Waste Characterisation Study for the City of Kigali

May 2023

Contents

.....1

Executive Summary.....3

Working Definitions.....3

Key Outputs Citywide.....4

Summary of Characterisation Outputs.....5

Key Messages:.....5

SPECIAL NOTES ON VALIDATION WORK.....6

Methodology.....8

Part 1: OVERALL METHODOLOGY.....8

Part 2: SAMPLING.....8

COMMERCIAL WASTE.....8

DOMESTIC/HOUSEHOLD WASTE.....9

Part 3: ANALYSIS.....11

HOUSEHOLD.....11

COMMERCIAL.....12

Part 4: THE SORTING CENTRE AND POINTS OF COLLECTION.....13

Part 5: VALIDATIONS.....15

Results.....16

HOUSEHOLDS.....16

Characterisation Tables:.....16

Characterisation Charts.....17

COMMERCIAL.....18

Characterisation Tables:.....19

Characterisation Charts.....19

ANALYSIS.....20

Quantitative.....20

Qualitative.....22

Conclusion.....24

Photolog.....25

References.....28

Executive Summary

A characterisation of the Kigali city waste has been carried out. Waste samples were collected directly from 354 households; deliveries bound for Nduba dumpsite and containing waste from some 413 households were redirected to the characterisation centre, as well as direct collections from 5 commercial installations – including 3 public markets, a mixed use hybrid building housing offices, eateries and shops – and a hotel.

An overall city-wide specific waste generation rate of 0.56 kg/capita/day was arrived at. Recyclables were found to be getting generated at a rate of 0.08 kg/capita/day. The Recyclables rate currently translates to 100.5 tons/day. These figures are understood to be slightly higher than actual on dry basis as some of the samples from public spaces and those redirected from Nduba deliveries were found to be inadequately protected from rainwater. Water addition to the waste tends to amplify the weights of the waste especially those of the organics, cardboard and textiles. An exercise to regress the results to moisture contents reflective of the *as-generated* nature of this waste has not been carried out as the *as-received* nature of the waste is the more important factor for the later tasks in this work.

A proximate characterisation of these waste streams has been carried out and is presented further below.

It has been observed that the organic fraction occupies a large portion of the waste from households, at 83.1%. For commercial installations, the organics have been found to be slightly less but still predominant at 57.6%. Further, only 15.8% of the waste streams were found to be (visually) dry, while only 5.4% were found to be pre-sorted. As such any project targeting recyclable materials as a separate stream needs to deliberately design sub-processes to deal with:

(1) the organic fractions, as well as
(2) the wetness of the materials.

There seemed to be some informal rummaging through the waste found in the public spaces – especially the markets – which skewed the characterisation results toward materials which currently have little or no demand from existing recyclers. Such recyclable materials found in "unnatural" excess quantities were glass and cardboard.

Working Definitions

	Entire Stream	Organics Only	Recyclables no Organics
Working Definition	The entire waste volume as received	The "Remaining Fraction" after removal of "other recyclables" and "inerts".	All materials reusable "as is" or treatable to be re-applied in some other form.
Includes	All waste materials	Oils, food waste, vegetation (except wood)	Plastics, PET (polyethylene terephthalate) bottles, PP (polypropylene) woven bags, paper, wood, glass, aluminium. Diapers are expressly *excluded*.

Key Outputs Citywide

	Entire Stream	Organics Only	Recyclables no Organics
Calculation Basis			
Generating population	1,318,000 people 286,664 households		
Sampled Population	767 households + 5 Commercial Installations		
Overall Volumes			
Collected Amount	5,748 kg, direct from Households, inc. 233kg (4.1%) diapers 354 Households	4,778 kg (83.1%)	624 kg (10.8%)
	5,339 kg dumpsite entry, inc 195kg (3.7%) diapers 413 Households	4,288 kg (80.3%)	755 kg (14.1%)
	2,043 kg from Commercial Installations 5 Installations, 2,832 Workers	1,177 kg (57.6%)	794 kg (38.9%)
Generation Period	7 days		
Total Samples	13,131 kg	10,243 kg (78%)	2,173 kg (16.5%)
Specific Waste Generation Rates			
Per Capita Gen. Rates	0.56 kg/capita/day	0.45 kg/capita/day	0.08 kg/capita/day
Water and wetness			
Dry Arrivals	15.8% of total stream		
Separation at Source			
Pre-Sorted Arrivals	5.4% of total stream		

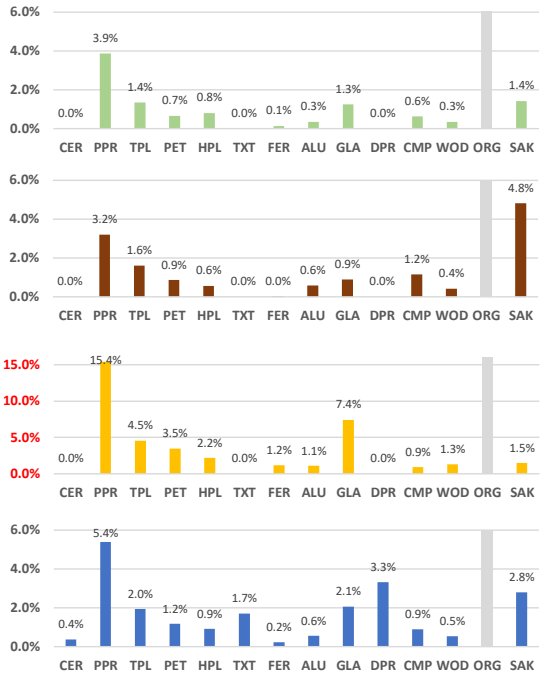
Comments

- Above figures likely higher than actual generation due to some samples – especially the ones from public places and from Nduba Arrivals – not receiving adequate protection from rain which increases weight, especially of organics and cardboard.
- From the results of the commercial installations – particularly the samples from the public markets – it has been deduced that these samples were rummaged through by agents of recyclers or similar waste pickers. This is because, certain expected fractions were missing entirely from the samples or their composition seemed unnatural, e.g., Nyarugenge market had zero PET bottles, thick-plastics and aluminium cans but a disproportionately large amount of glass. There is no fully industrialised glass recycler in Rwanda (except for a yet-to-scale project downcycling glass into aggregate substitutes in mortar for cement blocks).
- Remarkably, there was zero e-waste of any description in all the samples taken.
- By using the difference between volumes sampled at source and volumes re-directed from Nduba deliveries, an estimation has been made of the quantities of waste which side-step the Nduba trip and end up directly at private sorting/recycling centres.

Summary of Characterisation Outputs

HouseHolds Only				
Households	354	Whole Sample	Orgs Only	Rec Only
Weight Sampled	kg	5,748	4,778	624
Sampled Gen Rate	kg/day	821.2	682.6	89.1
City-wide Gen Rate	**ton/day**	665.0	552.8	**72.1**
CW Specific Gen Rate	**kg/person/day**	0.50	0.42	**0.05**
			83.1%	10.8%
Nduba Arrivals				
Households	413	Whole Sample	Orgs Only	Rec Only
Weight Sampled	kg	5,339	4288	755
Sampled Gen Rate	kg/day	762.8	612.6	107.8
City-wide Gen Rate	**ton/day**	529.4	425.2	**74.8**
CW Specific Gen Rate	**kg/person/day**	0.40	0.32	**0.06**
			80.3%	14.1%
Commercial				
Working Population in Sites Sampled	2,382	Whole Sample	Orgs Only	Rec Only
Weight Sampled	kg	2,043	1,177	794
Sampled Gen Rate	kg/day	291.9	168.1	113.5
Specific Gen Rate - Sample Only	kg/person/day	0.12	0.07	0.05
Waste from Workers	ton/day	72.9	42.0	28.4
Re-based to City Popul	kg/person/day	0.06	0.03	**0.02**
			57.6%	38.9%
City-Wide				
		Whole Sample	Orgs Only	Rec Only
Per Capita Gen Rate	**kg/person/day**	**0.56**	**0.45**	**0.08**
City-wide Gen Rate	**ton/day**	**737.9**	594.8	**100.5**
Gen Rate implied by Nduba Arrivals	ton/day	529.4	425.2	74.8
To Bishenyi & Other Locations	ton/day	208.5	169.6	25.7
			Bishenyi+ Bypass	**26%**

Total Households Sampled	767	3,526	Inhabitants
Commercial Installations Sampled	5	2,382	Workers
Total Waste Analysed	13,131	of which	
Recyclables	**2,173**	**16.5%**	
Organics	10,243	78.0%	
loaded Diapers	438	3.3%	
Inerts (ceramics, textiles)	277	2.1%	
Dry Samples	**2,080**	**15.8%**	**15.9 tpd**
Wet Samples	11,051	84.2%	**dry Recs in City**
Sorted Samples	**712**	**5.4%**	**5.4 tpd**
Unsorted Samples	12,419	94.6%	**sorted Recs in City**



Key Messages:

(1) Analysis was based on 13.131 tons of waste from 767 unique (none repeated) households and 5 commercial installations housing a total working population of 2,382 people.

(2) 16.5% of the Kigali city waste streams are Recyclable, 78% are Organics, 3.3% are loaded diapers and 2.1% Inerts (textiles and other non-recyclable residues).

(3) The high organics share is irrespective of wealth bracket for households

(4) For Commercial Waste from hybrid complexes the Organics remain high at 58% but recyclables are significantly higher at 38.9% (including glass at 7% and paper+cardboard at a combined 15%)

(5) Effective analysis of recyclables required that organics be specifically excluded from the datasets

(6) Total Recyclables generation rate for the city is 100.5 tpd or 0.08 kg/capita/day. However a significant portion of these recyclables by-pass the route to Nduba and go to other places such as the private sorting station located at Bishenyi (which happens to also host the disposal site for Kamonyi District) to sustain existing recycling business models. There is a leading private waste transfer station at Bishenyi whose key business model is recovery of recyclables including compost from the organics. The total by-pass is therefore conveniently referred to in this work as the Bishenyi+ by-pass. It is referred to as Bishenyi+ because Bishenyi is not the only means via which recyclable materials drop off from the city's waste management process at or near the point of generation; others include the waste pickers themselves rummaging and picking out what they can sell directly to waste recyclers. The Bishenyi+ by-pass has been calculated at 26% of the total city-wide generation rate of recyclables.

