.20
	Middle	1	19.93	19.93	19.93	19.93
Southdale	High	8	4.27	6.06	5.76	9.51
	Low	3	6.56	7.51	7.46	8.50
Waterval	Middle	2	.	.	.	.
Zondi	Low	2	0.57	1.96	1.96	3.36

The number of households serviced per vehicle varies depending on the size of the truck and the volumes of waste in the bins on the collection day.

The variables influencing households waste behaviour are numerous and not included in the scope of this project.

5.6 Challenges encountered during sampling

The collection and analysis of samples for this project was not without challenges, but the project team worked around the challenges as effectively as possible. The challenges resulted in fewer samples collected than initially planned and in some instances different samples than what was planned.

In instances where the truck was delayed, for example as a result of a break down, the sorting team had to work over time to complete the sorting. It will be essential for the City to address these challenges to improve their own operations and especially improve the collection of data during subsequent projects. Challenges encountered at the depots and landfill sites are listed in Table 21.

Table 21 | Summary of specific challenges

Date	Challenge
8 September 2014	Ripping of tarpaulin (no apparent influence on the sampling)
17 September 2014	Vehicle breakdown (only two samples instead of three).

Date	Challenge
	There were a number of other incidents where the vehicles broke down.
22 September 2014	For the night time sampling the street sweepings did not go over weighbridge and sorting was done following day. However an average was estimated for the weight of the trucks so as not to lose this information.
25 September 2014	Ennerdale weighbridge not functioning. The sorting team moved base to Goudkoppies in order to utilise the weighbridge there. Waste in the RCR trucks was therefore taken to Goudkoppies for weighing and sorting which resulted in increased time for the drivers as they were forced to travel additional distances.
29 September 2014	Only two samples were collected due to a meeting at a depot running late. One sample did not pass over the weighbridge due to arriving late.
30 September 2014	Vehicle breakdown (only two samples instead of three).
13 November 2014	Vehicle broken down, not possible to find alternative truck. Only two samples of RCR were analysed on this day.
1 and 2 December 2014	No sampling occurred on these two days. It was not possible to get permission from Interwaste for the sampling team to sort at the private landfill site despite intervention / requests from the City at least one week before sampling was due to take place. The inaccessibility of the FG site required the project team to redeploy the team on very short notice and replan the sampling protocol to minimise the risk to the overall project.
10 December 2014	Two trucks with garden waste samples were diverted to the landfill working face where sorting could not be done safely. This was attributed to the change in reporting structure at the landfill which was not communicated with the project team and resulted in miscommunication. This incident cost the project team two samples that could not be replaced with alternative samples.

5.7 Calorific value of waste sampled

A total of 19 samples were sent to the laboratory for analysis of moisture content, ash and gross calorific value (Appendix D). A summary of the results is presented in Table 22. The results are on par with calorific values reported in literature and therefore confirm the potential of the waste as a possible source of energy.

Table 22 | Summary of laboratory results for moisture ash and gross calorific value

Category	Sub-category	Moisture at 105 ºC (Gravimetric) (% m/m)	Ash at 950ºC (% g/g)	Gross calorific value
Paper	Newspaper	7.81	0.26	17.54
	H1 – all white office paper	6.02	11.25	12.07
	Non-recyclable paper	6.12	11.92	14.94
	K4	7.14	6.14	14.23
	Common mix	9.12	9.20	11.89
	Tetrapak	9.65	2.00	18.90
Plastics	HDPE drink bottles	6.09	0.10	44
	PET drink bottles	0.44	0.05	21
	Polypropylene	0.10	1.44	44
	Polystyrene	1.03	0.67	36
	CDs, DVDs	0.28	0.51	30

Category	Sub-category	Moisture at 105 °C (Gravimetric) (% m/m)	Ash at 950°C (% g/g)	Gross calorific value
	LD – clear plastic	0.15	2.75	44
	LD – mixed plastic	0.88	5.25	42
	LD - Stretch	0.70	0.75	44
	Non-recyclable / unidentified plastics	0.18	5.61	37
Garden waste		64	4.66	9.42
Food waste*		59	1.26	18.52
Wood waste		7.32	1.12	15.11
Textile waste		35	2.59	14.15

Note: * the calorific value for food waste is determined on a dry basis due to the high moisture content of this waste stream.

