MORPHOLOGICAL ASSESSMENT OF MIXED MUNICIPAL WASTE AND PRACTICAL SOLUTION FOR PET PACKAGING MANAGEMENT IN URBAN AREA

ORIGINAL SCIENTIFIC ARTICLE

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DOI: 10.51558/2232-7568.2025.18.1-2.33

RECEIVED 2025-08-27 **ACCEPTED** 2025-09-23

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ABSTRACT:
This study analyzed the current state of mixed waste collection, with a special focus on the treatment of PET packaging waste in the urban area of a smaller town. The morphological composition of mixed waste from containers at three locations adjacent to the elementary school, healthcare facility and residential complex, was determined to assess the amount of polymer waste, and its composition was subsequently analyzed. It was concluded that the proportion of polymer waste is higher in the waste container near the school, followed by the waste container near the healthcare facility. The proportion of PET bottles in mixed waste near healthcare facility was some higher to that near the elementary school. It was also observed that PET bottles in waste near residential buildings were larger in size compared to those in waste near the elementary school. To improve the management of PET packaging waste, smaller bottle collection bins were proposed, along with suggested locations for these bins on the map of the town of Zvornik. Additionally, a collection system for PET bottles was proposed, including a company for emptying the bins and transporting the waste to a recycling facility.

KEYWORDS: PET packaging waste, waste recycling, urban area

INTRODUCTION

Plastics are synthetic organic polymers, derived mainly from petroleum-based chemicals [1], to which appropriate chemical additives have been added, such as carbon or silica to strengthen the matter, thermal stabilizers, plasticizers, fire retardants, UV stabilizers, colorants, matting agents, opacifiers, or lustre additives [2]. Polymers can be produced by one of two main processes, ie. either by addition polymerization or condensation polymerization [3]. The first process links individual olefins to form a polymer chain without the formation of any byproducts. Examples of addition polymers are polyethylene [4], polypropylene [5], polystyrene [6] and polyvinyl chloride [7]. On the other hand, condensation polymerization combines hydrocarbons containing one or more functional groups into a polymer chain, with a release of byproducts. Examples of such polymers are [8]: polyethylene terephthalate, polyamide and polycarbonate.

Based on their response when exposed to high temperature, plastics can be classified into thermoplastics and thermosets [9], whereby both groups of materials can acquire a certain shape under the influence of an external force and retain it after cooling, but only in the first case can this procedure be repeated without a significant change in their structure [10].

Considering their typical lightweight, durability, general low-cost production and easy shaping into different forms, the production and applications of plastics have grown exponentially [11]. Today, these materials are ubiquitous in many industries and fields, including [12]: construction and building, textile and automotive industry, aerospace and aviation, electrical and medical applications, agriculture and food packaging. Among numerous plastic materials, polyethylene terephthalate, commonly abbreviated as PET, is the most widespread and widely used [13]. It is commonly produced by direct esterification of terephthalic acid and ethylene glycol, or by transesterification of dimethyl terephthalate with ethylene glycol. The combination of its properties, such as light weight and chemical resistance [14], temperature and dimensional stability [15, 16], high mechanical strength and good gas barrier properties

[17], combined with a low price [1] makes polyethylene terephthalate the material of choice for packaging industry, where three major packaging applications include [18]: 1) bottles and containers, 2) thermoformed trays and blisters, and 3) thermoformed packaging. Additionally, polyester fibers are responsible for most applications in textile products [19]. Due to above, world production of PET has experienced significant growth over the past decades; as a comparison, global production of polyesters increased from 25–30 mt in 2000, to 55 mt in 2012 and mostly consisted of polyethylene terephthalate [20].

However, widespread application of PET has also led to unwanted implications, such as: increased depletion of fossil fuels and air pollution, deterioration of soil and water quality, and potential inclusion of harmful chemical compounds in the food chain. Namely, as energy-intensive, the production of PET has a high consumption of raw fossil resources and energy [21] and in this connection a negative environmental impact of energy consumption [22], contributing to carbon emissions. In addition, the properties of this material that make it desirable for use, such as durability and resistance to degradation, simultaneously lead to excessive accumulation of discarded PET in the environment [23]. Plastic discarded on the roads is washed by rain into the nearby water reservoirs, canals, and drains, and such accumulations in populated areas can clog sewer systems and even cause flooding [24] and create favorable conditions for disease-carrying mosquitoes and waterborne microorganisms [25]. In soil can reduce the infiltration rate of rainwater and affect soil fertility [26]. Plastic waste degradation to particles of micro to nano sizes facilitates their further distribution in air, soil and water, and thus entry into the food chain, with various negative consequences for terrestrial and aquatic animals and humans [27].