(7) The Recyclables are wet and poorly sorted. Pre-sorting only observed in 5% of the over 13 ton of samples collected and sorted. However, interviews indicated that some commercial facilities practice higher levels of pre-sorting but these volumes of pre-sorted waste are captive to certain collectors who by-pass the public waste management system and sell to recyclers.

(8) Although water/moisture content was not determined in this exercise, it was noticed that only 16% of the total samples arrived dry (by visual inspection only).

(9) To plan activities targeting recyclables only, it is important to first have an efficient and effective solution for excluding the organics and for dealing with the wetness (especially wet papers and cardboard) and which wetness encourages adherence of organics to the surfaces of the recyclable materials.

(10) Loaded baby diapers (though only organic in their received content) took up such a *significant* and *ever-present* portion of the waste that they needed their own explicit category in the characterisation exercise. There is currently no successful industrial process designed for recycling used diapers. It is therefore important, in designing a supply chain system for recyclables for the city, that an efficient and effective exclusion system be designed for loaded diapers as well.

SPECIAL NOTES ON VALIDATION WORK

(1) In May 2023, the Waste Characterisation work was re-conducted from two selected areas with a view to:

a. Check the possibility of collecting higher volumes of recyclable materials by avoiding rummaging in the first mile (rummaging by the collectors).

b. Check the possibility of collecting higher volumes of drier recyclables from higher income households.

c. Verify the fraction of organics.

(2) The results are shown below:

Areas	Two areas	Kigarama	Rugando
Households	274	134	140

Weights	Description/Category	kg	fraction
	Total	***6,437.8***	***100%***
"Non-Recyclable"	***Ceramics***	***0***	***0.0%***
	Paper + Cardboard	*138*	*2.1%*
	Plastic (Thin Film)	*118*	*1.8%*
	Plastic (PET) bottles	*50*	*0.8%*
	Plastic (High Density)	*13*	*0.2%*
"Non-Recyclable"	***Textiles and Inerts***	***271***	***4.2%***
	Metal – ferrous	*9.8*	*0.2%*
	Metal – Aluminium	*10*	*0.2%*
"Non-Recyclable"	***Glass***	***101***	***1.6%***
"Non-Recyclable"	***Loaded Diapers***	***289***	***4.5%***
	Composite Packaging	*21*	*0.3%*
	Wood	*14*	*0.2%*
"Non-Recyclable"	***Remaining (= Organics)***	***5,302***	***82.4%***
	PP Sacks	*97*	*1.5%*
	E-waste (Cables)	*4*	*0.1%*

(3) The analysis of the results according to the objectives of the validation work are:

a. Higher fraction of recyclables? No.

   7.4% compared to 10.8% in the wider exercise.

   The "recyclables" are identified as all the waste categories except for the following five: *organics*, *ceramics*, *textiles & mixed inerts*, *diapers* and *glass*.

   Recall that a working definition of "non-recyclable" is being used. For example, organics are well understood to be readily recyclable to fertiliser, among other circular economy valuables; however, for the purposes of this work, the organic fraction has been expressly defined as a non-recyclable since the organics will not be sorted by the equipment to be designed, installed and commissioned in Phase II of this work.

b. Higher volumes of recyclables? No.

   The total Recyclables were 474.8kg. This quantity was generated by 274 households. This is equivalent to 1.73kg/household for the accumulation period. The accumulation period was claimed to be 7 days but this could not be verified.

   At the official average of 4.6 inhabitants per household, the generation of Recyclables for the accumulation period was 1.73/4.6 = 0.376kg/person.

   For an accumulation period of 7 days, the specific generation rate of recyclables in the two areas sampled would be 0.376/7 = 0.05 kg/capita/day, lower than the 0.08 found for the wider city. For the rate to be equal to that of the wider city, the real accumulation period would have to be 4.7 days. It is known, however, that the total volume of waste collected from the two areas (6.4 metric tonnes) cannot be accumulated in a shorter period than 5-7 days. As such, it was concluded, even without strict verification of the accumulation period, that the specific generation rate of recyclables from the two areas was lower than had been seen in the wider exercise. The recyclables still appear to be greatly overshadowed by the organics.

   Further, the waste was mixed and moderately wet throughout.

c. The fraction of organics (vegetation and other organic fraction materials) was found to be 82.4%, higher than the wider city at 78.0%.

(4) The presence of 0.1% e-waste (via standalone cables, *not* from the internals of electronic/electrical items) was noted for the validation exercise as a difference with the analysis for the wider city. A comment stating "no e-waste was observed…" was deleted from the report.

(5) The results of the validation work were noted and taken account of in the final report (specifically, an alteration on observations related to e-waste). However, they did not show any analytically opposed difference from the earlier work, i.e., recyclables are still indicated as "low", recyclables arising from households are still predominantly wet, and organics are still indicated as "high". As such, the validation work did not generate any basis to warrant changes to the conclusions for the wider city.

Methodology

Part 1: OVERALL METHODOLOGY

1. In keeping with international best practice for waste characterisation, the analysis shall be proximate (vs. ultimate) in nature. This means that physical (vs. chemical) groupings are used. So, for example, while chemically speaking, plastics, food, wood and paper are all organic materials (being based on carbon or hydrocarbon chains), the "Organics" category in this work expressly excludes all but the second of these materials and refers only to food, oils and vegetation.
2. A waste accumulation period of 7 days was provided.
3. Taking into account the pre-requisite meetings with key stakeholders, including the City of Kigali administration and a local search for a rain-safe Waste Sorting Centre as well as identification *of* and commercial arrangements *with* Waste Collectors, the entire Waste Characterisation period was some 21 days long.
4. Psychological philosophy was to avoid "stuffing" (placing in the waste bag only the materials which are perceived to be "correct" or "safe" because someone is watching with motives that may or may not be trusted, regardless of the "marketing" explanations). The most minimal intrusions into the process of collection and transportation was therefore aimed at. As such, the waste continued being collected by the Waste Collector Companies under supervision of the GV/ICU Waste Characterisation Team.
5. In a departure from the initial plan of working with Final-Year students from the College of Science and Engineering of the University of Rwanda as Sorting and Analysis Assistants, the waste collection company, *Baheza*, was engaged to supply *experienced* sorting labour working under the supervision of the GV/ICU Waste Characterisation Team.
6. Waste bags were procured by the WC Team and handed over to the Collection Company.
7. Waste Collectors brought the samples daily in *un-opened* waste bags (except for the 5.3ton Nduba Sample as well as the samples from public spaces at the markets and commercial buildings.
8. Clean-up after the materials had been weighed and analysed was also outsourced to the Collection Company.
9. Kimihurura Sector Government Hygiene 7 Sanitation Office (Ms. Pelagie) provided the interface to key social stakeholders for the duration of the exercise.
10. Another departure from initial plan was in down-sampling. Initial plan was that only the commercial samples would be down-sampled. However, due to the big and irregular items which were being encountered form the household wastes too, it was decided that no down-sampling be carried out and all samples sorted and analysed in full as received.

Part 2: SAMPLING

COMMERCIAL WASTE

Out of all trucks collected per day, samples are received from a chosen street/cell to be used for the entire sampling period, as follows:

3 District Markets
1 A mixed-use/hybrid building housing offices, eateries and shops

DOMESTIC/HOUSEHOLD WASTE

Cultural Context:

There is a unique cultural background influencing how waste is collected in Kigali. There are particularly three factors which influenced the design of the sampling plan: these are: *geographic sectoring*, *frequency* of collection and *socio-economic stratification*.

- Collection of domestic/household waste is done ***once per week*** for each household. Different ***Sectors*** of each of the ***three Districts*** are visited each day. As such, there is household waste travelling every day of the week, but each day of the week sees waste coming from *different point sources* within the overall category of 'Household Waste'.
- Rwanda society is economically stratified into five ***Ubudehe*** categories. 'Ubudehe' itself translates into something close to "collective helping action" and is a Rwandan cultural practice which was adopted into Rwandan governance systems in the early 2000s. The *Ubudehe* program has been receiving improvement updates to its formalised implementation and utilisation over its almost two decades of life in formal Rwandan governance systems. The Ubudehe categories are now accepted as the one formal proxy for wealth classification in Rwandan society. This is the categorisation that is used for determining such things as social welfare subsidy (e.g., for public medical insurance) and for, among other things, waste collection fees for each household.
- The Rwanda Utilities Regulatory Authority, RURA, sets and revises the waste collection fees according to the *Ubudehe* category. The Waste Collection companies are not at liberty to vary these fees for households. As such, only three levers for sustaining and/or growing revenue and profitability remain for those waste collectors who service households:
  1) *aggregation* – increasing the volume of *paying households* served using few collection assets,
  2) *logistics* – reducing the cost of handling, storage and transportation,
  3) *grid monetisation* – creating income at other points in the waste processing chain apart from at the entry point (the waste collection fees paid by households), such as selling of certain fractions of the aggregated waste to recyclers, composters, etc., seeking "green funds" from impact investors, and other post-collection initiatives.

Samples:

Due to the wealth categorisation above, more than one collection was carried out from each identified Sector in each District. This was an attempt to spread across the wealth categories where the majority of the city's population is to be found. On each cycle, only one wealth category was targeted so that the samples would not end up mixing as they were opened and processed at the Sorting Centre.

Number of Households in the samples:

- From the NISR (National Institute of Statistics of Rwanda)'s report on Characteristics of Households and Housing, the population of the City of Kigali was read off as 1,318,000 and the number of households as **286,664**. This – 286,664 households is the population for purposes of the sampling plan. The same report indicated how the household population was distributed across the three district as: Nyarugenge: 72,280, Gasabo: 137,146 and Kicukiro: 77,238.
- Taro Yamane (1967)'s formula (small populations) was used to calculate the **representative sample** size, *n*, as follows:

$$n = \frac{N}{1 + Ne^2}$$

Where:

N is the population size, 286,664, and

e is a factor of the precision level expected, set at 0.091

The representative sample size was thus calculated at 123 households. However, 354 households ended up being sampled, targeting higher representativity.

