

The First Assessment of Plastic Pollution in a Tourism Route of Serra da Mantiqueira Environmental Protection Area, São Paulo State, Brazil

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Keywords

Tropical Mountains
Sustainable Tourism
Solid Wastes

Abstract

This article presents a comprehensive field study on plastic pollution along a tourist route in the Serra da Mantiqueira Range, an area characterized by intensive tourism and ecotourism activities. Through systematic field surveys, solid waste discarded along the Gomerall Touristic Circuit was identified and georeferenced, enabling both material-based classification and the mapping of critical zones of improper disposal. Plastic waste predominated in the analyzed road section, accounting for 44% of the total identified material, mainly in the form of food packaging and food transport-related items. Approximately 40% of the waste could not be classified due to its advanced state of degradation; however, field observations suggest that a substantial portion consisted of paper products, such as toilet paper, tissues, and napkins. Metals accounted for 8% of the identified waste and consisted almost exclusively of aluminum cans, particularly beer cans, indicating considerable recycling potential. Glass represented only 1% of the total waste and was primarily associated with bottles for beer and other alcoholic beverages. All multilayer carton packaging was exclusively related to beverage consumption, especially dairy products. A total of 668 plastic waste items were identified across the surveyed sections, corresponding to an abundance of 95.5 items per km. Bottles (32%) and packaging (29%) were the predominant categories. Packaging fragments, bags, and sacks accounted for 12% of the plastic waste, while bags and sacks alone represented 10%. Most discarded plastic bottles were associated with hydration products, mainly drinking/mineral water, isotonic beverages, and soft drinks, and were predominantly composed of poly (ethylene terephthalate) (PET). Packaging waste was mainly associated with peanut candy, cookies/biscuits, cereal bars, carbohydrate gels, savory snacks, banana candy, chocolate-coated wafers, and candies. Most of these packages were composed of polypropylene (PP), whereas a smaller proportion was made from other resins. Preliminary mitigation strategies proposed include the installation of waste bins at identified irregular disposal hotspots and the implementation of targeted environmental education initiatives.

INTRODUCTION

Plastic pollution (PP) has emerged as one of the major environmental risks of the present day. According to MacLeod *et al.* (2021), PP is poorly reversible, given that the mineralization of this material occurs slowly, while remediation solutions are unlikely. Also, according to MacLeod *et al.* (2021), the main impacts of PP are: changes in carbon and nutrient cycles, habitat changes in soils, sediments and aquatic ecosystems, concomitant biological impacts on endangered or fundamental species, ecotoxicity and social impacts.

Borrelle *et al.* (2020) indicate that the efforts needed to significantly reduce global plastic pollution are extraordinary. If there is no reduction in the production and use of plastic, the solution to the problem must involve a change in the economic approach about this material, through the valorization of the plastic products at the end of their life cycle, instead of their mere transformation into waste (Borrelle *et al.*, 2020).

Research on plastics and microplastics pollution began and continues to focus predominantly on aquatic environments, particularly marine areas e.g. (Brabo *et al.*, 2024; Eriksen *et al.*, 2014; Perold *et al.*, 2024; