The importance of characterizing residual household waste at the local level: a case study of Saguenay, Quebec (Canada)

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Accepted 15 April 2018

Keywords

Residual household waste, characterization, waste management plan

Highlights

- An approach for understanding the composition of garbage.
- A dataset contributing to the creation of a regional database for waste management.
- An inspiration for municipalities faced with similar realities.
- A simple method for characterizing the composition of residual household waste

Abstract

Knowledge of the quantity and the type of residual household waste (RHW) generated by a population within a given territory is essential for developing affordable, effective, and sustainable management strategies for waste. This study aims to accurately describe the composition of residential residual materials collected directly from households over the course of a year. Household waste was collected from urban and rural sectors that were representative of the study territory. Samples were collected during the winter, summer, and fall of 2014. A total of 3,039 kg of RHW was collected and sorted into 9 categories and 39 subcategories. Statistical analysis showed, except for organic matter, that the weight percentage of each category of material did not significantly differ among sampling periods or locations. Therefore, the results for a category were compiled to generate a single value to calculate the relative abundance of each type of residual material. Organic matter made up the majority fraction of the RHW (53% to 66%). This was followed by plastics (9%), bulky items and renovation/demolition debris (6%), textiles (5%), metals (4%), paper and cardboard fiber (4%), glass (2%), and household hazardous waste (2%). This approach has allowed us to improve the accuracy of the data used in MRM, contribute to the creation of a regional dataset for waste, and develop a methodology more applicable to local realities. Specific to the immediate needs of municipal MRM, we updated knowledge regarding the generation, recovery, and disposal of the contents of the residential sector, and tracked the evolution and the variation of contents over a given period. We believe our methodology is applicable to other regions having similar characteristics in terms of climate, socio-economic status, and other parameters that affect the composition of RHW.

1. Introduction

Waste management in regional municipalities remains challenging and continues to evolve due to the new and continually increasing amounts of consumer products. Efforts have been directed toward the principles of the 4R-E (first prioritize a reduction (R) at the source, then (R) reuse, recycling (R), and recovery (R) before elimination (E)) and toward information, awareness, and education of citizens to reduce the amounts of waste directed to landfills. However, municipalities often do not have good datasets regarding consumer behaviour nor patterns of consumption. Establishing affordable, effective, and sustainable practices for the management of residual material (MRM) is the foundation of sustainable development, yet it remains a challenge due to the increased generation of residual material of all kinds and the associated pollution.

Understanding the generation and composition of residual household waste (RHW) produced within a given territory is key to success for the MRM of a regional municipality (Sakai et al., 1996; Gidarakos et al., 2006; Ojeda-Benítez et al., 2008; Aguilar-Virgen et al., 2013). Thus, characterizing RHW can provide an estimate of the potential mass of materials available for 4R-E, identify the sources of the generated materials, and establish the physical, thermal, and chemical properties of RHW to facilitate the design of equipment for the treatment of waste (Zeng et al., 2005; Chang and Davila, 2008). These data can help establish an effective management approach to reach goals and to comply with national, provincial, and local regulations or benchmarks for waste management.

Despite the importance of knowing the types and amounts of RHW across a territory, there are no international standard methods for characterizing household waste (Dahlén and Lagerkvist, 2008; Lebersorger and Schneider, 2011). MRM planners are often left on their own to undertake the required studies. Segregation of RHW is, however, well documented in the scientific literature and numerous approaches have been developed (Parfitt and Flowerdew, 1997; Petersen et al., 2005; Dahlén and Lagerkvist, 2008; Lebersorger and Schneider, 2011; Edjabou et al., 2015). The methods used to characterize RHW vary widely due the different means of obtaining samples of waste: garbage has been collected from households (Abu Qdais et al., 1997; Bernache-Pérez et al., 2001; Qu et al., 2009), vehicle loads (Petersen et al., 2005; Gidarakos et al., 2006; Aguilar-Virgen et al., 2013), and landfills (Bernache-Pérez et al., 2001; Zeng et al., 2005; Sharholy et al., 2007; Chan and Davila, 2008; Pattnaik and Vikram Reddy, 2010). Furthermore, there is also variability in determining the number of categories into which material is segregated, the level of specificity of these categories, and the number of samples required (Zeng et al, 2005; Dahlén and Lagerkvist, 2008). This diversity of approaches in sampling and sorting make comparisons between studies very difficult.

The most accurate method for determining the composition of RHW is to collect the refuse at the location where it was generated and immediately sort the waste into different categories (Brunner and Ernst, 1986; Abu Qdais et al., 1997). Collection of the refuse directly at the residence facilitates the identification of the material, eliminates the uncertainty as to its origin (residential vs industrial, commercial, institutional), and allows a simpler calculation of waste generation rates (Abu Qdais et al., 1997; Bernache-Pérez et al., 2001; Qu et al., 2009).