- The Comprehensive Food Security & Vulnerability Analysis (CFSVA) report for Rwanda, (World Food Program 2018), provided the percentage households in each wealth quintile (the 5 Ubudehe categories) by province and Kigali City. It broke down the population of Kigali City by Wealth Category as shown by the diagram below (A: 64%, B: 23%, C: 6%, D: 5%, E: 1%). It must be mentioned that this distribution was starkly different from the rest of Rwanda. This split was used to proportion the samples across the five strata for each of the three districts as shown below. The data shows that, for example, for both Kicukiro and Nyarugenge districts, it is *not* necessary for the sampling team to seek any Category E (poorest households) from these areas, and that the importance of Categories D and C are very low compared to Categories B and A. As a result, it would be safe even to sample only 116 households. Nonetheless, 354 households were sampled from each District, as shown below.

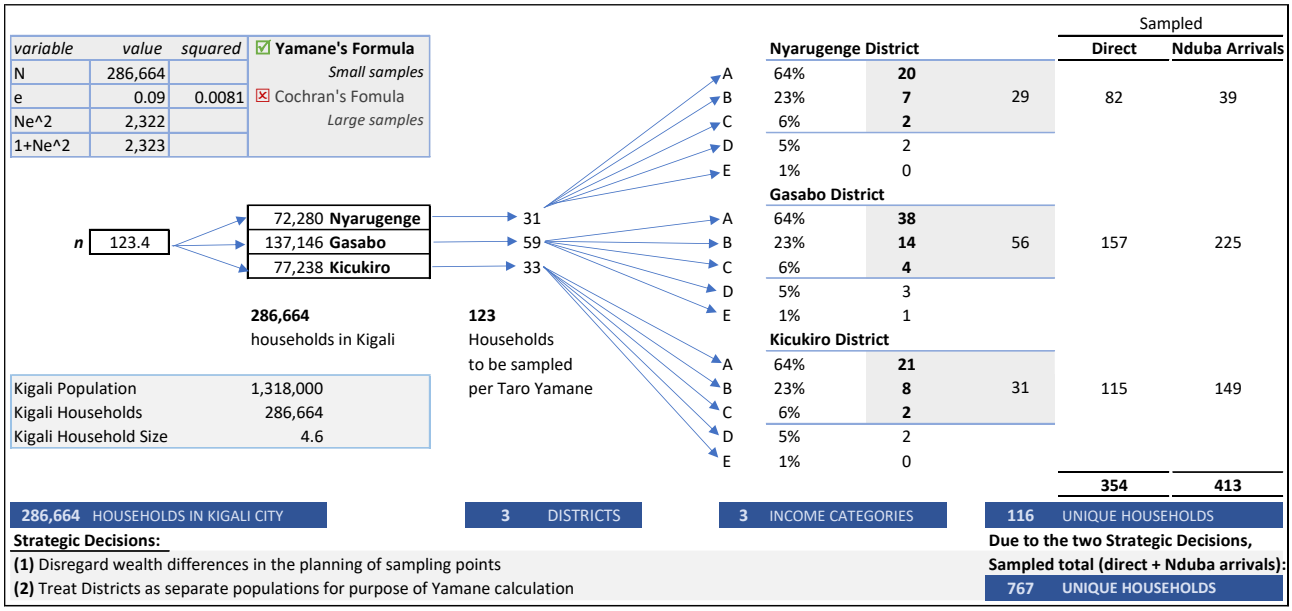


FIGURE 1 – Planning the number of samples to take per District.

THE NDUBA SAMPLE

"Arrivals at Nduba": Strictly defined, this does *not* belong only to householders but may even include commercial waste. However, as the predominant majority of arrivals at Nduba were confirmed by the operating company, Kalisimbi, as originating from households, a truck containing household waste was diverted to represent Nduba Arrivals. The difference between this sample and the household samples could be viewed as a "by-pass" factor representing what materials are normally removed from the waste "as generated" to arrive at the waste "as received" in the following manner:

As Received = As Generated + [As generated x The By-Pass Factor]

LEGACY WASTE AT DUMPSITE

Not Needed

Part 3: ANALYSIS

HOUSEHOLD

1. Complete the *Waste Acceptance Form* (*WAF*) which captures:
    a. The source of the waste
    b. The estimated weights
    c. Visual indications (wet, dry, big-piece, sorted)
2. Weigh the bag and record in the right place on the *WAF for Households (WAF-H)*.

		Wednesday, 7		Thursday, 8		Friday,9		Sat	Sun	Monday, 12		Tuesday, 13	
		HDP	NDP	HDP	NDP	HDP	NDP			HDP	NDP	HDP	NDP
Source													
District													
Sector													
Cell / Road													
Time													
Time Collected	HH:MM												
Time Dropped	HH:MM												
Visuals													
Weight Bag 1	kg												
Weight Bag 2	kg												
Weight Bag 3	kg												
Weight Bag 4	kg												
Weight Bag 5	kg												
Weight Bag 6	kg												
Weight Bag 7	kg												
Weight Bag 8	kg												
Total Weight	kg												
State1: Dimensions (big/heavy, easy-sort)													
State2: Wetness (Wet/Dry)													
State3: Pre-Sorting (Sorted/Mixed)													
State4: Smell (Heavy/Moderate/Low/Zero)													

The Waste Acceptance Form for Households (WAF-H)

3. Open the bag and pour onto the either the Household Daily Pile (HDP) or the Nduba Daily Pile (NDP)
4. When the targeted number of daily bags have been poured onto the daily pile, carry out the down-sampling work module (remember that the HDP and the NDP are to be sorted separately as shown on the WAF):
5. Sorting & Recording:

    a. 12 bins are placed around the waste pile, behind a ring of Sorters with one supervisor whose task is to ensure only the correct fractions are placed in each bag by the sorting team.

    b. Each sorter targets only one of the 12 Categories of waste according to the *Separation Specification* below. They place the materials they take into the bags behind them. Each bag that is full or at the end of the exercise – whichever comes first – each bag is weighed and the weight entered onto the *Waste Analysis Sheet* (bottom part of the WAF), see below.

    c. At the end of the process, the residues will be composed of mainly organic and inert materials which do not fall into any of the 12 Categories. The supervisor ensures that the inert objects are separated now from the organic materials and the two Categories (organics and inert residues) recorded in their separate rows on the Waste Analysis Sheet.

    d. A clean broom is used to pile the residue materials together at the end, care being taken to ensure the broom brushes do not retain any weight from the waste on the floor.

    e. Once all weights have been recorded, the bags are put aside to be picked up and delivered to their original destinations according to the cities current Waste Management System.

			Wednesday, 7		Thursday, 8		Friday,9		Sat	Sun	Monday, 12		Tuesday, 13	
			HDP	NDP	HDP	NDP	HDP	NDP			HDP	NDP	HDP	NDP
Source														
District														
Sector														
Cell / Road														
Time														
Time Collected	HH:MM													
Time Dropped	HH:MM													
Visuals														
Sorting and Measurements	ID	Unit												
Paper	1	kg												
Cardboard	2	kg												
Plastic (Thin Film)	3	kg												
Plastic (PET) bottles and Containers	4	kg												
Other Plastics	5	kg												
Textiles	6	kg												
Metal – ferrous	7	kg												
Metal – non-ferrous	8	kg												
Glass	9	kg												
E-waste	10	kg												
Compound materials	11	kg												
Wood	12	kg												
Remainings (= Organics by Subsample)	13	kg												
Other	14	kg												
C&D Waste	15	kg												
TOTAL Weights	T	kg												

The Waste Analysis Sheet (WAS)

COMMERCIAL

1. Complete the *WAF-Commercial* which captures:
    a. The point sources mixed in the waste (various aspects captured as shown below)
    b. The estimated weights
    c. Visual indications (wet, dry, big-piece, sorted)
2. Where any of the waste is packed in bags, weigh each bag and record in the right place on the *Waste Acceptance Sheet*.
3. If any of the waste is not already in bags, batch them and place in bags or otherwise tie together so that it can be weighed in batches, and record in the right place on the *Waste Acceptance Sheet*.
4. Open any bags or batches and pour onto the daily pile.
5. Follow the Sorting and Recording module as shown above for Households.

		Friday, 9	Saturday, 10	Sunday	Monday, 12	Tuesday, 13	Wednesday, 14
Source							
District							
Sector							
Cell/Road							
Waste Generator Type							
Estimated Population Served Per Day							
Waste Generator Category							
Other Key Data							
Date & Time							
Date Collected	DDMMYY						
Time Collected	HH:MM						
Time Dropped	HH:MM						
Visuals							
Weight Bag 1 - or heap	kg						
Weight Bag 2	kg						
Weight Bag 8	kg						
Total Weight	kg						
State1: Dimensions (big/heavy, easy-sort)							
State2: Wetness (Wet/Dry)							
State3: Pre-Sorting (Sorted/Mixed)							
State4: Smell (Heavy/Moderate/Low/Zero)							

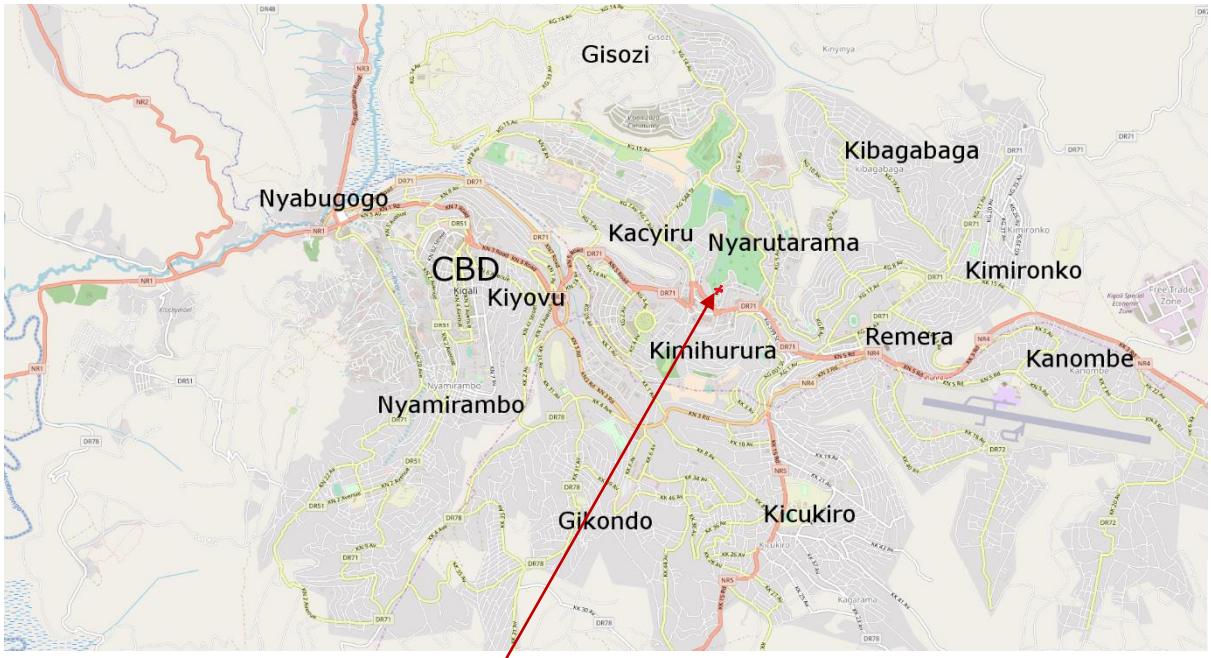
The Waste Acceptance Form for Commercials (WAF-Com)

Part 4: THE SORTING CENTRE AND POINTS OF COLLECTION

Kigali city is mapped out and administered in three districts: Gasabo (largest), Kicukiro and Nyarugenge. As shown in Part B, above, the three districts were covered in the exercise by sampling from households and commercial installations in each district.

