Domestic Plastic Waste in the city of Guayaquil: Generation Rate and Classification

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***Abstract*– A significant contributor to the waste streams nowadays are domestic plastics. However, in Ecuador most of them end up in the local landfills impacting the environment in a major form. The aim of this paper is to classify and quantify the total amount of household plastics generated for the city of Guayaquil. To obtain this, we developed a novel methodology with the help of students from a local university. Each household produces approximately 1.64 kg of plastics daily. From all plastic waste, PET occupies the 1st place as the most disposed of with approximately 44%, followed by HDPE with 20% and PP with 10%.**

Keywords—quantification, classification, domestic, plastic, waste.

I. Introduction

The rising awareness of decreasing natural resources has brought forward the idea of a circular economy and resource efficiency worldwide. In general, information about waste composition is needed for several purposes from decision-making concerning waste utilization to the development of city waste management systems. Although waste composition studies traditionally are time-consuming and costly, they are essential to make recycling more efficient [1 - Olli Sahimaa].

Like several other developing countries, Ecuador is facing a great challenge in managing the increasing quantity of municipal solid waste (MSW) due to its industrial and population growth, improvement in lifestyle conditions, migration of people from rural to urban areas and many other factors [2].

Ecuadorian domestic waste management has historically been focused on the collection and removal of residues from the urban communities and their final disposal in remote locations with the aim of protecting public health. However, it is apparent that the disposal of waste, mainly by landfill could have a range of off-site impacts, including greenhouse gas generation, leachate contamination of groundwater and exposure of neighboring communities to air smell, dust, litter, and vermin.

Nowadays, a significant contributor to the domestic waste stream are plastic residues (approximately 7.73% of the total domestic waste [3]. Because of legal requirements, which have been enforced to protect the environment, there is a pressing need to develop methods to recycle plastic waste. The number of landfill sites and their capacity are decreasing rapidly, and in most countries, the legislation of landfills is becoming increasingly stringent.

Digital Object Identifier: http://dx.doi.org/10.18687/LACCEI2021.1.1.168
ISBN: 978-958-52071-8-9 **ISSN**: 2414-6390
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In this context, the city hall of Guayaquil, aims to regulate the manufacture, trade (of any type), distribution and delivery of single-use plastics with the emission of an ordinance to oblige manufacturers to change the formula in their process, to a new formula or product agreeing with any of the following options: 1) products are 100% biodegradable, 2) 70% of total product mass comes from recycled materials and 3) using other reusable materials in the lapse of 30 months [4].

Even though, options 1) 100 % biodegradable plastics or 3) reusable containers would be ideal for waste reduction, many problems could arrive due to the high start-up costs and pose several production related issues for the manufacturers. However, thermoplastics are the most suitable materials for recycling as, in theory, they can be molten and reprocessed to form new products an infinite number of times [5].

In order to plan a municipal recycling scheme, first it becomes necessary to identify the quantities and classification of the plastic waste generated at each household. In response to this situation, and as pre-requisite for the future recycling management of domestic plastic waste in Guayaquil, we carried out a 14-day field project from February to March 2020 in 406 households. In this paper, we report the project methodology including plastic generation rates and composition.

For this purpose, in **section 2** we present a literature review on the process to quantify and classify plastic waste from a selected sample of households. After we develop a novel methodology to collect in situ information from homeowners in **section 3**. Results of types and quantities of plastics and geographical stratification are shown in **section 4** alongside a discussion on the recycling mechanisms available. Finally, conclusions are presented in **section 5** (Figure 1).

II. Literature Review

Plastics are synthetic polymer compounds mostly made from petrochemical sources with high molecular mass and elasticity [6]. They play an important role in modern life due to their numerous properties that render them superior to other materials such as low weight, versatility, and low production cost. Their widespread use makes recycling essential to sustainable development. Given that the basic objective of recycling is to secure environmental benefits, it is imperative that the weight of collection through both bring/drop-off and curbside is considered with the quantification and classification of plastic waste.