6 Conclusions and recommendations

This waste characterisation study established seasonal and socio-economic variation in the composition and generation rates of RCR waste in the City of Johannesburg Metropolitan Municipality. The results of this WCS represent a snap-shot in time and caution must be exercised when using this data for planning purposes.

The project team is comfortable that a representative sample of RCR waste in the City was analysed during both sampling rounds.

The samples relating to special waste streams is however too small to generalise or extrapolate conclusive findings.

The difference in composition between September and November is statistically significant, although the difference in composition is relatively small for most waste streams. Although the project team is satisfied with the accuracy and representivity of the data obtained during this study, the reader is cautioned that the full extent of seasonal variability has not been established due to the fact that no true winter sample was done. It is therefore recommended that a true winter WCS be done in the winter of 2015 to confirm the full extent of seasonal variability in the composition and generation of household waste in the City.

Waste separation at source is currently being rolled-out to households in the City. The composition of the source separated waste analysed indicates that more awareness creation and education on source separation of waste is required, as food waste and garden waste were found amongst source separated recyclables from low income households.

An analysis of residual waste from areas with kerbside collection of source separated waste indicated that separation of recyclables is not very efficient. This may be due to not all households participating in these initiatives, as well as inefficient sorting at household level. The same applies to garden waste centres where education on separation is required.

The City is therefore advised to invest time and money in continued education and awareness creation of communities about source separation of recyclables.

Findings from the WCS, indicating considerable amounts of recyclables remaining in the residual waste after waste separation at source, support the inclusion of a dirty materials recovery facility as part of the alternative waste treatment technology option. It also confirmed that enough RCR waste is generated in the City to feed into an alternative waste treatment technology option with a capacity to treat 500 000 tonnes per annum, as proposed in the feasibility study.

7 Human capital development

Approximately 22 people were directly deployed as fieldworkers to meet the data collection requirements of this project; they were all permanent employees from the Johannesburg and Pretoria WastePlan depots. These employees would have normally been actively engaged in separation activities at the two sorting plants. Because experienced people were deployed to the CityJ waste characterisation project, there was a need for additional casual employees to fill the gap left at the WastePlan plants. These additional casual workers, although not directly employed on the City project, found temporary employment and some will be taken on as permanent employees (Pers. Comm. Ferreira, 2015).

The WastePlan employees (Figure 17) working on the City project underwent intensive training and mentorship on site from CSIR staff, to meet the expectations of the project. It was considerably easier to get the team up to speed with what was required because of their previous experience in sorting waste.

Learning points for the team included the additional classes of waste which would normally have been discarded in their daily sorting regime because it would not have been considered recyclables.

The team was complimented for their professional conduct during the execution of this project.

Figure 17 | Part of the WastePlan team

8 Acknowledgement

The Aurecon / CSIR team acknowledges the dedicated assistance of the Pikitup and CoJ staff on this project. The number of people who have made this project a success are too numerous to mention here; however special thanks are made to the following:

- From the landfill sites:
  - Mr. Desmond Mannerson
  - Mr. Gerhardus Loggerenberg

- From an administrative perspective the depot managers and the following cluster heads:
  - Mr. Patrick Galloway (Northern Cluster)
  - Mr. Peter Hlubi (Southern Cluster)
  - Ms. Rochelle Ludick (Central Cluster)

The team is also grateful to the PSC team members who facilitated the project and ensured that information was received on time. In particular special thanks are due to:

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- Mr. Simphiwe Mbuli (CoJ – EISD)
- Mr. Sibusiso Komane (CoJ-Pikitup)
- Mr. Mlawule Mashego (CoJ-Pikitup)
- Mr. Li-Pei Huang (GFA)