The City of Kigali allocated the project team a Waste Sorting Centre located nearest the confluence of the three districts and in a "odour safe" zone. This Centre fell under Kimihurura Sector government and was located in the open greens (locally referred to as "Sahara") facing Kigali Convention Centre, Kigali Heights and such mapped locations as the Kigali Diplomat Hotel and University of Kigali.

From the Waste Sorting Centre, the key population centres (Sectors) such as Kicukiro, Kigarama, Gikondo in Kicukiro District; Kacyiru and Kimihurura in Gasabo District, as well as Nyamirambo and Kiyovu in Nyarugenge District were traversed in the collection rounds to represent the City of Kigali. Detailed Sector sources as well as collection times are included in the results tables presented later in this report.



The Temporary Waste Sorting Centre established at Kimihurura.

Surrounding are the Sectors within the three Districts from which waste was collected.

FIGURE 2 – The WSC and the Sectors from which the waste was collected.

Part 5: VALIDATIONS

Several validation steps were programmed into the Waste Characterisation file to flag erroneous inputs.

The results obtained were also compared with published results in peer reviewed national and international publications. This step ensures consistency of methodology with internationally accepted best practices as well as requiring that any departures from expectation are explained accurately, adding to the overall understanding of the problem of municipal solid waste and recyclables in the city of Kigali.

			Friday, 9	Saturday, 10	Sunday	Monday, 12	Tuesday, 13	Wednesday, 14
Source								
Date & Time								
Visuals								
Weight Bag 1 - or heap		kg	1104.5	80.5		38.3	80.5	599
Weight Bag 2		kg						
Weight Bag 8		kg						
Total Weight		kg	**1104.5**	**80.5**		**38.3**	**80.5**	**599**
State1: Dimensions (big/heavy, easy-sort)			Easy Handle	Easy Handle		Easy handle	Easy handle	Easy handle
State2: Wetness (Wet/Dry)			Wet	Wet		Wet	Wet	Wet
State3: Pre-Sorting (Sorted/Mixed)			Mixed	Mixed		Mixed	Sorted	Sorted
State4: Smell (Heavy/Moderate/Low/Zero)			Moderate	Moderate		Moderate	Moderate	Moderate
Sorting and Measurements	ID	Unit						
Ceramics	1	kg	0.5	9.5		0	3	0
Paper + Cardboard	2	kg	215.5	3		19.5	25	0
Plastic (Thin Film)	3	kg	67.5	3		0	6	4
Plastic (PET) bottles and Containers	4	kg	45.5	4.5		2	3	0.5
Other Plastics (High Density)	5	kg	32.5	0		2.5	1.5	0.5
Textiles and Inerts	6	kg	10.5	4		2	4	3.5
Metal – ferrous	7	kg	16.5	0.5		2	0	0
Metal – Aluminium	8	kg	15.5	0		1	2	0
Glass	9	kg	99	0		3.5	18	13.5
Loaded Daipers	10	kg	5.5	0		0	1	1.5
Composite Packaging	11	kg	4	4.5		1	0.5	0
Wood	12	kg	14.5	0		0	5.5	0
Remainings (= Organics by Subsample)	13	kg	571.5	3.5		4.5	4.5	571
Woven PP Sacks	14	kg	6	3		0.3	6.5	4.5
E-waste	15	kg						
TOTAL Weights	T	kg	**1104.5**	**35.5**		**38.3**	**80.5**	**599**
Validations				1		1	1	
1. All "before" and "after" weights entered			TRUE	TRUE		TRUE	TRUE	TRUE
2. Totals post-sorting </= Totals "as received"			TRUE	TRUE		TRUE	TRUE	TRUE
3. All WC Categories data checked - No Blank			TRUE	TRUE		TRUE	TRUE	TRUE
4. Sample weight acceptable			TRUE	FALSE		FALSE	FALSE	TRUE

FIGURE 3 – part of the auto-validation system. Note the red-flagged data due to insufficient daily sample weights. This prompted the collection of more bags from the flagged areas. "FALSE" means that the condition set has not been met, and "TRUE" means the opposite.

Key published literature used to perform result comparisons include Rajashekar, Bowers, Gatoni (2019); Iraguha, Ramelan, Retyono (2022); Nikuze et al (2021) and Kabera, Wilson, Nishimwe (2019). These pieces of literature were consulted after the characterisation exercise to ensure that any differences from peer published figures could be interrogated and repeat work conducted where necessary. The results were found to be consistent with published figures (statistically insignificant and/or explainable differences from published literature), hence no repeat/confirmation tests became necessary.

In this work, for example, the specific generation rate of waste in Kigali was found to be 0.56 kg/capita/day. Iraguha et al (2012) estimated the same figure at 0.49 while Wilson & Kabera (2017) worked it out at 0.57.

For the current work, it has been analysed that the figure of 0.56 is higher than the "as generated" situation due to water loading which happened to some of the samples in the exercise.

Results

HOUSEHOLDS

			Friday, 16	Saturday, 10	Sun	Monday, 19	Monday, 19	Monday, 19	Tuesday, 21	Tuesday, 21	Thursday, 22	Thursday, 22	Thursday, 22
Source													
District			GASABO	GASABO		KICUKIRO	KICUKIRO	GASABO	GASABO	GASABO	NYARUGENGE	NYARUGENGE	NYARUGENGE
Sector			Kacyiru	Kigarama		Kigarama	Kigarama	Kacyiru	Kacyiru	Kacyiru	Rwezamenyo	Rwezamenyo	Rwezamenyo
Cell/Road			Kamatamu	Nyamurama		Nyamurama	Nyamurama	Kamatamu	Kamatamu	Kamatamu	Rwezamenyo 1	Rwezamenyo 1	Rwezamenyo 1
Waste Generator Type			Household	Household		Household	Household	Household	Household	Household	Household	Household	Household
Ubudehe Cat			**A - top**	**A - top**		**C**	**D**	**D**	**A - top**	**C**	**A - top**	**C**	**D**
Other Key Data			Nduba Sample	Households 5600FRW		Households 3700FRW	Households 1900FRW	Households 2000FRW	Households 5000RW	Households 3000FRW	Households 5500FRW	Households 3600FRW	Households 1800FRW
Date & Time													
Date Collected	DDMMYY		161222	161222		161222	161222	171222	171222	171222	211222	211222	211222
Time Collected	HH:MM		5:30	6:30		6:30	6:30	7:30	7:30	6:30	11:00	6:30	11:00
Time Dropped	HH:MM		13:45	11:00		11:00	11:00	9:00	9:00	9:00	12:40	9:00	12:40
Visuals													
Weight Bag 1 - or heap		kg	5339.35	520.5		489	283	987.2	1363	610.5	677	1188	215
Weight Bag 7		kg											
Weight Bag 8		kg											
Total Weight		kg	**5,339.35**	**520.5**		**489**	**283**	**987.2**	**1363**	**610.5**	**677**	**1188**	**215**
State1: Dimensions (big/heavy, easy-sort)			big pieces, hard sort	easy sort		easy sort	easy sort	heavy	heavy	heavy	EASY SORT	EASY SORT	EASY SORT
State2: Wetness (Wet/Dry)			wet	wet		wet	wet	wet	wet	wet	DRY	DRY	DRY
State3: Pre-Sorting (Sorted/Mixed)			mixed	mixed		mixed	mixed	mixed	mixed	mixed	MIXED	mixed	MIXED
State4: Smell (Heavy/Moderate/Low/Zero)			moderate	moderate		moderate	moderate	moderate	moderate	moderate	MODERATE	moderate	MODERATE
Sorting and Measurements	ID	Unit											
Number of Households			***413***	***42***		***45***	***28***	***56***	***64***	***37***	***32***	***32***	***18***
Ceramics	1	kg	0	2		0.75	1.5	0	0	0	13	7	6
Paper + Cardboard	2	kg	171	27.5		19	20	22.5	55	25	2	50	1
Plastic (Thin Film)	3	kg	86	8.1		4.9	4.5	7	24.5	7	6	14	2
Plastic (PET) bottles and Containers	4	kg	46	3.9		3.1	4	3.5	4.5	4	4	8	3
Other Plastics (High Density)	5	kg	30	7.5		5	3	3	18.5	2.5	2	5	0
Textiles and Inerts	6	kg	102	10.9		5.1	9	7	20.5	8	7	16	0
Metal – ferrous	7	kg	0.1	0		0	0	1.5	3.5	0.4	1	0.8	1
Metal – Aluminium	8	kg	31.75	5.2		1.3	2	1.5	4	1.6	1	3.2	0
Glass	9	kg	48	10.5		3.5	4	17	4.5	8	7	16	2
Loaded Daipers	10	kg	194.5	60.8		27.2	5	2	47	28.5	5	57	0
Composite Packaging	11	kg	62	4.9		4.6	3.5	4	7.5	4	0	8	0
Wood	12	kg	23	2.1		2.9	0	4	0.5	2.5	3	5	0
Remainings (= Organics by Subsample)	13	kg	4288	352.5		344.9	209.5	473	1093	495.5	622	991	197
PP Sacks	14	kg	257	20		18	8.6	7.5	7	7	4	7	3
E-waste	15	kg	0										
TOTAL Weights	T	kg	**5,339.35**	**515.9**		**440.25**	**274.6**	**553.5**	**1290**	**594**	**677**	**1188**	**215**
Validations													
1. Weights entered			TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
2. Totals separate </= Totals fresh			TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
3. All key WC data entered			TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
4. Sample weight acceptable			TRUE	TRUE		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Normalised Distribution													
Sample Label			NDUBA	GAA16		KIC16	KID16	GAD17	GAA17	GAC17	NYA21	NYC21	NYD21
Ceramics	1		**0.0%**	**0.4%**		**0.2%**	**0.5%**	**0.0%**	**0.0%**	**0.0%**	**1.9%**	**0.6%**	**2.8%**
Paper + Cardboard	2		**3.2%**	**5.3%**		**4.3%**	**7.3%**	**4.1%**	**4.3%**	**4.2%**	**0.3%**	**4.2%**	**0.5%**
Plastic (Thin Film)	3		1.6%	1.6%		1.1%	1.6%	1.3%	1.9%	1.2%	0.9%	1.2%	0.9%
Plastic (PET) bottles and Containers	4		**0.9%**	**0.8%**		**0.7%**	**1.5%**	**0.6%**	**0.3%**	**0.7%**	**0.6%**	**0.7%**	**1.4%**
Other Plastics (High Density)	5		**0.6%**	**1.5%**		**1.1%**	**1.1%**	**0.5%**	**1.4%**	**0.4%**	**0.3%**	**0.4%**	**0.0%**
Textiles and Inerts	6		1.9%	2.1%		1.2%	3.3%	1.3%	1.6%	1.3%	1.0%	1.3%	0.0%
Metal – ferrous	7		**0.0%**	**0.0%**		**0.0%**	**0.0%**	**0.3%**	**0.3%**	**0.1%**	**0.1%**	**0.1%**	**0.5%**
Metal – Aluminium	8		**0.6%**	**1.0%**		**0.3%**	**0.7%**	**0.3%**	**0.3%**	**0.3%**	**0.1%**	**0.3%**	**0.0%**
Glass	9		0.9%	2.0%		0.8%	1.5%	3.1%	0.3%	1.3%	1.0%	1.3%	0.9%
Loaded Daipers	10		3.6%	11.8%		6.2%	1.8%	0.4%	3.6%	4.8%	0.7%	4.8%	0.0%
Composite Packaging	11		1.2%	0.9%		1.0%	1.3%	0.7%	0.6%	0.7%	0.0%	0.7%	0.0%
Wood	12		**0.4%**	**0.4%**		**0.7%**	**0.0%**	**0.7%**	**0.0%**	**0.4%**	**0.4%**	**0.4%**	**0.0%**
Remainings (= Organics by Subsample)	13		0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PP Sacks	14		4.8%	3.9%		4.1%	3.1%	1.4%	0.5%	1.2%	0.6%	0.6%	1.4%
E-waste	15		0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	T		20%	32%		22%	24%	15%	15%	17%	8%	17%	8%
Conditions Tally													
Wetness													
Dry	2,080	19%	0	0		0	0	0	0	0	677	1,188	215
Wet	9,008	81%	5,339	516		440	275	554	1,290	594	0	0	0
Pre-Sorting													
Sorted	0	0%	0	0		0	0	0	0	0	0	0	0
Mixed	11,088	100%	5,339	516		440	275	554	1,290	594	677	1,188	215