This sampling strategy may be more accurate than vehicle load or landfill methods in regard to the integrity of the contents as the processes of decomposition, compaction, and mixing of contents in the collection truck can alter the physical condition and initial chemistry of the materials. Cross-contamination between individual fractions also occurs, leading to inaccuracies that can neither be measured nor corrected afterwards (Edjabou et al., 2015). However, to determine the chemical and physical parameters of each fraction contained in municipal garbage, evaluate the influence of a given factor on the abundance of a material, estimate changes in the composition of materials over time, and evaluate the impacts of different material collection systems, the vehicle load strategy is the most reliable (Brunner and Ernst, 1986, Peterson et al., 2005).

To reach zero waste, achieve the objectives of both the Quebec action plan on climate change and the provincial energy strategy, and to empower all actors involved in the MRM, the Government of Quebec developed the *Quebec Residual Materials Management Policy* (QRMMP) (Environment Quality Act, 2017). The main goal of the policy is to make end-waste the only residual material sent for disposal in Québec. End-waste is the remaining waste after residual materials have been sorted, processed, and reclaimed; "end-waste cannot be processed any further under existing technical and economic conditions to extract reclaimable content or reduce its polluting or hazardous character" (Environment Quality Act, 2017). However, waste management planners in Quebec (and Canada) have not yet developed a standard method for the sampling of residual material for a municipality to provide critical information for achieving this objective.

Over the last decade, Recyc-Québec and Eco Entreprises Quebec (henceforth referred to as RQEEQ) have developed an applicable methodology for characterizing the generation of residential waste for the province of Quebec. Across the 11 administrative regions of Quebec, they selected 30 communities and within each, 20 clusters were chosen at random, each cluster comprised of at least five housing units (RQEEQ, 2007). Nearly 68,000 kg of residual material was sampled and sorted into 9 major categories and 85 subcategories of waste.

However, according to Chang and Davila (2008), national/provincial averages are not very specific and do not reflect the local conditions of communities. The methods of large-scale inventories provide a portrait of the quantity of each type of material found in municipal waste, but do not consider the particular characteristics of local waste that may vary considerably from those at the national/provincial level. In addition, the composition of residential waste may vary according to the seasons, the geographical situation (Zeng et al., 2005), the socio-economic status of citizens (Maystre and Viret, 1995), the demography, the climatic zone, as well as the local regulations and services offered in terms of the collection, transportation, and disposal of residential materials (Dahlén and Lagerkvist, 2010). Without knowledge of these factors, assessing the composition of waste becomes difficult (Gidarakos et al., 2006; Ojeda-Benítez, 2008; Thitame et al., 2010-cited in Aguilar-Virgen et al., 2013). In Quebec, as each regional municipality is responsible for the planning and the management of waste on its territory, characterization of RHW should therefore be conducted at the municipal level. As well, municipalities often contribute to the creation of regional datasets and to the development of an approach for estimating waste inventories that is more adapted to local realities.

The main objective of this study is to accurately describe the composition of residential residual materials collected directly from households over the course of a year. Further objectives include demonstrating that characterization of RHW at the local level is more accurate than at the national/provincial level. Furthermore, we aim to calculate the economic impact of materials that may be 4R but that are still landfilled. The developed approach will also respond to the provincial-level requirements established by the QRMMP and its action plan for 2011–2015.

2. Materials and methods

2.1 Description of the study area

The study area is located in central Québec, Canada, slightly north of the 49^{th} parallel, in the administrative region of Saguenay-Lac-Saint-Jean (SLSJ). It has a humid continental climate where the average temperature is 2.8 °C marked by very cold winters (-15.7 °C) and cool summers (18.4 °C). Mean annual precipitation is 931 mm in the form of either rain or snow (Bagotville A meteorological station, Environment and Climate Change Canada, 2015). The territory covered by the study includes the 13 municipalities of the regional county of Fjord-du-Saguenay (FDS) and the City of Saguenay made up of three administrative units, called boroughs; units whose function is to ensure the supply of local services. This territory covers an area of approximately 45,000 km^2. However, almost 90% of the territory is occupied by unorganized territories (Mont-Valin, Lac-Ministuk, and Lalemant) with inhabited areas covering only 7,000 km^2. The FDS and the City of Saguenay represent 60% of the population of the SLSJ region with the City of Saguenay representing more than 50% of the population of the region alone. Both are part of the eastern portion of the SLSJ commonly referred to as Saguenay. As of 2014, the population of the City of Saguenay was 145 990 with a population density of 128.5 inhabitants/km^2.

The FDS has a population of 21,718 with a density of 0.5 inhabitants/km^2 (Quebec Institute of Statistics, 2017).

The regional economy is based on forestry, aluminium production, wood and paper industries, agriculture, and tourism. The City of Saguenay has a great influence on the surrounding municipalities of the FDS especially in terms of employment and services with the socio-economic characteristics being similar for both the FDS and the city. It can then be assumed that the level of stratification of this study is appropriate as factors such as culture, socio-economic contexts, climate, collecting systems, residential organization, and the availability of alternative sites of waste discharge are similar among the urban and rural sectors.

2.2. Municipal solid waste collection

The collection of household garbage (RHW) and recyclable materials is available across the entire territory of the Saguenay (rural and urban sectors). RHW is defined as the solid residues produced during purely domestic activity, for which the municipalities are obliged to collect. Garbage bins are collected at the curb side and transported to a landfill site located on the territory of the City of Saguenay. The RHW in containers and bags are accepted by this municipal collection. However, containers available for multi-family units (having six or more units) have volumes of 2 to 8 cubic yards. For RHW collection in the City of Saguenay, there are 39 collections during the year; one collection every two weeks between the end of October and the beginning of May and then for each week over the summer period (early May to the end of October). During the winter, RHW collection is every two weeks for a household. In 2014, the quantities of produced RHW were 42,696 tonnes (t) for the City of Saguenay and 7,327 t for the FDS (a total of 50,023 t) (Ville de

Saguenay et MRC du Fjord-du-Saguenay, 2016). Waste from the industrial, business, and institutional sectors were not considered in this study.

In the study area, recyclable materials are collected directly from households every two weeks and are transported to the regional sorting centre in the City of Saguenay. Here, materials are sorted and sent to different collectors according to the available markets. Accepted materials are containers, printed matter, and packaging. Permitted containers for municipal collection of recycling material are 360 L plastic blue bins. About 16,000 tonnes of recyclables are processed per year.

These two municipal collection systems take place from Monday to Friday, following specific routes to provide service in municipalities and boroughs through the five days of the week. Fixed collection days for an area remain the same for the entire year and a collection schedule is provided for each residence.

There is no dedicated collection of organic matter for the territory. The City of Saguenay has provided its citizens four “eco-centres” located in the different districts and five others are located across the territory of the FDS in the municipalities of Saint-David-de-Falardeau, Saint-Félix-d'Otis, l'Anse-Saint-Jean, Saint-Honoré, and Saint-Ambroise. These centres are accessible free of charge for citizens, and they are used to recover materials not accepted as curbside residential waste or recycling. These materials include tires, concrete and asphalt, construction materials, renovation and demolition (RDD) debris, household hazardous waste (HHW), appliances, electronic devices, tree branches and green waste, metals, and other waste voluntarily brought in by the citizens. In 2014, 37,850 t of material were recovered at the eco-centres for the City of Saguenay and 177 t of material at eco-centres across the FDS (Ville de Saguenay et MRC du Fjord-du-Saguenay, 2016).

2.3. Sample collection

To properly represent the urban (City of Saguenay) and rural (FDS) areas of the territory, we collected samples of RHW from six strategic sectors (three rural and three urban sectors), grouping together in the same sector municipalities located close to each other (Table 1). In each sector, we selected six randomly distributed addresses, giving a total of 36 addresses to represent the 78,381 housing units on the territory (Table 1).

The RAND function in Excel was used to produce random sampling. A list of all the addresses of each municipality was compiled using the existing municipal database. The addresses were then separated into six strategic sectors (see Table 1); the addresses for each sector were on separate Excel sheets. Each address was numbered and placed in a column. A second column consisted of the issued number of the RAND function that generated a number between 0 and 1. The generated RAND numbers were sorted in ascending order and the first six addresses in the list represented the selected samples. This methodology allows residual material managers from other municipalities, having access to occupational unit lists, to apply this simple random sampling protocol.

For each selected residence, we sent a letter to the owner to inform them of the study and asked if they wished to participate in the study. In the case of a refusal, we chose another address at random. However, to avoid influencing the consumption habits and altering waste disposal, no collection period was specified in the letter. The owner was advised that sampling would occur at the residence six times during the year (2014).

To decrease the heterogeneity related to seasonal variations, we staggered sampling over a one-month period during three seasons (winter, summer, and fall). Each selected month was representative of the season. As the frequency of municipal collection of RHW is every two weeks for the greater part of the year, each sampling event covered a period of two weeks repeated twice during the month.

Following the recommendations of Abu Qdais et al. (1997) and Dahlén and Lagerkvist (2008), we collected RHW samples directly from the residences. We recovered the complete contents of the garbage bin placed at the edge of the street as scheduled for municipal collection. In the case where the selected address was a multi-family dwelling, we collected three plastic garbage bags at random from the container as the representative sample.

2.3.1. Separation of the constituents

The collection of each sample was carried out early in the morning by a sorting team, composed of four volunteers, prior to the passage of the collection truck picking up RHW at the curb side. Bins were then transported to a triage yard where the contents of each garbage bin were transferred to a container identified to the corresponding sample, then each sample was weighed using a balance. This was then the initial weight of the sample.

Sample material was brought inside to a closed building. The materials were therefore not subjected to the weather during the period between collection and separation of the materials. Material was not sieved but was sorted by hand or with small tools. The tools used for manual sorting consisted of: 1) a sorting table with an outline of a height of about 10 cm, with an open end and funnel-shaped to slide the materials into the containers; 2) containers of different capacities to collect and weigh the various separated materials—

materials were weighed using electronic scales having a precision of ± 0.01 kg; 3) safety equipment (e.g. a "Biohazard" box for the recovery of needles and syringes, a first aid kit, disinfectants); and 4) personal protective equipment. Health and safety precautions were adopted for all persons responsible for separating waste. This included vaccinations, the wearing of personal protective equipment (disposable Tyvek coveralls, anti-needle/anti-cut waterproof gloves, slip-resistant boots, breathing masks, safety glasses). The volunteers, who always repeated the same task for all samples, separated the waste material into distinct categories and transferred the respective fractions into identified containers of known weight. They recorded the total weight of each sample and the weight of each (sub)category. This separation of the constituents was undertaken the same day as the collection to avoid physical and chemical changes due to degradation and decomposition. Although the garbage was sorted and weighed on the same day as the collection of the samples, for some samples, the garbage had already been stored for up to two weeks in the collection container prior to collection. Given our harsh winters, this garbage was frozen at the time of sorting. Thus, for several samples the segregation of materials occurred before they were fully thawed.