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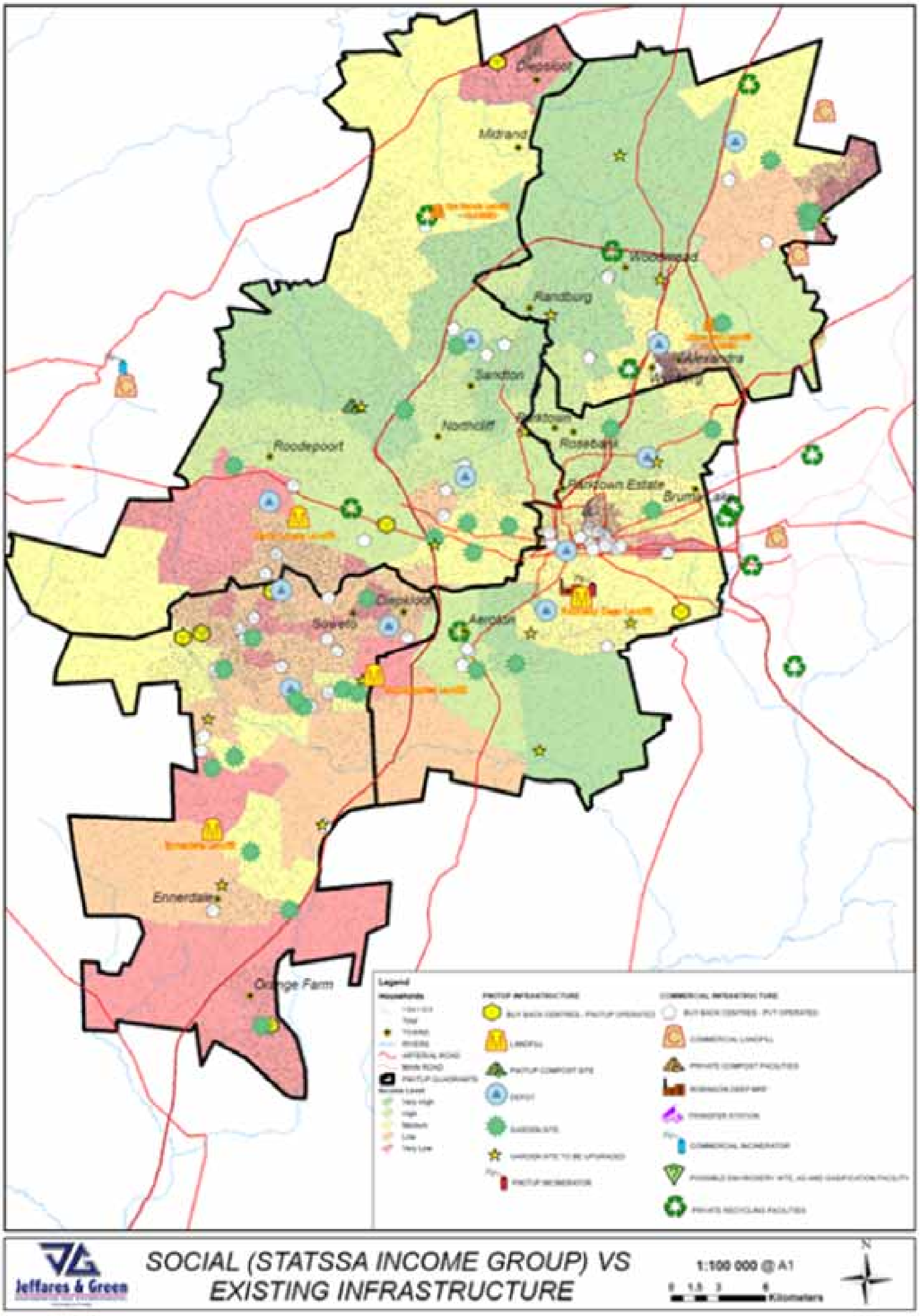
Appendix A: Distribution of socio-economic areas in the CoJ



Appendix B: Statistical seasonal comparison (September 2014 and November 2014 data)

Results from the comparison of waste percentages between Sept and Nov samples

Statistical note: The Mann-Whitney test was used to compare the two samples, not the t-test, because of the skewness of the data

All waste streams, all waste categories:

p-value	interpretation	
0.0009	statistically significant difference	*(p-value < 0.05 => significant)*

Per waste stream, all waste categories: *not all waste streams in both samples*

p-value	interpretation	Waste stream
0.039	statistically significant difference	Recyclables
0.0023	statistically significant difference	RCR
0.7502	no significant difference	Residues
0.0405	statistically significant difference	Illegal dumping

Per waste category, all waste streams:

p-value	interpretation	Waste category
0.0043	statistically significant difference	E- WASTE
0.9731	no significant difference	Fines (<10mm)
<.0001	statistically significant difference	Food waste
0.0004	statistically significant difference	Garden waste
0.3561	no significant difference	Glass
0.9626	no significant difference	Hazardous wastes
0.9124	no significant difference	Healthcare waste
0.2833	no significant difference	Metal: ferrous and non-ferrous
0.1771	no significant difference	Miscellaneous combustible
0.0021	statistically significant difference	Miscellaneous non-combustible
0.246	no significant difference	Paper and Cardboard
0.4954	no significant difference	Plastic
0.3238	no significant difference	Textiles and footwear
0.6711	no significant difference	Tyres
0.0002	statistically significant difference	Wood waste