Characterisation Tables:

Sample Label		NDUBA 5.339ton	GAA16 516kg	KIC16 440kg	KID16 275kg	GAD17 553kg	GAA17 1.290ton	GAC17 594kg	NYA21 677kg	NYC21 1.188ton	NYD21 215kg
Ceramics	1	0.0%	0.4%	0.2%	0.5%	0.0%	0.0%	0.0%	1.9%	0.6%	2.8%
Paper + Cardboard	2	3.2%	5.3%	4.3%	7.3%	4.1%	4.3%	4.2%	0.3%	4.2%	0.5%
Plastic (Thin Film)	3	1.6%	1.6%	1.1%	1.6%	1.3%	1.9%	1.2%	0.9%	1.2%	0.9%
Plastic (PET) bottles	4	0.9%	0.8%	0.7%	1.5%	0.6%	0.3%	0.7%	0.6%	0.7%	1.4%
Plastic (High Density)	5	0.6%	1.5%	1.1%	1.1%	0.5%	1.4%	0.4%	0.3%	0.4%	0.0%
Textiles and Inerts	6	1.9%	2.1%	1.2%	3.3%	1.3%	1.6%	1.3%	1.0%	1.3%	0.0%
Metal – ferrous	7	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	0.1%	0.1%	0.1%	0.5%
Metal – Aluminium	8	0.6%	1.0%	0.3%	0.7%	0.3%	0.3%	0.3%	0.1%	0.3%	0.0%
Glass	9	0.9%	2.0%	0.8%	1.5%	3.1%	0.3%	1.3%	1.0%	1.3%	0.9%
Loaded Diapers	10	3.6%	11.8%	6.2%	1.8%	0.4%	3.6%	4.8%	0.7%	4.8%	0.0%
Composite Packaging	11	1.2%	0.9%	1.0%	1.3%	0.7%	0.6%	0.7%	0.0%	0.7%	0.0%
Wood	12	0.4%	0.4%	0.7%	0.0%	0.7%	0.0%	0.4%	0.4%	0.4%	0.0%
Remaining (= Organics)	13	80.3%	68.3%	78.3%	76.3%	85.5%	84.7%	83.4%	91.9%	83.4%	91.6%
PP Sacks	14	4.8%	3.9%	4.1%	3.1%	1.4%	0.5%	1.2%	0.6%	0.6%	1.4%
E-waste	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Total	T	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

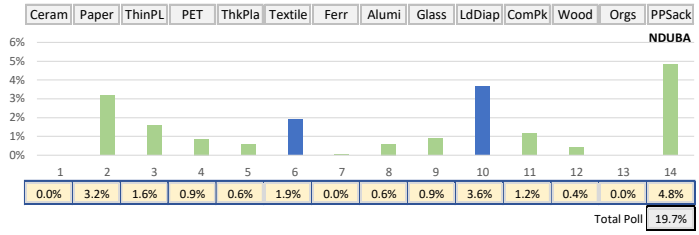
Characterisation Charts

Where:

Ceram	Ceramics	Paper	Paper
ThinP	Thin-film Plastic	PET	PET bottles and containers
ThkPla	Other (higher density) plastics	Textile	Textiles, Synthetic and Human Hair, etc
Ferr	Metal – Ferrous	Alumi	Aluminium Cans and materials
Glass	Glass	LdDiap	Loaded Diapers
Wood	Wood	PPSack	PP sacks
Compk	Composite Packaging (paper+plastic+other as a toughened packaging material)		
Orgs	Organics incl. vegetation – *removed from charts to give scale to Recyclables*		

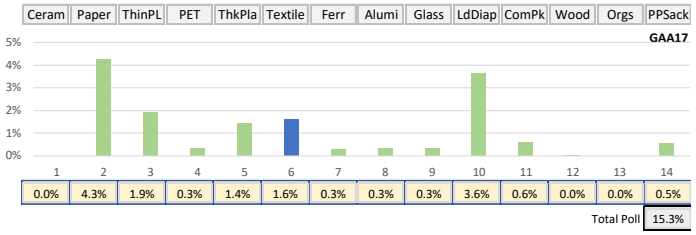
Recyclable material — Non-Recyclable material

Weighted Summary for this sub-section (weighted average of all the charts)



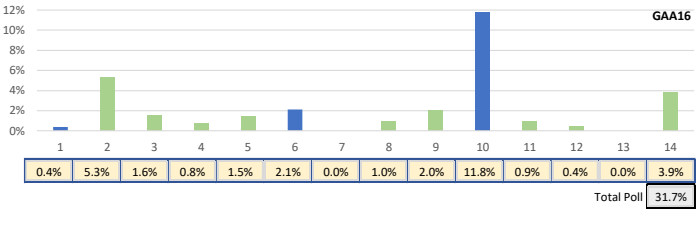
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.0%	3.2%	1.6%	0.9%	0.6%	1.9%	0.0%	0.6%	0.9%	3.6%	1.2%	0.4%	0.0%	4.8%

Total Poll 19.7%



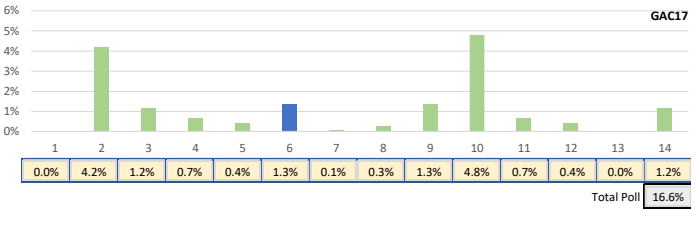
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.0%	4.3%	1.9%	0.3%	1.4%	1.6%	0.3%	0.3%	0.3%	3.6%	0.6%	0.0%	0.0%	0.5%

Total Poll 15.3%



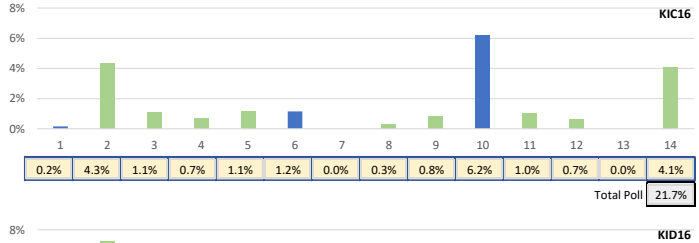
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.4%	5.3%	1.6%	0.8%	1.5%	2.1%	0.0%	1.0%	2.0%	11.8%	0.9%	0.4%	0.0%	3.9%