Among the available options to address the problem of PET waste management are the techniques of landfill disposal, incineration and recycling [28]. Since landfill disposal of PET waste consumes available landfill space and by plastic leakage caused by a long-term degradation process still can contribute to air, water, and soil pollution [29], this technique can only be considered as a final or temporary option.

PET waste incineration is done by heating the waste materials in the presence of oxygen, and flue-gases that are created contain the majority of the available fuel energy as heat [30]. However, due to emission of chemical compounds with serious risk to health and the environment [11,31], this method is less favored than recycling. Additional reasons for the need to recycle PET instead of incineration is its significantly lower heating value than that of other packaging polymers [32].

Among the recycling techniques, the following are distinguished: mechanical recycling, chemical recycling and biorecycling. The first one is a process that includes operations of material collection, cleaning and polymer reprocessing [33] without the change of the chemical structure of the material, thus enabling multiple re-use/recycling of polymeric materials while maintaining its original properties [34].

Chemical recycling, by using chemical reactions, break down PET products into their basic units, ie. monomers that can be used to produce new PET products [35] and manages to deal with low quality and contaminated wastes [36].

In the European Union, PET recycling is focused on packaging waste, and since it is commonly used for the packaging of bottled water and soft drinks, the collection of bottles from consumers is carried out both through a deposit-return scheme and through separate waste collection [37]. In this way, the recyclable plastic is separated before its leakage into landfill waste, which can help reduce PET contamination and improve recovery for recycling operations [29].

The aim of this paper is to analyze the current state of PET packaging waste in an urban area (the city of Zvornik) and propose a method for organized collection of the same, which will be the basis for a system of organized collection of all types of waste provided for by the municipal, city and republic plans and other normative acts [38-41] in the aforementioned area and by the guidelines and Directives of the European Union.

MATERIALS AND METHODS

The morphological composition of mixed municipal waste was analyzed from three locations: Location 1 (adjacent to the elementary school), Location 2 (adjacent to the health center), and Location 3 (residential complex). The analysis was conducted using a manual waste-sorting method.

Within the category of mixed polymer waste, the composition by product category was determined using the same procedure. Based on the findings, recommendations were formulated for the establishment of organized PET bottle collection points, as well as for the selection of suitable waste bins for their disposal.

RESULTS AND DISCUSSION

Below are the results of determining the morphological composition of municipal waste and composition of polymer waste by product category (wt.%).

Results of the Determination of the Morphological Composition of Mixed Municipal Waste

The morphological composition of mixed municipal waste collected from waste containers placed at three locations is presented in Tables 1–3. It should be emphasized that, in addition to the elementary school and the healthcare facility, houses and smaller residential buildings are also situated in the vicinity, and their residents dispose of waste in the same waste containers. At Location 1, the morphological composition of mixed municipal waste was analyzed during the school term and during the school holidays (Table 1).

Table 1. Waste Fractions of Mixed Municipal Waste at Location 1 (wt.%): (a) During the School Term, (b) During the School Holidays

Type of waste	Waste Fraction, wt.%	
	a	b
Polymer Waste	36.88	24.43
Paper and Cardboard Waste	14.39	7.67
Metal Waste	1.88	5.50
Glass Waste	5.63	6.10
Textile Waste	0.35	0.40
Electronic Waste	0.38	-
Other Waste (organic waste, bulky waste, etc.)	40.49	55.85

From the results presented in Tables 1–3, it can be concluded that the morphological composition of waste differed depending on location. When considering a specific type of waste, at locations 1 and 2, polymer waste dominates, while at location 3, other waste. The share of polymer waste is higher in the waste container near the school, than that near the healthcare facility. In general, the most common specific types of waste at the aforementioned locations are polymer, and paper and cardboard. Furthermore, the morphological composition of waste at Location 1 during the school holidays differs from that during the school holidays, that is, the proportions of the aforementioned most common types of waste are higher during the school holidays. The high proportion of other waste at Location 2 may be attributed to medical and organic waste that is not classified under other categories. The smallest proportion of waste at all three locations are textile and electronic waste.