Per waste category, RCR waste stream only:

p-value	interpretation	Waste category
0.1026	no significant difference	E- WASTE
0.8759	no significant difference	Fines (<10mm)
<.0001	statistically significant difference	Food waste
0.0164	statistically significant difference	Garden waste
0.9581	no significant difference	Glass
0.2085	no significant difference	Hazardous wastes
0.9917	no significant difference	Healthcare waste
0.3172	no significant difference	Metal: ferrous and non-ferrous
0.3079	no significant difference	Miscellaneous combustible
0.0011	statistically significant difference	Miscellaneous non-combustible
0.6099	no significant difference	Paper and Cardboard
0.5743	no significant difference	Plastic
0.3779	no significant difference	Textiles and footwear
0.24	no significant difference	Tyres
0.0015	statistically significant difference	Wood waste

Note that a statistically significant difference means a consistent difference, but the difference could be small, e.g. a consistent 1% difference could be statistically significant.

Appendix C: Spatial distribution of socio-economic groups in the CoJ

Table 23 | Total number of households per depot area and income area

Depot area	2011			
	High income	Middle income	Low Income	Total
Avalon	7641	34300	81391	123332
Central Camp	1371	43056	80431	124858
Marlboro	49911	33271	63641	146823
Midrand	29273	39376	142644	211293
Norwood	29587	40057	36382	106026
Orange Farm	286	3881	46447	50614
Randburg	60267	21048	41953	123268
Roodepoort	45081	36478	81743	163302
Selby	4064	21723	11430	37217
Southdale	34842	29302	49188	113332
Waterval	22318	20186	25114	67618
Zondi	4308	68495	96682	169485
Total	288949	391173	757046	1437168

Table 24 | Total population per depot area and income group

Depot area	2011			
	High income	Middle income	Low Income	Total
Avalon	29444	128508	285012	442964
Central camp	5576	158022	289581	453179
Marlboro	120598	89812	171708	382118
Midrand	76035	102130	364253	542418
Norwood	79307	117307	104679	301293
Orange farm	1059	14139	164215	179413
Randburg	159073	57433	113726	330232
Roodepoort	134190	114148	252443	500781
Selby	13137	71481	36181	120799
Southdale	115425	91749	148833	356007

Depot area	2011			
Waterval	61960	68640	83530	214130
Zondi	15892	249058	351707	616657
Total	811696	1262427	2365868	4439991

Appendix D: Calorific value report

Introduction

The National Waste Management Strategy (DEA, 2012) sets a goal of 25% diversion of recyclables from landfill for reuse, recycling or recovery. In addition, the National Norms and Standards for disposal of waste to landfill place restrictions on the disposal of certain waste to landfill (RSA, 2013).

In this regard disposal of garden waste must see a 25% diversion from landfill in five years and a 50% diversion in ten years (RSA, 2013). This level of diversion can be achieved through mechanical-biological treatment (MBT) or by incineration of municipal solid waste (MSW). Decisions on technology options for waste should be geared towards maximum value recovery within a circular economy (Oelofse, 2014). Energy recovery being a once-off value extraction process should therefore only be considered for materials that cannot be economically recycled (Rimaityte et al, 2010; Oelofse, 2014).

Literature review

The energy content of the waste material as well as the self-sustained combustibility of the waste stream needs to be assessed to inform the technology choice to be implemented as alternative waste treatment technology for municipal solid waste (MSW) (World Bank, 1999; Komilis et al, 2014). Both these aspects are directly related to the economic viability of the alternative waste treatment technology project. The absence of self-sustained combustibility of the waste will require use of external fuel which in turn will reduce the overall energy efficiency of an incineration plant (Komilis et al, 2014).