We chose to separate the contents at two levels (a category and a subcategory level). The idea behind this approach was to have a classification system that was easy to use and that minimized any subjective interpretation. As such, we sorted samples into nine categories for the first level of sorting and 39 subcategories at a secondary level (Table 2). The nine selected categories are those commonly found in the reports of the Quebec authorities (i.e. RQEEQ). The category ‘other’ represented the fraction of the materials that could not be classified into other named categories. For example, this included samples containing communication and information technology (CIT) waste, electrical wires, rubber, lightbulbs, and liquids. The categories of bulky items and renovation/demolition debris, household hazardous waste, and 'other' also contained a subcategory named 'other', to classify contents that did not fit into any of the subcategories.

2.4. Statistical analyses

The weight percentage of each category was calculated using equation 1.

$$Weight\ percentage\ (\%) = \frac{weigh\ \ (kg)}{total\ weig\ \ \ of\ the\ sample\ (kg)} \times 100\ (1)$$

Normality and homogeneity were verified before any statistical analyses. The homogeneity of the variance was tested using Levene's test, whereas the normality was verified graphically (before and after transformation) with the *Explore* procedure in SPSS (SPSS version 23; IBM Corp., 2015). Three types of transformations were used to improve data normality (square, square root, and log) (Quinn & Keough 2001) to:

- Ensure the data and the model errors had a more normal distribution
- Reduce any relationship between the mean and the variance
- Reduce the influence of outliers
- Improve linearity in regression analysis

The applied transformations were square root for plastic and fiber, square for organic matter, and log for glass, metals, bulky items, RDD, textiles, HHW, and 'other'.

We performed an analysis of variance with the transformed variables using a general mixed linear model (SPSS version 23; IBM Corp., 2015) where the fixed factors were sampling period (winter, summer, and fall) and location (City of Saguenay (urban) and the MRC of Fjord-du-Saguenay (FDS – rural)) (Gbur et al. 2012). The random factor was the sectors (three rural and three urban sectors).

3. Results and discussion

3.1. Number of samples

The number of samples collected by period and by location varied greatly. A total of 138 samples of a possible 216 samples was collected (36 households sampled twice during each of three seasons). The missing samples were primarily due to there being no garbage bins placed at the side of the road at the time of sampling from the selected address. Our 64% sample capture was much less than the 86% obtained for the 2010 RQEEQ survey (RQEEQ, 2014). Several reasons may explain these missing samples: i) there was not enough waste generated during the period of collection; ii) the residents were absent; (iii) RHW was placed along the street after we had passed by; and (iv) for other unknown reasons. Directly informing the citizens of sample collection dates would certainly have helped reduced the number of missing samples. However, this may have had a potential effect on the resident's behaviour, and therefore, would introduce a bias toward the measured variables.

We recovered a total of 3,039 kg of RHW and sorted this residual material into different categories. Seasonally, 936 kg, 865 kg, and 1,238 kg were collected in the winter, summer, and fall, respectively. Of the total amount of RHW, 1,732 kg was collected from the Saguenay and 1,307 kg from the FDS (Table 1).

To reduce experimental error, the number of samples could be increased. However, the number of samples required to ensure a statistical meaning varies for each category of material. Categories representing a small proportion of the waste require many samples to obtain a satisfactory level of statistical significance (Zeng et al., 2005; Dahlén and Lagerkvist, 2008). Zeng et al. (2005) suggested that if the size of the sample is greater than 100 kg, a minimum of 10 samples is required. However, this estimate of a 100 kg sample refers to samples taken from garbage trucks or directly from landfill sites. In our study, it was virtually impossible to obtain 90 kg samples as they were taken directly from households; the average weight of a sample was 21 kg. (The average weight of the samples collected at the residence was approximately 15 kg elsewhere in Quebec (RQEEQ, 2015)). Furthermore, it is often financial resources and manpower that dictate the number of collected samples (Abu Qdais et al., 1997).

Based on previous work, such as Sharma and McBean (2007), we determined that six replicates were sufficient to calculate analysis of variance. As we used sectors (La Baie, Chicoutimi, Jonquière, etc.) as the random factors in our model, we ended up with 36 replicates.

3.2. Composition of residual household waste

Analysis of variance showed that the weight percentage of each category of material was not significantly different among sampling periods nor location except for organic matter ($\alpha < 0.05$) (Table 3). Therefore, except for organic matter, the results for a category were compiled to generate a single value for calculating the relative abundance of each type of residual material.