Total Poll 31.7%



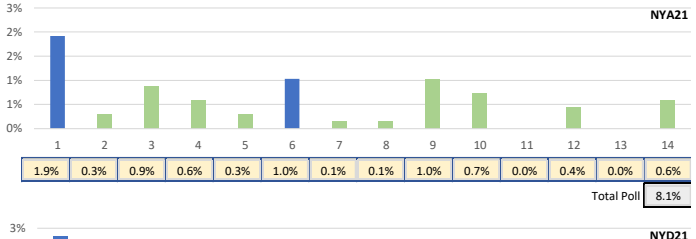
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.0%	4.2%	1.2%	0.7%	0.4%	1.3%	0.1%	0.3%	1.3%	4.8%	0.7%	0.4%	0.0%	1.2%

Total Poll 16.6%



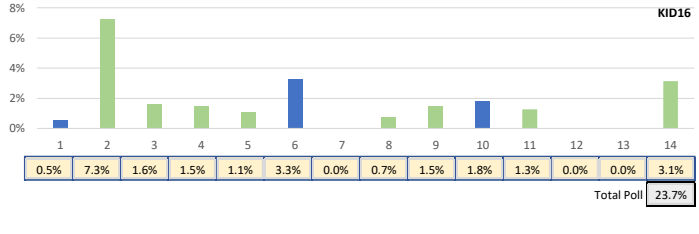
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.2%	4.3%	1.1%	0.7%	1.1%	1.2%	0.0%	0.3%	0.8%	6.2%	1.0%	0.7%	0.0%	4.1%

Total Poll 21.7%



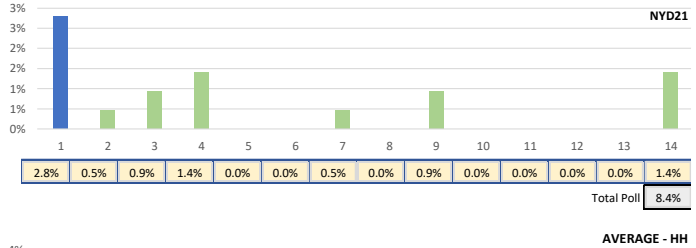
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
1.9%	0.3%	0.9%	0.6%	0.3%	1.0%	0.1%	0.1%	1.0%	0.7%	0.0%	0.4%	0.0%	0.6%

Total Poll 8.1%



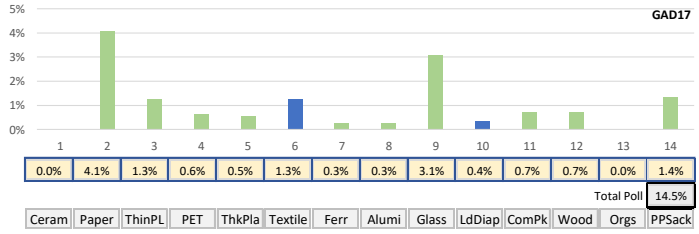
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.5%	7.3%	1.6%	1.5%	1.1%	3.3%	0.0%	0.7%	1.5%	1.8%	1.3%	0.0%	0.0%	3.1%

Total Poll 23.7%



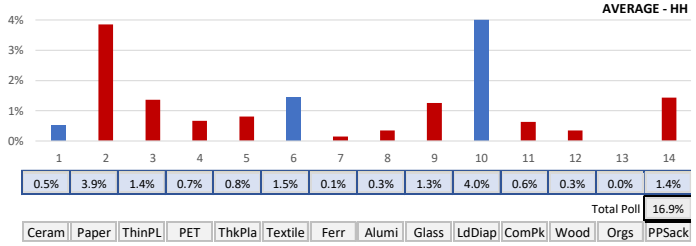
Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
2.8%	0.5%	0.9%	1.4%	0.0%	0.0%	0.5%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	1.4%

Total Poll 8.4%



Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.0%	4.1%	1.3%	0.6%	0.5%	1.3%	0.3%	0.3%	3.1%	0.4%	0.7%	0.7%	0.0%	1.4%

Total Poll 14.5%



Ceram	Paper	ThinPL	PET	ThkPla	Textile	Ferr	Alumi	Glass	LdDiap	ComPk	Wood	Orgs	PPSack
0.5%	3.9%	1.4%	0.7%	0.8%	1.5%	0.1%	0.3%	1.3%	4.0%	0.6%	0.3%	0.0%	1.4%

Total Poll 16.9%

COMMERCIAL

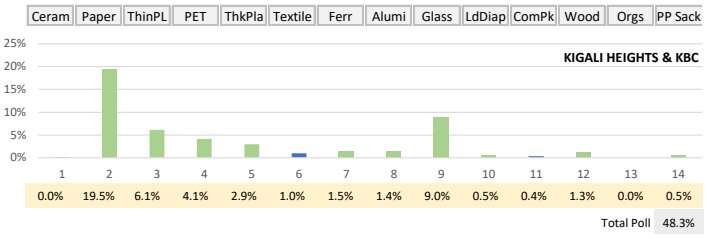
		Friday, 9	Saturday, 10	Sunday	Monday, 12	Tuesday, 13	Wednesday, 14	Totals	Averages
Source									
District		1. NYARUGENGE	1. KICUKIRO		2. GASABO	2. GASABO	3. NYARUGENGE		
Sector		??	KIGARAMA		KIMIHURURA	KICUKIRO	NYARUGENGE		
Cell/Road		??	KIGARAMA		RUGANDO	NGOMA	NYARUGENGE		
Waste Generator Type		ADMIN. OFFICE	MARKET		HOTEL	MARKET	MARKET		
Estimated Population Served Per Day		450	600		132	600	600	2,382	
Waste Generator Category		**Tert. Ed. Institutions**	**District Markets**		**Hotels & Restuarants**	**District Markets**	**District Markets**		
Other Key Data		KIGALI HEIGHTS & KBC	GIKONDO MARKET		GLAZIA HOTEL	ZINIA MARKET	NYARUGENGE MARKET		
Date & Time									
Date Collected	DDMMYY	191222	201222		201222	201222	191222		
Time Collected	HH:MM	4:00	6:00		9:00	10:00	9:00		
Time Dropped	HH:MM	6:00	7:00		9:45	10:40	10:50		
Visuals									
Weight Bag 1 - or heap	kg	1104.5	160.4		111.55	112.5	599	2,088	
Weight Bag 2	kg							0	
Weight Bag 8	kg							0	
Total Weight	kg	**1104.5**	**160.4**		**111.55**	**112.5**	**599**	**2,088**	
State1: Dimensions (big/heavy, easy-sort)		Easy Handle	Easy Handle		Easy handle	Easy handle	Easy handle		
State2: Wetness (Wet/Dry)		Wet	Wet		Wet	Wet	Wet		
State3: Pre-Sorting (Sorted/Mixed)		Mixed	Mixed		Mixed	Sorted	Sorted		
State4: Smell (Heavy/Moderate/Low/Zero)		Moderate	Moderate		Moderate	Moderate	Moderate		
Sorting and Measurements	ID / Unit								
Ceramics	1 kg	0.5	16		0	4	0	21	1.0%
Paper + Cardboard	2 kg	215.5	11.5		53	34	0	314	15.4%
Plastic (Thin Film)	3 kg	67.5	9.5		3.5	8	4	93	4.5%
Plastic (PET) bottles and Containers	4 kg	45.5	11		9	4.5	0.5	71	3.5%
Other Plastics (High Density)	5 kg	32.5	2.5		6.8	2	0.5	44	2.2%
Textiles and Inerts	6 kg	10.5	15		5.5	6	3.5	41	2.0%
Metal – ferrous	7 kg	16.5	1.6		5.5	0	0	24	1.2%
Metal – Aluminium	8 kg	15.5	1		2.75	3	0	22	1.1%
Glass	9 kg	99	4.5		9.5	25	13.5	152	7.4%
Loaded Daipers	10 kg	5.5	2.5		0	1.5	1.5	11	0.5%
Composite Packaging	11 kg	4	11		2.5	1	0	19	0.9%
Wood	12 kg	14.5	4.8		0.5	7.5	0	27	1.3%
Remainings (= Organics by Subsample)	13 kg	571.5	15		12	7	571	1,177	57.6%
Woven PP Sacks	14 kg	6	9.5		1	9	4.5	30	1.5%
E-waste	15 kg							0	0.0%
TOTAL Weights	T kg	**1104.5**	**115.4**		**111.55**	**112.5**	**599**	**2,043**	
Validations									
1. All "before" and "after" weights entered		TRUE	TRUE		TRUE	TRUE	TRUE		
2. Totals post-sorting </= Totals "as received"		TRUE	TRUE		TRUE	TRUE	TRUE		
3. All WC Categories data checked - No Blank		TRUE	TRUE		TRUE	TRUE	TRUE		
4. Sample weight acceptable		TRUE	TRUE		TRUE	TRUE	TRUE		
Normalised Distribution									
Sample Label		1????19	1KIKI20		2KIRU20	2KING20	3NYNY19	Chart Selector	AVERAGE - COMMERCIAL
Ceramics	1	**0.0%**	**13.9%**		**0.0%**	**3.6%**	**0.0%**	1	**1.0%**
Paper + Cardboard	2	**19.5%**	**10.0%**		**47.5%**	**30.2%**	**0.0%**	1	**15.4%**
Plastic (Thin Film)	3	6.1%	8.2%		3.1%	7.1%	0.7%	1	4.5%
Plastic (PET) bottles and Containers	4	**4.1%**	**9.5%**		**8.1%**	**4.0%**	**0.1%**	1	**3.5%**
Other Plastics (High Density)	5	**2.9%**	**2.2%**		**6.1%**	**1.8%**	**0.1%**	1	**2.2%**
Textiles and Inerts	6	1.0%	13.0%		4.9%	5.3%	0.6%	1	2.0%
Metal – ferrous	7	**1.5%**	**1.4%**		**4.9%**	**0.0%**	**0.0%**	1	**1.2%**
Metal – Aluminium	8	**1.4%**	**0.9%**		**2.5%**	**2.7%**	**0.0%**	1	**1.1%**
Glass	9	9.0%	3.9%		8.5%	22.2%	2.3%	1	7.4%
Loaded Daipers	10	0.5%	2.2%		0.0%	1.3%	0.3%	1	0.5%
Composite Packaging	11	0.4%	9.5%		2.2%	0.9%	0.0%	1	0.9%
Wood	12	**1.3%**	**4.2%**		**0.4%**	**6.7%**	**0.0%**	1	**1.3%**
Remainings (= Organics by Subsample)	13	51.7%	13.0%		10.8%	6.2%	95.3%	1	57.6%
Woven PP Sacks	14	0.5%	8.2%		0.9%	8.0%	0.8%	1	1.5%
E-waste	15	0.0%	0.0%		0.0%	0.0%	0.0%	1	0.0%
Total	T	100%	100%		100%	100%	100%		100%
Conditions Tally									
Wetness									
Dry	0 0%	0	0		0	0	0	0	
Wet	2,043 100%	1,105	115		112	113	599	0	
Pre-Sorting									
Sorted	712 35%	0	0		0	113	599	0	
Mixed	1,331 65%	1,105	115		112	0	0	0	