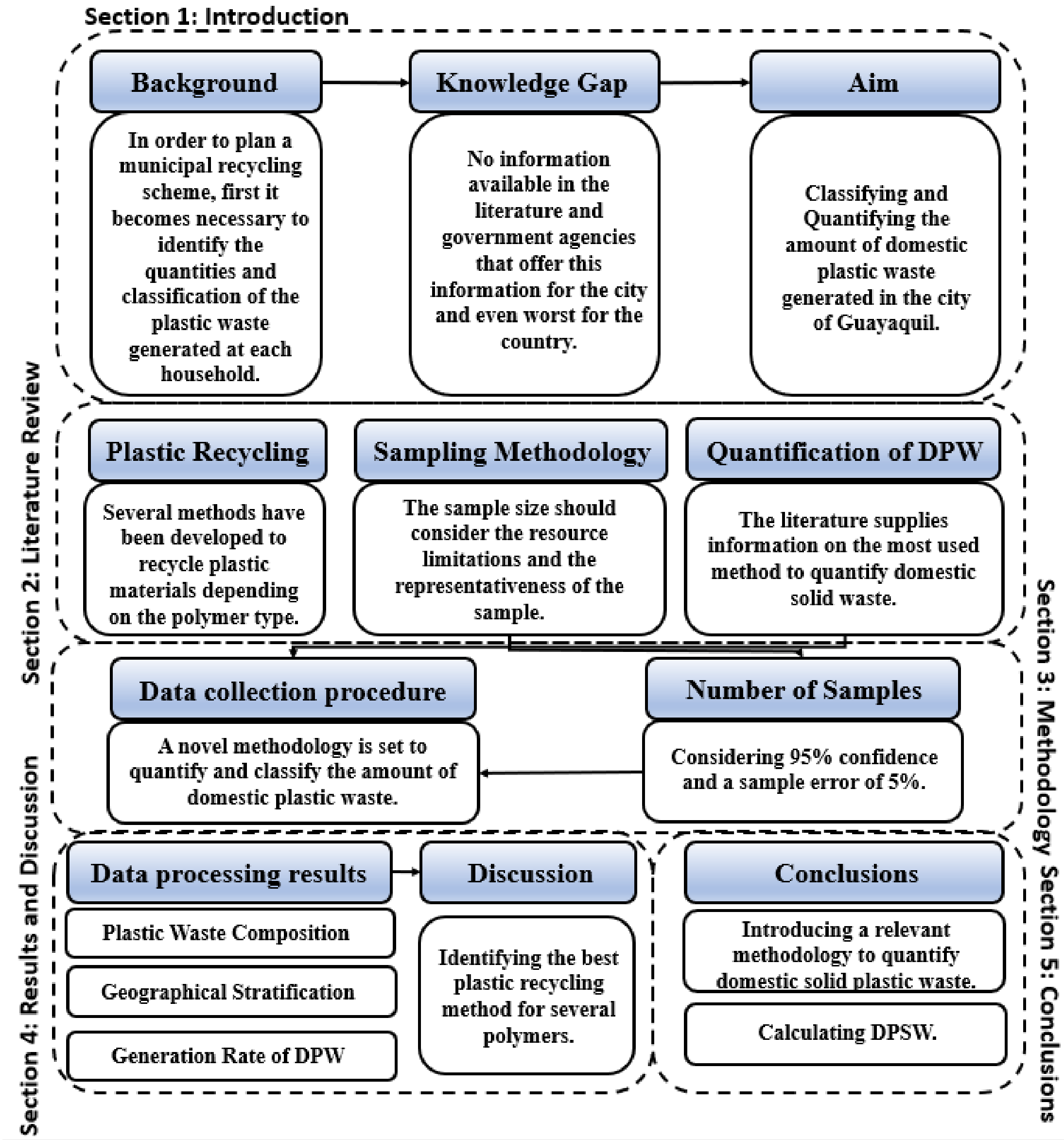


Fig. 1 Complete structure and logical flow of the article

2.1 Classification and Quantification of Domestic Waste

Information on the quantity and composition of residential waste is important for effective planning of the household waste management structure. Additionally, it is necessary to monitor waste streams to make recycling more efficient. Different studies have evaluated household waste, using different methods, such as keeping a waste diary, self-report through tables, self-collection, analysis of waste composition or observation at home with photographs [7].

Each method of waste measuring has advantages and disadvantages, and all can be subject to bias. The three most relevant methods of obtaining the self-reported amount of household waste that are commonly used in the available literature are weighting the amount, estimating the amount, and self-assessment of the amounts.

In Method 1, data on the amount of waste is obtained by weighing the discarded food and recording it in a journal. In Method 2, the amount of waste is estimated by conclusion, whereby the total amount of product purchased and grown at home is compared to the number of products consumed, and the difference represents the waste. The alternative to measurement and estimation is the self-assessment (Method 3) of the quantities of waste discarded.