Table 2. Waste Fractions of Mixed Municipal Waste at Location 2 (wt.%)

Type of waste	Waste Fraction, wt.%
Polimer Waste	14.50
Paper and Cardboard Waste	9.00
Metal Waste	1.00
Glass Waste	4.50
Textile Waste	0.95
Electronic Waste	0.30
Other Waste (organic waste, bulky waste, etc.)	69.75

Table 3. Waste Fractions of Mixed Municipal Waste at Location 3 (wt.%)

Type of waste	Waste Fraction, wt.%
Polimer Waste	16.20
Paper and Cardboard Waste	25.79
Metal Waste	5.86
Glass Waste	6.21
Textile Waste	0.47
Electronic Waste	1.72
Other Waste (organic waste, bulky waste, etc.)	43.75

Results of the Determination of Polymer Waste Composition

The proportion of polymer waste in containers at the specified locations can be presented in descending order: 36.88 (Location 1-a) > 24.43 (Location 1-b) > 16.20 (Location 3) > 14.50 (Location 2), and its composition is given in Tables 4–6.

The proportion of PET packaging (bottles of various volumes) used for packaging drinking water, mineral water, carbonated and non-carbonated soft drinks, beer, and wine, in waste containers from different locations can be presented in the following descending order: 51.72 (Location 2) > 42.37 (Location 1-a) > 31.91 (Location 3) > 30.61 (Location 1-b).

The higher proportion of PET bottles at Location 1 during the school term compared to school holidays (Table 1) likely comes from students consuming bottled beverages. During holidays, the number of students decreases, leading to a lower share of PET bottles, while PE/PP packaging and plastic bags/films more often originate from local residents and nearby shops.

Table 4. Composition of Polymer Waste (wt.%) at Location 1: (a) During the School Term, (b) During the School Holidays

Type of Waste	Waste Fraction, wt.%	
	a	b
PET Bottles	42.37	30.61
PE and PP Bottles and Containers	10.17	18.37
Nylon and Other Films, Bags	47.46	51.02

The high proportion of PET bottles at Location 2 (Table 5) may result from patients and staff consuming bottled water, as health institutions often recommend it. The lower proportion of nylon and films is likely due to fewer retail activities compared to residential areas.

Table 5. Composition of Polymer Waste (wt.%) at Location 2

Type of Waste	Waste Fraction, wt.%
PET Bottles	51.72
PE and PP Bottles and Containers	13.79
Nylon and Other Films, Bags	34.49

At Location 3 (Table 6), the dominance of nylon and films (57.45%) is most likely linked to household waste, especially plastic bags from shops and food packaging. The relatively lower proportion of PET bottles compared to other locations may be due to higher use of other types of packaging (glass, cardboard) or local consumption habits. Also, waste PET bottles were of larger dimensions to those near the Location 1, which can be explained by the family economy.

Table 6. Composition of Polymer Waste (wt.%) at Location 3

Type of Waste	Waste Fraction, wt.%
PET Bottles	31.91
PE and PP Bottles and Containers	10.64
Nylon and Other Films, Bags	57.45

The City of Zvornik, in accordance with the obligations stipulated in various normative acts of the Republic of Srpska and Bosnia and Herzegovina, has adopted several acts related to waste management [38-41], one of the most important of which is the Local Waste Management Plan for the period 2022-2027. This Plan envisages the formation of green islands, i.e. places where semi-aboveground or aboveground selective containers for the separate collection of packaging waste will be placed. Considering the results obtained in Tables 4, 5 and 6, the high share of PET bottles in municipal waste could be addressed by installing smaller-sized bins for their collection in the urban area of the city of Zvornik. Figure 1 shows a schematic representation of suitable collection bin for waste PET bottles. Such bins are often part of educational and environmental campaigns and are typically placed in front of schools, sports halls, shopping centers, or other public spaces to encourage children and citizens to separate PET bottles. They are usually designed in the shape of a large bottle to visually indicate their purpose and are constructed from wire mesh to ensure ventilation and allow easy visual inspection of the contents.