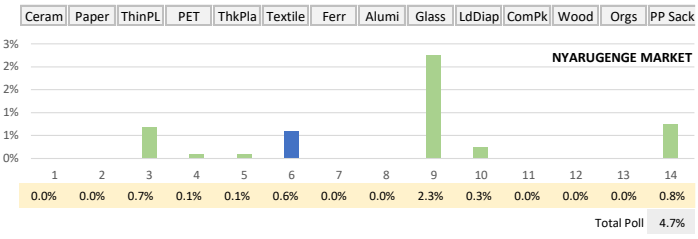
Characterisation Tables:

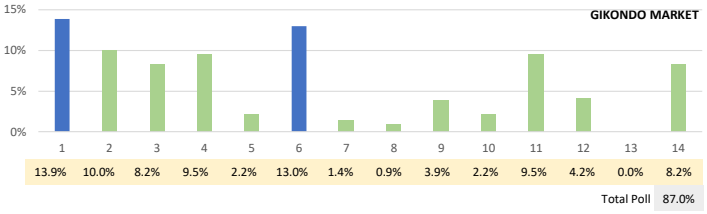
Sample Label		1KIRU19 1.104ton	1KIKI20 115kg	2KIRU20 111kg	2KING20 112kg	3NYNY19 599kg	WEIGHTED AVERAGE - COMMERCIALS
Ceramics	1	0.0%	13.9%	0.0%	3.6%	0.0%	1.0%
Paper + Cardboard	2	19.5%	10.0%	47.5%	30.2%	0.0%	15.4%
Plastic (Thin Film)	3	6.1%	8.2%	3.1%	7.1%	0.7%	4.5%
Plastic (PET) bottles	4	4.1%	9.5%	8.1%	4.0%	0.1%	3.5%
Other Plastics (High Density)	5	2.9%	2.2%	6.1%	1.8%	0.1%	2.2%
Textiles and Inerts	6	1.0%	13.0%	4.9%	5.3%	0.6%	2.0%
Metal – ferrous	7	1.5%	1.4%	4.9%	0.0%	0.0%	1.2%
Metal – Aluminium	8	1.4%	0.9%	2.5%	2.7%	0.0%	1.1%
Glass	9	9.0%	3.9%	8.5%	22.2%	2.3%	7.4%
Loaded Diapers	10	0.5%	2.2%	0.0%	1.3%	0.3%	0.5%
Composite Packaging	11	0.4%	9.5%	2.2%	0.9%	0.0%	0.9%
Wood	12	1.3%	4.2%	0.4%	6.7%	0.0%	1.3%
Remaining (= Organics)	13	51.7%	13.0%	10.8%	6.2%	95.3%	57.6%
Woven PP Sacks	14	0.5%	8.2%	0.9%	8.0%	0.8%	1.5%
E-waste	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	T	100%	100%	100%	100%	100%	100%

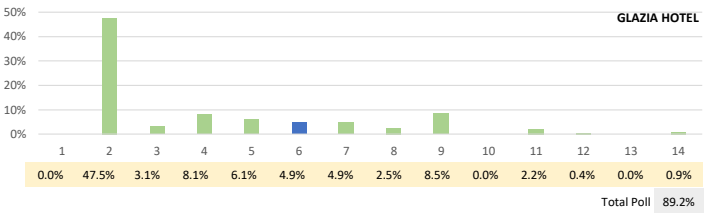
Characterisation Charts

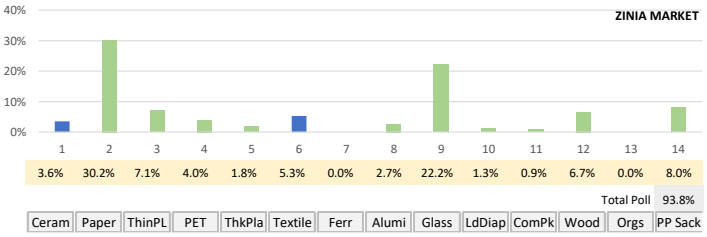
See Households Charts for key/legend.

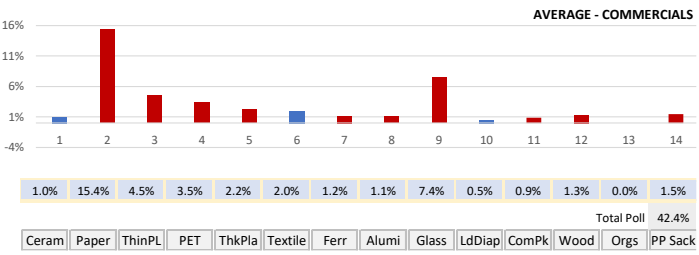












ANALYSIS

Quantitative

Weights

It will be noticed that the various samples characterised where of different total weights and were analysed in whole (rather than taking a constant pre-determined weight of a down-sample from each mother sample). This was done because the various samples were, as is normal in waste streams, extremely heterogeneous in their composition in terms of physical size and shape. For example, to downsample a *mother weight* totalling 500kg to, say, 100kg for a consistent *analysis weight*, would require that a 20% weight fraction be taken and 80% rejected. Now if this mother sample included one large piece of wood, three items of ceramics and 7 aluminium cans, then a precise cutting process would be needed for that piece of wood to take only 20% of it, one of the ceramic items to take only 60% of it, and one of the aluminium cans to take 40% of it.

That 0.2 cut piece of wood would then represent the wood fraction in the *analysis sample*, the 0.6 piece of ceramic would represent the ceramic fraction and 1 whole can plus the 0.4 piece would together represent the aluminium weight fraction. Now, the accuracy of the cutting process as well as its time demand would become an extra layer of complexity potentially introducing multiple points of error, and placing further time demands on an already time-constrained overall process. The alternative route was to analyse the entire mother sample and then use *weighted* (vs. simple) averages when calculating combined results for the city.

For their part, the different sample weights were taken in order to provide a faithful representation of the rate of generation by their various sources over the sampling period. This would then give an accurate figure of person-time (per capita per day) Specific Generation Rate (SGR) for the city.

From the Qualitative Analysis (further below), it will be noted that most of the uncertainties and risks of sample compromise (due to rummaging by informal waste pickers in search of recyclables to sell) were in the commercial samples from public waste bins. But it is also the commercial samples which contributed a smaller weight fraction to the overall SGF for the city. This is an auto-correction rendering the SGF accurate still despite the pronounced uncertainties in the commercials figures. Completely removing the impact of informal waste picking (rummaging for anything of value) in public waste receptacles or prior to the arms-length disposal into such receptacles would require much more concerted efforts from all stakeholders – including the recycling industry itself – for the duration of the sampling exercise.

Generation Rate

This is simply the speed at which waste is produced in the city, measured in kg per day. A Specific Generation Rate (SGR) refers to a (global) generation rate which has been made specific to a single individual by dividing the Generation Rate by the total population in an area. Thus, the units of SGR are kg per day per person (kg/p.d), or, the more common form, kg per capita per day (kg/c.d).

It needs to be noted that an SGR requires a known quantity by *weight* of waste to *accumulate* over a known period of *time*. This is a combination of *weight*, *time* and an *accumulation process*. These three factors must all be accurate for the calculated generation rate to be true (error, δ, equals zero). However, no SGR derived from city-wide *ex situ* data ever has $\delta = 0$. This is largely because of challenges with the second and third factors (time constraints or changes happening in or upon the waste during accumulation, such as the artificial processes of rummaging and foraging or an entire range of natural processes like fermentation, evaporation, condensation). These processes tend to falsify the report of strictly and precisely how much waste had been *generated* into the waste receptacle by the waste producer.

In this current exercise, the key factors leading to a non-zero δ were:

- Rainwater, and
- Rummaging

Rainwater: Some of the samples diverted from the route to Nduba dumpsite had been rained on. In addition to a sample-wide effect of increasing the weights of the various waste fractions (water absorption and adsorption), there is also the different water retention factors by the various waste fractions, e.g., compare

water affinity and absorption by pieces of bread vs. plastics. This distorts the ratio of bread (organics) to the plastic. As such, it is known that:

1. The content by weight of, particularly, the organic fraction was exaggerated although the extent of the exaggeration could not be determined since the *starting moisture contents* of each weight fraction was and remains unknown.
2. The total weight of the sample was exaggerated but the extent of exaggeration cannot be determined directly. As a result, comparison of the total/global SGR with published literature became mandatory. This was to check whether, or not, the general quantum of weights had fallen in the right region.
3. The data has been retained in the exercise to represent the *"as received"* form of the waste at the waste disposal point. This is an equally important factor (vs. the *"as generated"* form) in deciding the *tolerances* of the sorting equipment that will be designed based on these results.

Rummaging and foraging: This is the practice whereby unregistered hands search through the waste pile seeking anything that may be of use to them. These are third-party agents who sell to recyclers or the waste pickers themselves, locally called *abatwala-miyanda*, picking out what they think that they may sell for added income.

On the first day of waste collection, some sacks of sorted materials were found separately tied down on the roof of the waste truck. Upon enquiry, it was discovered that the waste belonged to the waste pickers themselves who had rummaged through the waste they had picked up to bring to the sorting centre and selected out what they wanted to keep for themselves. It was only after assurance that they would get these materials back after weighing that they reluctantly agreed to have their personalised sacks offloaded and added to the total sample. However, this anecdotal evidence is not the only reason for inclusion of rummaging as a significant factor in this exercise.