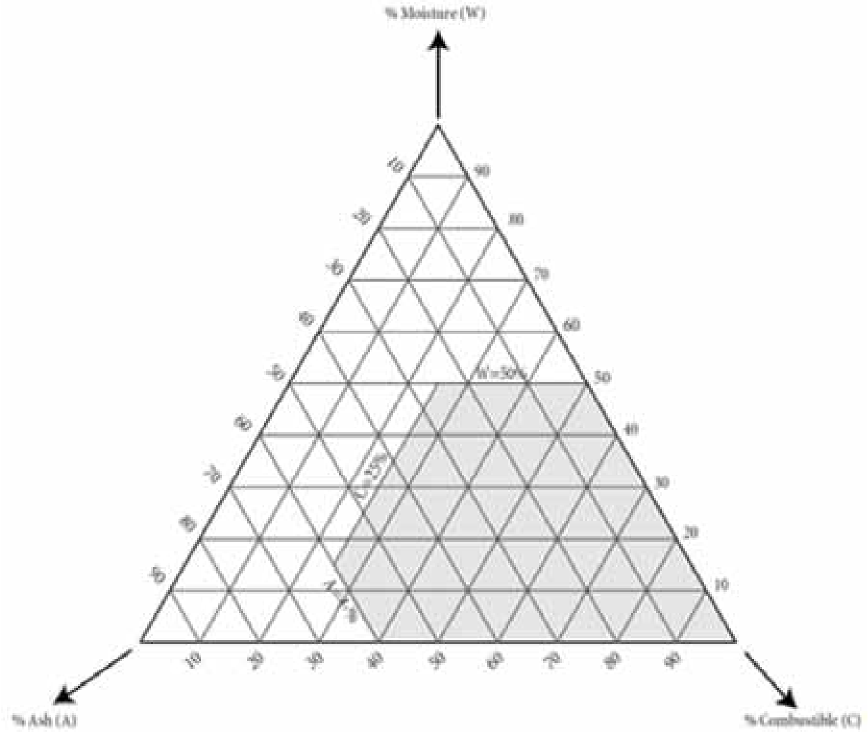
Self-sustained combustibility

Moisture content is probably the most important factor impacting on the sustained combustibility and calorific value of municipal solid waste. Moisture content varies by location (climatic variation) and by season and causes a directly proportional change in the real calorific value of the waste (Australian Greenhouse Office, 2001). Increased moisture content of the waste results in decreased calorific value due to the heat of vaporisation of water (latent heat of water) (Komilis et al, 2014). Komilis et al (2014) notes that one of the oldest graphical plots to assess the self-sustained combustibility of MSW, is the so-called Tanner diagram (Figure 1) which is still in use today.

The Tanner diagram is a triangular plot with the three axes being the combustibles (organic matter or volatile solids), the ash and the moisture content. All these 3 variables have to be expressed on a wet weight basis (wb) (Komilis et al., 2014). Each location within a Tanner diagram represents a solid waste mixture in which the sum of the organic matter (OM) content (% wb), the ash (A) content (% wb) and the moisture (M) contents (% wb) should always equal 1 (or 100 %). The proposed self-sustained combustibility of MSW is the shaded area within the Tanner diagram (Figure 1). According to the diagram, MSW mixtures with ash content ≤ 60% (wb), water content ≤ 50% (wb) and combustible (organics) content ≥ 25% can maintain self-sustained combustion without the support of external fuel (Komilis et al., 2014). Mixtures outside the shaded area can still burn but with the support of external fuel. However, the Tanner diagram fails to depict the change in calorific value within the area of self-sustained combustion (Komilis et al., 2014)

The research by Komilis et al. (2014) found that self-sustained combustion can be maintained at organic matter contents as low as 15% db provided that the corresponding moisture contents are less than 20% wb. In addition, substrates with moisture contents up to 60% wb can maintain self-sustained combustion as long as their organic matter contents are greater than 40% wb (or 75% dry weight based (db)) (Komilis et al., 2014).

Figure 18 | Tanner Triangle for assessment of combustibility of MSW (Tanner 1965 in Worldbank, 1999)



Energy content

Municipal solid waste is an inhomogeneous fuel that differs greatly from conventional fossil fuels. The energy content of the waste, the so-called lower calorific value (LCV) must be above a minimum level for waste to be incinerated (Worldbank, 1999). According to the Worldbank (1999) municipal solid waste should normally have an annual average lower calorific value of at least 7 MJ/wet kg to render incineration a viable treatment option. Other viability criteria that must be met include an average lower calorific value of no less than 6 MJ/kg throughout all seasons and an incineration rate of at least 50 000t/annum (Worldbank, 1999). The minimum required lower calorific value for a controlled incineration also depends on the furnace design. Low-grade fuel requires a design that minimises heat loss and allows the waste to dry before ignition (Worldbank, 1999).