A preliminary investigation on the three methods was conducted from January to April 2017 in 15 families (five for each method) for 7 days [8]. The third method proved to be the most convenient for household members, as all five households successfully monitored produced waste, which was not the case for methods 1 and 2, because some households dropped out of the investigation due to the complexity of the methodology. Therefore, Method 3 was selected for the main research as the easiest to use. To obtain reliable estimates of the actual amounts of waste discarded in a household, the monitoring time should be an average week (7 days) at least.

The household solid waste (HSW) generated by the community of the city of Mexicali was identified in 2002 [9]. For this purpose, they selected the participating households randomly through a detailed map. The project lasted 16 weeks where the researchers removed the waste deposited in a bag 3 times a week. Each sample was weighed, and its content separated into the categories of organic, recyclables and non-recyclables.

The characteristics of the generation of household solid waste for the city of Suzhou in East China was evaluated in 2015 [10]. A systematic four-stage follow-up survey of 240 households was conducted for one week in each season, from summer 2011 through spring 2012 using community assemblies and face-to-face home visits multiple times during the pre-survey and survey periods. Trash bags were collected from designated locations at a specific time (early morning) during the survey period. Each participating household was assigned an identification (serial code), which helped to distinguish urban waste in different categories of households.

2.2 Sampling of domestic solid waste

A critical component of the sample size formula is the estimation of the variance in the primary variables of interest in the study. There are two ways to estimate population variances for sample size calculations, (1) use the results of a pilot study and (2) use data from previous studies of the same or similar population. For the categorical dependent variable, a margin of error of 5% is acceptable and for the continuous dependent variable, a margin of error of 3% is acceptable. The sample size should consider the resource limitations and the representativeness of the sample. A list of households was generated from the local administrations to form the sampling frame. The choice of the sampling technique (probabilistic or non-probabilistic) depended on the purpose of the study. For a quantitative investigation of classification and quantification of waste, the probability sampling technique is appropriate compared to the non-probability sampling technique because it gives each sample household the same probability of being interviewed. [11].

One common formula used to determine the sample size is as follows:

$$n = \frac{NZ^2PQ}{d^2(N-1) + Z^2PQ} \tag{1}$$

Where: n = sample size of housing units; Q = 1-P; N = Total number of housing units; P = variable of residential housing unit; Q = dwellings for commercial activities, offices, public centers, etc. Z = Standardized and valued normal variable that corresponds to a 95% confidence interval equal to 1.96; d = Allowed error (0.05).

The volume of solid waste generated in Robe Town, Ethiopia was quantified in 2018. Authors [12] used the systematic sampling technique to determine the representative sample size for the total target population. With a confidence level of 95% and a sampling error of 5%, they determined a sample size "n" of 372 households. Additionally, they used a structured and unstructured questionnaire to collect primary data from urban households, and observation and interviews to collect supplementary information.

2.3 Plastic recycling

Nowadays, the urban and suburban area of any city are the main source of plastic pollution which eventually end up in water bodies like rivers, lakes, seas, and oceans.

One solution to this problem is recycling, whose rationale is that the production from secondary feedstock and avoidance of waste disposal are environmentally benign than the use of virgin feedstock and the consequent use of landfill or incineration [13].

The Society of the Plastics Industry (SPI) established a classification system to help consumers and recyclers properly recycle and dispose of each different type based on its chemical makeup. Today, manufacturers follow a coding system and place a number, or SPI code, on each plastic product, usually molded into the bottom (Table 1).

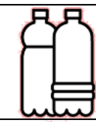
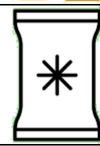
Other important waste that should be considered is Tetra Pack (TP), which is made of several components which are layered, being one of them polyethylene (a type of plastic).

Several methods have been developed to recycle plastic materials depending on the polymer type, package design and sources of plastics. Never mind the method of recycling adopted, plastic solid waste (PSW) must undergo different key steps, including collection, sorting cleaning, size reduction and separation, before the steps for recovery [14].

The International Organization for Standardization (ISO) [15] and the American Society for Testing and Materials (ASTM) [16] have standardized the recovery of plastic waste into four categories:

1) *Primary Recycling:* It involves the reintroduction of pre-consumer residues (scrap, edges, and parts) into the extrusion cycle to produce products of the same material.