Table 4 presents the weight percentage of each type of material found in the RHW of the Saguenay region (City of Saguenay vs FDS) over the combined sampling seasons. Overall, in terms of total RHW, plastic represented 9%, other 8%, bulky items and RDD 6%, textiles 5%, metals 4%, paper and cardboard (fiber) 4%, glass 2%, and HHW 3%.

Our results for the categories mirror those of the RQEEQ (2015) study for the province of Quebec. Our results had a lower percentage of fiber, glass, and metal than studies conducted elsewhere (Table 5; Aguilar-Virgen et al., 2013; RQEEQ, 2015; 2014; 2007; Gidarakos et al. 2006; Bernache-Pérez et al., 2001, Otten, 2001, Abu Qdais et al., 1997), likely because Quebec has a good system for the collection and processing of recyclable materials.

The common use of wood stoves in the region could explain why only 4% of fiber material was found in the garbage compared to 19% in the provincial survey; the fibers being used to start the fire of wood stoves.

Each year in Quebec, more than a million tonnes of residual material are recovered by the different sorting centres. For our study area, a little more than 16,000 tonnes of materials are recycled each year (Ville de Saguenay et MRC du Fjord-du-Saguenay, 2016). Although the system of recovery and recycling of residual materials is well established across the Saguenay territory, a greater weight percentage of plastic remains in the RHW. Indeed, as we did not separate food remaining in the packaging (plastic, glass, or metal), this may have biased the weight of categories including those of plastic, glass, metal, organic matter, and other. However, there is very little published information estimating the proportion of food found in packaging. Lebersorger and Schneider (2011) concluded that packaged food waste should not be separated from its packaging and should be included in the food waste category.

Furthermore, even if the collection of recyclable materials in the municipalities has relatively good yields, a considerable recyclable fraction remains in RHW (Velis et al., 2010). We estimated that 19% of the RHW consisted of paper, cardboard, glass, metal, and plastic (PCGMP) (Table 6). This represents 9,500 t of recyclable materials (19% × 50,023 t) that are still directed to a landfill. In financial terms, this represents a cost of more than $887,500 CDN ($93.38 per tonne for landfill costs, Services Matrec Inc., personal communication) to the city and FDS. Our results underestimate the province-wide results of the RQEEQ (2015) studythat estimated more than 35% (17,500 t) of PCGMP was destined for the landfill in the Saguenay at a cost of $1,634,000 CDN. This difference also confirms the benefit of characterizing RHW at a local level given the provincial and local level difference of 16% for PCGMP (Table 6).

The ‘other’ category also represents a significant percentage of RHW (8%). This category includes residual material that could not be classified into another category. Although there are many places for recycling CIT, we found these devices in our samples, as well as electrical wires and electronic, rubber, and bulbs. In addition, a subcategory was added during the process of segregation as more than 65 of the 216 study addresses contained disposable coffee pods (e.g. Keurig coffee®). In fact, a marked quantity of coffee pods was recorded in the ‘other’ category. Of the total 3,039 kg of RHW collected, coffee pods accounted for 20 kg, representing 0.7%. These pods therefore represent new waste heading to landfills avoiding the recycling and composting streams of recovery. Compared to RQEEQ (2015), our study has a higher percentage of ‘other’, which represents a difference of 3,201 t heading to the landfill at a cost of ca. $299,000 CDN (Table 6).

There is great variability among studies characterizing waste (Aguilar-Virgen et al., 2013; RQEEQ 2015, 2014, 2007; Gidarakos et al., 2006; Zeng et al., 2005; Bernache-Pérez et al., 2001; Abu Qdais et al., 1997) as municipalities do not offer identical waste management services. Some municipalities offer the collection of recyclable material and/or organic materials, others favour the use of voluntary drop off sites for recycling and compost material, while the actual accepted materials for recycling differs from one place to the other. Some regions have specific recovery programs for certain materials (as is the case in Quebec), whereas in some developing countries, bin looters are authorized in landfills, and as such, the local municipality does not offer specific collection. Hence, the characterization of RHW at the local level becomes a priority (Zeng et al., 2005).

3.2.1 *Organic matter*

Significant differences were found between the seasons (α = 0.046) and sampled MRCs (α = 0.012) for organic matter (Table 3). The *a posteriori* least significant difference (LSD) test of the significant differences between sampling periods showed that the percentage of organic matter was significantly higher during autumn (average of 65.5%) than summer (average of 52.9%) (Table 7). However, the percentage of organic matter collected in the RHW during the winter (average of 61.1%) was not significantly different from the other two periods. As with this study, previous work has shown that the organic fraction comprises the majority fraction of residential waste (Aguilar-Virgen et al., 2013; RQEEQ, 2015; 2014; 2007; Gidarakos et al., 2006; Bernache-Pérez et al., 2001, Otten, 2001, Abu Qdais et al., 1997).

Organic matter was significantly (α = 0.05) higher in RHW from the sectors of the City of Saguenay (average of 63.6%) compared to the sectors of the FDS (average of 56.0%) (Tables 3 and 8). The overall percentage average organic matter of the two MRCs was calculated with equation 2:

$$\bar{x} = \left(\frac{(\%OM_{City}\ x\ Twaste_{City})+(\%OM_{FDS}\ x\ Twaste_{FDS})}{Twaste\ total}\right) \quad (2)$$

where $\bar{x}$ is the overall average, $\%OM_{City}$ is the organic matter content (in %) for RHW recovered in the City of Saguenay, $Twaste_{City}$ is the quantity (tonnes) of waste collected in 2014 for the City of Saguenay, $\%OM_{FDS}$ is the organic matter content (in %) for RHW of the Fjord-du-Saguenay, $Twaste_{FDS}$ is the quantity of total waste collected in 2014 for the MRC Fjord-du-Saguenay and $Twaste_{FDS}$ is the total quantity (City and FDS) of waste collected in 2014.

$$\bar{x} = \left(\frac{(63.62\%\ x\ 42{,}696\ t) + (56.02\%\ x\ 7{,}327\ t)}{50{,}023\ t}\right)$$

The overall combined average ($\bar{x}$) was 62.5% organic matter.

Significant differences in the amounts of organic matter across seasons and locations can be explained in part by more leaves and green residues being sent to the RHW during the fall. Indeed, the quantity of these materials in the RHW during the fall is greater for urban dwellers compared to that of the FDS, with leaves and green residues accounting for 185 kg (of 469 kg total organic matter) for the city and 56 kg (of 345 kg total organic matter) for the FDS (data not shown). As residential lots in the FDS are larger, the composting of leaves and green residues is likely one of the reasons that could explain the lower organic matter values for FDS. Given this data, city waste management planners could target a door-to-door collection of leaves and green residues in the fall to divert these items away from the landfill.

The provincial waste management policy aims to ban residential organic matter from landfills by 2020. Many municipalities in Quebec already offer the collection, transport, and disposal of organic material. The City of Saguenay and FDS are undertaking studies to select the technology for the treatment of organic matter that is best suited to the local situation. Characterizing the nature of the organic material to be processed is essential for selecting the appropriate technology. In the case of the Saguenay, the city is relying on the provincial data of RQEEQ (2015). However, there is a 16% difference between the provincial and local data (Table 6). At the provincial level, organic matter makes up 47% of residential waste compared to 63% for the Saguenay. This represents an annual difference of 8,000 t of organic matter (23,510 t for the provincial estimate versus 31,500 t from this study). Based on the operational costs of several organic matter treatment facilities, Provost and Laplante (2013) estimated a cost of $76.00 per tonne of organic materials for composting. As such, use of the provincial survey would underestimate composting costs in the Saguenay by more than $600,000 per year.

Some data, such as the quantities of RHW collected and household participation rates, are available from the waste management plans of municipalities already collecting household organic matter (Table 9). For comparison purposes, we selected the City of Sherbrooke, a city in southern Quebec having a similar population as the City of Saguenay. If we consider that 63% of residential waste brought to the landfill in Sherbrooke (30,259 t) is organic matter and that 61% of this amount is diverted by the collection of organic matter, this leads to 11,629 t of organic matter being composted (Ville de Sherbrooke, 2016). This estimate differs by only 859 t using this study as opposed to a difference of 8,675 t using the provincial data from 2012–2013 (RQEEQ, 2015). Our estimates of the quantities of organic matter are also more representative than the data from RQEEQ (2015).

5. Conclusion

This study is a first of its kind for Quebec and represents an essential first step in the development of waste management and reduction strategies for the Saguenay region. Sampling directly from residences allowed us to determine that organic matter constitutes much of the RHW (66% and 53%) for residents of the rural FDS municipality and the urban City of Saguenay, respectively. This was followed by plastic (9%), bulky items and RDD (6%), textiles (5%), metal (4%), paper and cardboard fiber (4%), glass (2%), and HHW (3%). These results are representative across the entire territory as this characterization was carried out locally on a territory where all municipal waste collection systems are the same and where the contents arrive at the same landfill sites.

As each regional municipality is responsible for the planning and the management of waste on its territory, the proposed approach showed that it is possible for residual material managers to identify the composition of their deposits using easily accessible, relatively simple tools. The characterization of RHW at the local level permits: 1) establishing a database of the characteristics of residential waste over the course of the year; 2) building a basis for assessing the performance of waste management systems; 3) noting the emergence of new forms of waste; 4) observing the impact of seasonal variability on the physical characteristics of waste; 5) offering adapted and appropriate services for specific waste forms and the different territories; 6) estimating of the mass of organic material needing collection and treatment, selecting the appropriate technologies for organic matter treatment, and determining the seasonality of inputs that enter the organic material processing system; 8) being aware of the economic impact of 4-R materials that are still landfilled; 8) provide information, awareness, and education adapted to specific identified residual materials; and 9) addressing provincial-level (and other levels of government) requirements and action plan objectives in terms of waste management and waste reduction.

Acknowledgements

This study was funded by the City of Saguenay. The authors wish to acknowledge the support of the elected representatives and members of the municipal administrations of City of Saguenay and the MRC of Fjord-du-Saguenay, members of the Commission for the environment and sustainable development of the City of Saguenay, Eurêko! who carried out the characterization of RHW in the field, our managers at Sustainable Development and Environmental Services, and the citizens who permitted collection of their RHW as part of this study.