Based on the obtained results and data provided by companies engaged in the collection and transportation of municipal waste and by the landfill operator, it was estimated that approximately 95 of such waste bins, that require little space and are easy to empty, should be installed in the urban area of Zvornik.

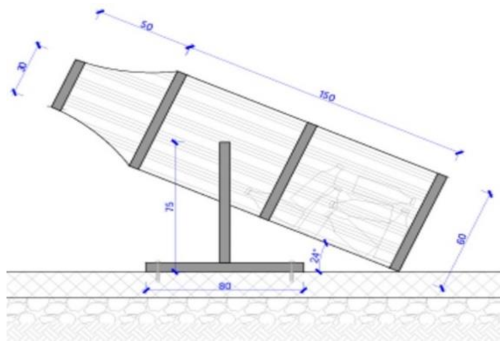

Figure 1. Schematic Representation of a PET Bottle Collection Bin

Considering that the Republic of Srpska possesses adequate capacity for PET bottle recycling - as exemplified by the industrial entity „Omorika Reciklaža" in Doboj [42], which converts PET waste into granulated PET, thermo-foils, and containers - the PET waste management process could be structured in the following two stages carried out by an authorized company:

1 The collection of waste PET packaging, sourced both from designated waste bins and through direct acquisition from hospitality establishments, shopping centers, enterprises engaged in the recovery of secondary raw materials, PET packaging manufacturers, as well as producers of bottled water and/or non-alcoholic beverages.

2. The transportation of the collected waste PET packaging to an industrial recycling facility for further processing.

Figure 2. presents a map of the urban area of Zvornik with the proposed locations for placing waste bins.

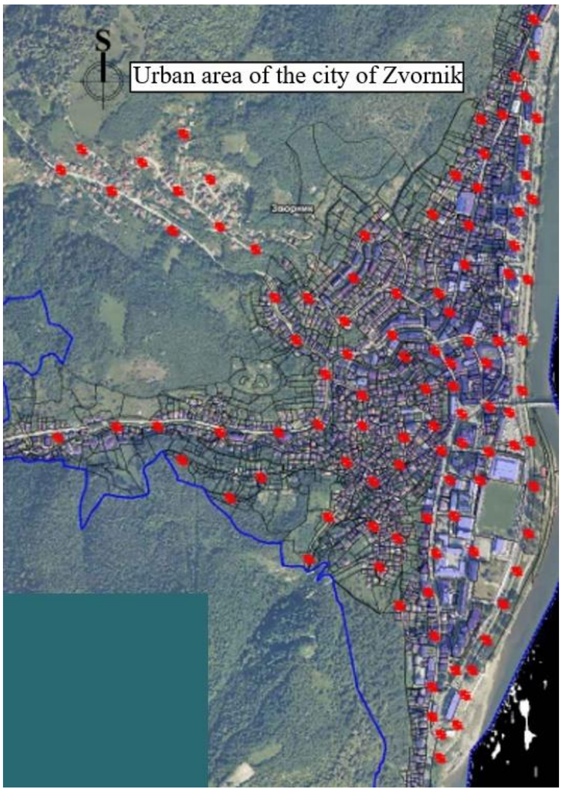

Figure 2. Map of the urban area of Zvornik with proposed locations of bins (marked in red) for PET bottle collection

CONCLUSION

The composition of mixed municipal waste in the city of Zvornik is closely associated with the functional characteristics of each location. Educational institutions predominantly generate polymer waste; residential areas exhibit a higher proportion of paper/cardboard and polymers, accompanied by a considerable share of organic and bulky waste; whereas healthcare facilities primarily generate waste classified as ‘other.’ Textile and electronic waste represent the least abundant fractions across all surveyed locations.

Waste PET bottles are most prevalent near the health center (51.72%), which can be associated with the need for bottled water in a medical environment. Waste nylon and films are most prevalent in the residential complex (57.45%), where household waste is the main source of plastic waste. Near the school, the waste composition changes seasonally — during the school term, PET bottles have a higher share than during holidays, while nylons and PE/PP products increase when the school is closed.

Wire mesh bins are a good solution for collecting waste PET packaging due to their small footprint, ease of emptying, the assumption that other types of waste will not be disposed of in them, as well as their cost. More precise quantities of the aforementioned types of waste, in relation to the seasons, can be easily obtained by placing 95 wire bins at designated locations and regularly emptying them over a specified time period during each season.

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