TABLE I
TYPES OF PLASTICS

SPI	Abbreviation	Type of Plastic	Common Uses
1	PET	Polyethylene Terephthalate	
2	HDPE	High Density Polyethylene	
3	PVC	Polyvinyl Chloride	
4	LDPE	Low Density Polyethylene	
5	PP	Polypropylene	
6	PS	Polystyrene	
7	OP	Other Plastics	

2) *Secondary Recycling:* Also called mechanical recycling. It refers to operations that recover plastic solid waste (PSW) via mechanical processes. The new recycled material can be converted into new plastic products, replacing virgin polymers or a portion of them.
3) *Tertiary Recycling:* Also known as chemical recycling. It is the term used for processes that chemically convert polymer chains into smaller molecules that can be used as feedstock to produce fuels, new polymers, or other chemicals.
4) *Quaternary Recycling:* Or energy recovery consists of the incineration of plastic wastes and the recovery of energy through the production of heat and/or electricity. In fact, their elevated calorific value makes PSW a convenient source of energy production.

From the four options, secondary recycling, specifically product-to-product is the most preferred option if it could replace a minimum of 70-80% of virgin plastics [17].

III. METHODOLOGY

The main objective of this research is the quantification and classification of domestic plastic waste in the city of Guayaquil. This paper provides a novel process for the collection of data from households with separation and weighing in situ.

3.1 Determination of number of samples

The sample size was determined according to the principles of statistics following equation 1. Considering 95% confidence interval and 5% standard error for a total population of 413 thousand households in the city of Guayaquil, the total amount of households should be no less than 385.

3.2 Data collection procedure

Considering that there are no previous studies for domestic plastic waste generation for the city of Guayaquil, this is the first attempt for classifying and quantifying this type of waste.

In Figure 2, we present the collection method to obtain the required information from each household. Using the cases from literature review, we developed a method were homeowners from the city who were willing to participate were asked for required data, such as geographical location, garbage truck collection schedule and size of the household. With this information a template was designed to collect the weights of the different plastic waste. To make the quantification reliable, a period of two weeks was selected. Participants were to sort, weight and register in the template the data from each type of waste. Following this methodology, the generation rate from the total and individual waste flow was determined for the city and per city zone.

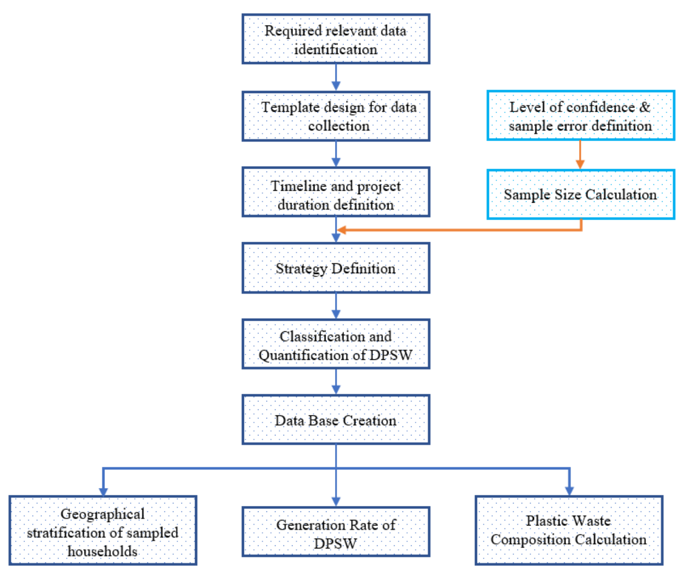


Fig. 2 Data collection procedure

IV. Results and Discussion

A total number of 406 households participated in the quantification project during the period between February and March 2020. A total of 206 students from a local university of the city participated in the project. Participants were to involve one neighbor to have a total of 2 households per participant. Students first registered via a questionnaire online to obtain information on their geographical location and city zone.

Participants were after trained in plastic identification and the separation template along with the collection and quantification procedure. Finally, weights were registered in the template and uploaded in the university platform.