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Table 1. Description of sampling locations.

MRCs	Sectors		Number of households	Number of households selected for sampling	Sampling periods	Total mass of waste sampled (kg)
City of Saguenay (urban)	1	Jonquière Shipshaw Lac-Kénogami	30,351	6	Winter	244
					Summer	224
					Fall	375
	2	Chicoutimi Canton-Tremblay Laterrière	30,246	6	Winter	191
					Summer	203
					Fall	100
	3	La Baie	10,002	6	Winter	59
					Summer	175
					Fall	164
MRC-Fjord-du-Saguenay (rural)	4	Bégin Larouche Saint-Ambroise St-Charles de Bourget	2,378	6	Winter	191
					Summer	109
					Fall	216
	5	St-Fulgence St-Honoré St-David-de-Falardeau Sainte-Rose	3,826	6	Winter	114
					Summer	88
					Fall	171
	6	L'Anse-St-Jean Petit-Saguenay Ferland-et-Boileau Rivière-Éternité St-Félix-d'Otis	1,578	6	Winter	138
					Summer	66
					Fall	212

Table 2. Categories and subcategories of materials separated from the collected waste.

Categories	Subcategories
Paper and cardboard fiber	White paper
	Brown paper
	Cardboard (broken down)
	Cardboard (not broken down)
	Waxed paper
	Tetra Pak
Glass	Non-refundable glass
	Refundable glass
Metal	Non-refundable metal
	Refundable metal
	Industrial metal
Plastic	Non-refundable plastic
	Refundable plastic
	Non-recyclable plastic (e.g. bags, packaging)
	Plastic No. 6
	Plastic packaging - cellophane type
	Plastic packaging - other than cellophane
	Plastic ties
Organic matter	Table scraps
	Leaves and/or green residues
	Cleaning fibers (paper towels, paper handkerchiefs)
	Diapers and sanitary fibers
Bulky items and renovation/demolition debris (RDD)	Raw wood
	Painted/varnished wood
	Treated wood (creosote, metal salts)
	Contaminated wood (nails, gypsum, etc.)
	Agglomerated/pressed wood
	Other CRD waste
Textiles	Textiles (reusable clothing)
	Textiles (rags)
Household hazardous waste (HHW)	Batteries
	Other
Other	Communication and information technology (CIT)
	Electrical wires and electronics
	Rubber
	Light bulbs
	Coffee pods
	Liquids
	Other waste

Table 3. Results of the analysis of the variance for each waste category. Significant *F*-values are in bold and the related probabilities are in parentheses.

Factors	Degree of freedom	Plastic	Glass	Metal	Fiber	Organic matter	Bulky items and RDD	Textiles	HHW	Other
		F-value								
Period[1]	2	0.9 (0.405)	0.2 (0.854)	0.1 (0.935)	1.0 (0.359)	**3.2 (0.046)**	0.9 (0.393)	0.6 (0.528)	0.2 (0.805)	0.6 (0.581)
MRC[2]	1	3.8 (0.054)	1.5 (0.223)	0.0 (0.887)	0.3 (0.613)	**6.5 (0.012)**	0.8 (0.373)	0.1 (0.721)	2.7 (0.102)	2.8 (0.099)
Period × MRC	2	1.3 (0.285)	0.8 (0.450)	0.2 (0.808)	0.2 (0.827)	0.1 (0.933)	1.8 (0.168)	0.1 (0.902)	1.0 (0.369)	0.1 (0.895)

[1]Three sampling periods were: winter, summer, and fall;

[2]MRCs: City of Saguenay and MRC of Fjord-du-Saguenay (FDS);

RDD: Renovation/demolition debris;

HHW: Household hazardous waste.

Table 4. Descriptive statistics for the categories of materials found in residential waste in the Saguenay region (organic matter being excluded).

Category	*N*	Average	Standard deviation
		------------------------%	------------------------
Plastic	138	9.12	6.55
Glass	138	1.64	3.01
Metal	138	4.05	9.81
Fiber	138	3.94	4.06
Bulky items and RDD	138	5.84	16.25
Textiles	138	4.82	10.09
HHW	138	1.59	3.32
Other	138	8.40	12.94

RDD: Renovation/demolition debris;

HHW: Household hazardous waste.

Table 5. Composition of residual household waste (%) and waste generation rates according to different studies.