The lower calorific value differs from the upper calorific value by the heat of condensation of the combined water vapours, which comes from the fuel's moisture content and the hydrogen released through combustion (Worldbank, 1999).

Typical lower calorific values for the ash and water free samples (Hawf) for different material types are listed in Table 1 (Worldbank, 1999).

Table 25 | Ash and water free calorific values (Hawf) for selected types of waste (Worldbank, 1999)

Main waste category	Subcategory	Hawf (MJ/kg)
Food scraps and vegetables		15-20
Plastics	Polyethylene (bottles, foil, etc.)	45
	PVC (bottles, etc.)	15-25
	Polystyrene (wrapping)	40
	Polypropylene	45
Textiles		19
Rubber and leather		20-25
Paper	Dry	16-19
	Wet	16-19

Main waste category	Subcategory	Hawf (MJ/kg)
Cardboard	Dry	16-19
	Wet	16-19
Wood and straw		19
Other combustible		*
Metals		0
Glass		0
Bones		0
Other non-combustible		0
Hazardous waste		*
Fines (< 12 mm)		15 (should be analysed in each case)

Note: * = Depends on chemical make-up of the material

Methodology

Waste samples (from the summer sampling round) were sorted into the same fractions as for the waste characterisation study. A total of 19 samples (Table 2), weighing approximately 500g each, were extracted from the waste samples collected on the 3rd of December 2014 and submitted to the analytical laboratory for moisture, ash and gross calorific value analysis.

Table 26 | Pictures of each waste category sent for laboratory analysis

Paper, newspaper		H1 – all white office paper	
Paper, common mix		Paper, K4	
Non-recyclable paper		Paper, Tetrapak	

Plastics, HDPE drink bottles		Plastics, PET drink bottles	
Plastics, Polypropylene		Plastics, Polystyrene	
Plastics, LD – clear plastic		Plastics, non-recyclable / unidentified plastics	
Plastics, CDs, DVDs			
Garden waste		Food waste*	
Wood waste		Textile waste	

Results

Table 27 | Summary of laboratory results for moisture ash and gross calorific value

Category	Sub-category	Moisture at 105 ºC (Gravimetric) (% m/m)	Ash at 950ºC(% g/g)	Gross calorific value

Category	Sub-category	Moisture at 105 ºC (Gravimetric) (% m/m)	Ash at 950ºC(% g/g)	Gross calorific value
Paper	Newspaper	7.81	0.26	17.54
	H1 – all white office paper	6.02	11.25	12.07
	Non-recyclable paper	6.12	11.92	14.94
	K4	7.14	6.14	14.23
	Common mix	9.12	9.20	11.89
	Tetrapak	9.65	2.00	18.90
Plastics	HDPE drink bottles	6.09	0.10	44
	PET drink bottles	0.44	0.05	21
	Polypropylene	0.10	1.44	44
	Polystyrene	1.03	0.67	36
	CDs, DVDs	0.28	0.51	30
	LD – clear plastic	0.15	2.75	44
	LD – mixed plastic	0.88	5.25	42
	LD - stretch	0.70	0.75	44
	Non-recyclable / unidentified plastics	0.18	5.61	37
Garden waste		64	4.66	9.42
Food waste*		59	1.26	18.52
Wood waste		7.32	1.12	15.11
Textile waste		35	2.59	14.15

Note: * Due to the high moisture content of food waste the CV value is determined on a dried basis

Discussion and conclusion

The calorific values (Table 3) were confirmed by analysis through Talbot and Talbot laboratories and the results of all the tested waste streams are comparable with values reported in literature.

The plastics returned a higher CV when compared to the paper categories. Also the recorded moisture was lower for plastics as compared to the paper categories. In addition to this the ash remaining upon combustion was also lower for the plastics compared to the paper categories.

It can therefore be concluded that there is energy potential locked in the waste streams (plastics, and paper respectively) which could be extracted through waste-to-energy technologies. The realisation of the energy potential locked in the waste will depend on the efficiency of the waste-to-energy technology choice as well as possible variation in composition and volume of the waste stream subjected to the technology.

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