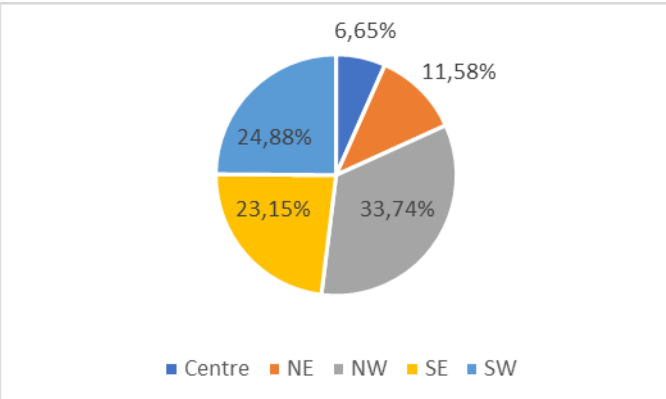


Fig. 3 Sampling Stratification.

Figure 3 shows the sampling stratification for the city of Guayaquil. Most samples were taken from the Northwest side (approximately 34%) and the least amount from center town (almost 7%) and Northeast (close to 12%). Number of households from Southeast and Southwest side sum up to 48%.

TABLE II
dOMESTIC PLASTIC QUANTIFICATION

Type	ALL	CENTRE	NE	NW	SE	SW
PET	723.46	491.19	469.88	715.05	862.13	785.90
HDPE	327.90	88.03	190.98	547.09	191.09	287.10
LDPE	144.06	22.62	195.42	80.95	81.03	296.88
PP	169.05	57.91	92.27	102.52	103.09	386.12
PS	86.04	17.31	16.26	33.39	72.546	220.85
PVC	140.43	13.89	8.70	44.84	64.74	435.66
OP	22.54	3.89	4.45	15.91	23.12	27.33
TP	24.54	6.07	15.87	25.60	29.63	44.40
T. A.	**1638.02**	**700.90**	**993.83**	**1565.35**	**1427.38**	**2484.25**

[a]All values are in grams.

Table 2 shows the total average (T. A.) value of plastic waste for each city zone. Each household produces approximately 1.64 kg of plastics daily. Considering an average of 4 people per house, the total amount of daily plastic per capita generation is 0.41 kg. From all plastic waste, PET occupies the 1st place as the most disposed of with approximately 44%, followed by HDPE with 20% and PP with 10%. The lowest values are for OP and TP with 1.38% and 1.50% respectively as shown in Figure 4.

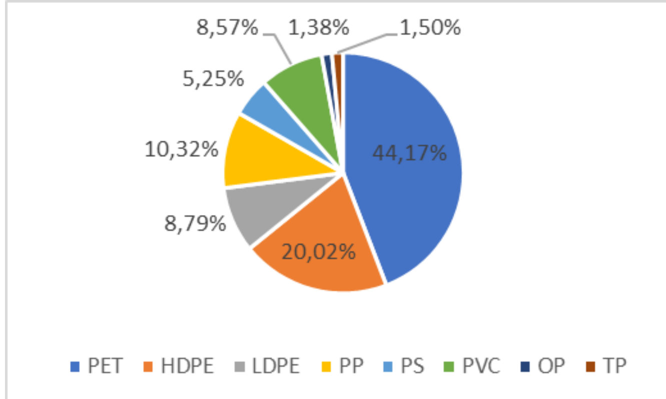


Fig. 4 Total Plastic Classification.

Important to remark according to Table II that the south sectors of the city present the highest average of plastic production per day per household with 2.48 kg in SW and 1.43 kg in SE. This reveal is very interesting considering that these sectors are usually considered low level and shows how well stratified are social conditions in each part of town where we can find high social group households next to low social groups.

Plastics from household waste (HHW) is a heterogeneous and contaminated resource, leading to recycled plastic with reduced quality, limiting the potential for closed-loop recycling. PET waste well-suited for closed loop as it can be multiple times recycled, even when the degree of heterogeneity in the waste is high. Additionally, the processability of different kinds of PE and PP packaging types varied considerably, especially for PP. Consequently, current recycling of mixed PP waste and even separate recycling of individual PP waste packaging types, will not technically facilitate recycling into new packaging products [18].

Recycling of postconsumer plastics is much difficult especially for mixed or comingled waste or single-stream collection. After mechanical recycling and eventually upgrading, residual plastic waste can possibly be converted into heat and power.

IV. Conclusions

The quantity and classification of domestic plastic waste was calculated for the city of Guayaquil. For this purpose, a novel methodology was developed using state of the art literature and considering local conditions.

A total of 406 households participated in the project giving an average plastic waste of 1.64 kg per household. Most generated plastic waste was PET, followed by HDPE, PP and LDPE.

From the city of Guayaquil, it´s shown that the south produces more plastic waste with 2.48 kg in SW and 1.43 kg in SE.

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