		This study	Aguilar-Virgen et al. (2013)	RQEEQ (2015)	RQEEQ (2014)	RQEEQ (2007)	Qu et al. (2009)	Gidarakos et al. (2006)	Zeng et al. (2005)	Bernache-Pérez et al. (2001)	Abu Qdais et al. (1997)
Location		Saguenay (Canada)	City of Ensenada (Mexico)	Province of Quebec (Canada)	Province of Quebec (Canada)	Province of Quebec (Canada)	Beijing (China)	Island of Crete (Greece)	Cities of Centralia, (Columbia) and Mexico City (Mexico)	Metropolitan Area Guadalajara, (Mexico)	City of Abu Dhabi (United Arab Emirates)
Population		167,775	311,554	8,084,754	7,870,000	7,631,873	15,810,000	431,755			
Sampling method		RHW collected from the residents	RHW collected from collection trucks	Subsample of RHW collected directly from a collection of five housing units	Subsample of RHW collected directly from a collection of five housing units	Subsample of RHW collected directly from a collection of five housing units	RHW collected from the residents	RHW collected from collection trucks	RHW collected at the landfill	RHW collected from the residents and at four landfills	RHW collected from the residents
Number of samples		138	29				113		536		840
Amount of RHW separated (kg sample^{-1})		21	90	16		40		91 to 136	140		14
Composition of RHW (%)	Plastic	9	12	8	7	8		17	16	9	12
	Glass	2	4	6	3	4		5	3	4	9
	Metal	4	3	2	2	3		5	6	2	8
	Paper and Fibers	4	22	19	9	13		20	41	11	6
	Organic matter	53 - 66	40	47	59	59		39	21	53	49
	Bulky items and RDD	6	2	12	12	8		3			
	Textiles	5	6	3	3	3		5			
	HHW	2		1							
	Other	8	7	2	3	2		6	13	22	16

To ensure the uniformity of the categories and thus obtain a comparison, some categories have been grouped among the studies;
RQEEQ: Recyc-Québec and Eco Entreprises Québec;
RHW: Residual household waste;
RDD: Renovation/demolition debris;

HHW: Household hazardous waste.

Table 6. Comparison of the categories of collected materials between this study and the RQEEQ (2015) study in terms of percentage (%), quantity (tonnes – t per year), and cost ($ per year).

Category	This study	RQEEQ (2015)	Difference	This study	RQEEQ (2015)	Difference	This study	RQEEQ (2015)	Difference
	%			t			$		
Plastic	9	8	1	4,562	4,002	560	426,009	373,692	52,317
Glass	2	6	-4	820	3,001	-2,181	76,607	280,269	-203,662
Metal	4	2	2	2,026	1,000	1,025	189,181	93,423	95,759
Fiber	4	19	-15	1,971	9,504	-7,533	184,043	887,518	-703,475
PCGMP	19	35	-16	9,504	17,508	-8,004	887,518	1,634,902	-747,384
Organic matter	63	47	16	31,264	23,511	7,754	2,919,467	2,195,439	724,028
Bulky items and RDD	6	12	-6	2,921	6,003	-3,081	272,795	560,538	-287,743
Textiles	5	3	2	2,411	1,501	910	225,149	140,134	85,015
HHW	2	1	1	760	500	260	71,001	46,711	24,290
Other	8	2	6	4,202	1,000	3,201	392,376	93,423	298,953
Total	102	100	2	60,443	67,531	-7,088	5,644,148	6,306,049	-661,902

Total quantity of ultimate residues landfilled in 2014: 42,696 t (City of Saguenay), 7,327 t (MRC Fjord-du-Saguenay (FDS)) and 50,023 t (City and FDS);
In 2014, the estimated cost of burial was $93.38 t^{-1} of residual material (Services Matrec Inc., personal communication); All amounts are in $CDN;
RQEEQ: Recyc-Québec and Eco Entreprises Québec;

PCGMP: Paper, cardboard, glass, metal, and plastic;
RDD: Renovation/demolition debris;
HHW: Household hazardous waste.

Table 7. Proportion of organic matter as a function of the sampling period.

	Season	*N*	Average[1]	Standard deviation
			--------------------%	--------------------
Organic matter	Winter	42	61.06 ab	2.27
	Summer	48	52.86 a	3.15
	Fall	48	65.54 b	3.05

[1]Averages not sharing the same letters are statistically different from each other according to *a posteriori* LSD tests at a significance level of $\alpha = 0.05$. *N* = number of samples.

Table 8. Proportion of organic matter measured as a function of the location (MRC).

	MRC	*N*	Average[1]	Standard deviation
			--------------------% --------------------	
Organic matter	City of Saguenay (urban)	77	63.62 a	2.43
	MRC Fjord-du-Saguenay (rural)	61	56.02 b	2.72

[1]Averages not sharing the same letters are statistically different from each other according to *a posteriori* LSD tests at a significance level of $\alpha = 0.05$. *N* = number of samples.

Table 9. Comparison of the quantities of organic matter (OM) recovered by different Quebec municipalities having a collection specifically for organic material (2014 data), this study, and data from RQEEQ (2015).

	Population	Households served	Quantity of landfilled residual material	Quantity of OM retrieved	Capture rate for the collection of OM (%)	This study	Difference	RQEEQ (2015)	Difference
			----------- t	--------------		----------------------------	t	----------------------------------	
City of Gatineau	273,905	92,336	60,624	21,619	56	21,388	231	15,956	5,663
City of Sherbrooke	159,448	44,391	30,259	10,770	61	11,629	-859	8,675	2,095
Intermunicipalities of Acton and Maskoutains	99,814	33,327	23,951	10,038	65	9,808	230	7,317	2,721
MRC Montcalm	51,163	15,516	16,857	2,840	39	4,142	-1,302	3,090	-250

OM: Organic matter;

RQEEQ: Recyc-Québec and Eco Entreprises Québec.