When the samples from the Markets and Hotel analysed out at very low percentage of recyclables compared to those from the Households, the most probable reason was not that the waste had been generated as indicated but rummaging. Unless round-the-clock security had been deployed to watch the public waste bins in these commercial sources, rummaging would continue to be squarely within reasonable doubt as having been a cause (if not *the* single cause) of the unexpected result. Nonetheless, the result was retained because:

1. It gives a true profile of the waste materials which shall be readily available when this project begins to source its feedstock i.e., this is the waste composition which will be obtainable from these areas unless targeted policy or city-level interventions were implemented to compel the whole bulk of waste to remain un-touched as generated;
2. It provides an accurate measure of the residual impact of the informal market which supplies the recycling industry in Kigali;
3. It indicates the categories of waste for which a market (formal or informal) already exists in the Kigali recycling industry.

City-wide Aggregate Results

As stated above, a non-zero δ is expected for this exercise. The reasons have been elaborated. Now the two reasons (rainwater and rummaging), have opposite impacts on the δ. While rainwater amplifies the weights of the wastes, rummaging reduces the weights. If these two factors happened in exact proportions to each other, it is possible that they may perfectly cancel out and, thus, yield a value of δ precisely equal to zero. Now the effects of these two factors are difficult to quantify. The results presented further above of 0.56 kg/capita/day for total city waste and 0.08 kg/capita/day for recyclables are to be understood with this uncertainty in mind.

Comparisons with Published Literature

The above results compare closely with those from published literature as shown below:

Authors	Year	Specific Generation Rate (SGR)	Population	Daily Generation Rate	Notes
		Kg/capita/day	Number	ton/day	
Current (Green Vista)	**2023**	**0.56**	**1,300,000**	**728**	
Mucyo	2019	0.55	1,126,400	669*	
Kabera, Wilson	2017	0.57	1,119,298	638	
Mucyo	2013	0.60	750,000*	450	Same author found 0.55 six years later. Population figure also problematic. This data point is the outlier.
Kigali Strategic Plan 2012	2012	0.47	868,085*	408	

TABLE 3 – Comparing current results with published literature.

Table 3 show that the city population has been increasing steadily, the SGR has remained – as it should – relatively stable.

The SGR will only be affected by:

- Change in wealth/economic status of the general population
- Change in regulation compelling a change in behaviour in the general population and economy on such aspects as packaging material, bulk buying behaviour, consumption preferences, etc.

Qualitative

The Waste Categories

The decision of which categories to use to characterise the waste was driven by the end needs of this project, i.e., the need to identify dry recyclable materials, their quantities and the ease with which mechanised or organised manual sorting could be achieved.

Some waste characterisation efforts focus on biodegradability or potential for supplying energy, etc. In the current exercise, separability was the key driver. As such, dryness, physical size, cross-contamination and prior sorting at point of generation were important.

Cross Contamination

This is and will remain a greater problem for the separation work to be achieved by the equipment. For example, pollution of other fractions by organics sticking to the surfaces of those other fractions is difficult to avoid, especially in the household wastes. The organics fraction may also have bits of paper, tiny plastics, glass particles etc. This is cross-contamination. It reduces the suitability of these materials as feedstocks for high purity processes. This means that, unless further – higher precision – separation and/or purification processes were carried out on these materials, they can only ever be *down-cycled* or re-cycled. Materials that exist in purer forms and enough quantities are sometimes *up-cycled*, being turned into product formats of a value higher than those from which they had come. Recycling and up-cycling are great ways of preserving earth's natural resources and reducing climate change impacts. Down-cycling, for its part, is only great as a sequester for materials which might otherwise be problematic if left to exist in their existing form. The cross-contamination cited above, tends to reduce the value of city waste as a consistent feedstock for anything other than down-cycling projects. Any level of segregation at source followed by separate handling and transport, therefore, would go a long way toward resolving this problem.

Cautions for Design Work

1. Have a solution for the inevitable volumes of organics with which the targeted recyclable wastes will come co-mingled. See (2) below on commercial incentivisation. Alternatively, the project developers could add a trommel screen and composting facility complete with quality assurance checks to admit or reject incoming waste batches. Organic infestation of the dry waste brings unwanted odours and stickiness. These matters make a process plant difficult to operate (odours discourage workers while stickiness discourages separation.

2. Have a solution for the wetness and inconsistent wetness which will inevitably be encountered in the project. For example, waste collectors operating in each district could be mandated to establish water-shedding points to help reduce water content reporting at Nduba. Dry waste could also be commercially incentivised with a fee waiver paid ultimately by the waste sorting station as an 'acquisition cost' for dry waste. Since this is a policy decision, it has not been modelled into the engineering designs until a positive indication is received. Wet waste will encourage smell and rust into the sorting station – two very destructive matters for process plant operations.

3. Have (a) solution(s) for the heavy cross-contamination. See (1) above for possible actions and the risks of failing to heed the caution.

Conclusion

A proximate Waste Characterisation study has been completed in accordance with accepted international best practice. Determination of the minimum sample size was done after Yamane (1967).

The Characterisation was based on 13.131 tons of waste from 767 households and 5 commercial installations housing a total working population of 2,382 people.

The National Institute of Statistics of Rwanda, which publishes a regular report on households and housing in Rwanda provided latest figures for Kigali at Nyarugenge: 72,280, Gasabo: 137,146 and Kicukiro: 77,238 households and a city-wide population of 1,318,000, giving an average household size of 4.6 people. These figures formed the basis of the Specific Generation Rates (SGR) – for both overall waste and recyclables in particular – calculated for the city.

For overall city waste, the SGR was found to be 0.56 kg/capita.day. This is consistent with but on the higher end of the scale of results in published literature for the city.

For households, 10.8% of the waste streams are Recyclable, 83% are Organics, 3% are loaded diapers and 2% Inerts (ceramics and textiles). The high organics share is irrespective of wealth bracket.

For commercial waste from hybrid complexes the Organics remain high at 58% but recyclables are significantly higher than the households at 38.9% (including glass at 7.4% paper+cardboard at a combined 15.4%).

The total generation rate for recyclables in the city is 16.5% or 100.5 tpd or 0.08 kg/capita.day. However a significant portion of these recyclables by-pass the route to Nduba and go to other places such as the private sorting station located at Bishenyi (which also happens to host the waste disposal site for Kamonyi District) to sustain existing recycling business models. This by-pass, called the Bishenyi+ Bypass for convenience, was calculated at 26% of the total city recyclables.

Overall, the characterisation of Kigali City waste is: Ceramics 0.4%, Paper 5.4%, Thin-film Plastics 2.0%, PET Bottles 1.2%, High Density Plastics 0.9%, Textiles 1.7%, Ferrous Metals 0.2%, Aluminium and Non-Ferrous Metals 0.6%, Glass 2.1%, Loaded Diapers 3.3%, Composite Packaging Materials 0.9%, Wood 0.5%, Polypropylene (PP) Sacks 2.8%, and Organics 78.0% out of a total of 737.9 ton/day of waste. Other than the organic fraction which is mass targeted for composting with varying extents of actual success, the other materials for which some level of recycling activity exists within Rwanda are shown in bold black numbering. These numbers translate to a city-wide recyclables fraction of 16.5%.

The Recyclables are wet and poorly sorted (pre-sorting only observed in 5% of the over 13 metric tonnes of samples collected and sorted. However, interviews indicated that some commercial facilities practice higher levels of pre-sorting but these volumes are captive to certain collectors who by-pass the public waste management system in their existing business models)

Although moisture content was not determined in this exercise, it was noticed that only 16% of the total samples arrived dry (by visual inspection only).

To plan activities targeting recyclables only, it is important to first have an effective solution for excluding the organics and for dealing with the wetness (especially wet papers and cardboard).

Loaded baby diapers (though only organic in their received content) took up such a *significant* and *ever-present* portion of the waste that they needed their own category in the characterisation exercise. There is currently no industrial process designed and implemented beyond the pilot stage for recycling used diapers. It is therefore important, in designing a supply chain system for recyclables for the city, that an effective exclusion system be designed for loaded diapers as well.

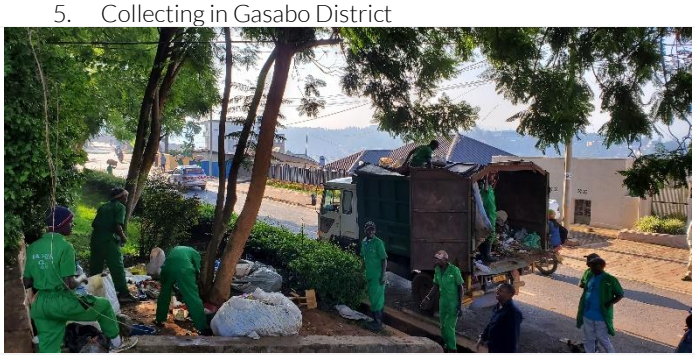
Photolog

1. Working the legacy waste at Nduba

2. Nduba arrivals and type of waste truck in Kigali

3. The Waste Sorting Centre for this project, in Kimihurura Sector, allocated by CoK, approved by Kimihurura Sector government. Tent erected for protection from sun and rain.

5. Collecting in Gasabo District



6. Receiving the Nduba Redirect Sample

7. Receiving the Nduba Redirect Sample unbagged

8. Very wet 5.3ton Nduba Redirect sample

9. More Water on Nduba sample first evening

10. Sorted Nduba Sample only organics remaining in place

1. Private sorting facility at Bishenyi. Note the large organics stockpiles (under green tarpaulins) undergoing composting process.

2. Some reasons why downsampling not favoured in this exercise. How to divide this large composite item across several fractions (plastic, metal, textile)?

3. Ensuring parallax correction is consistent across all staff for the weighing process.

4. Composite (plastic/paper) packaging

5. Aluminium materials

6. Some of the ferrous metal items

7. Wood items

8. Thin-film ("soft") plastics in front of the PP sacks

9. Hard plastics, before check-sorting out the PETs

10. Organics/"Remainings" on the sorting tarpaulin

11. All fractions bagged in readiness for weighing

12. The weigh-out. After weighing, the bags will be loaded back on waste truck for disposal at Nduba

13. All weighed, and site cleaned out.

14. Characterised wastes dispatched for damping at Nduba

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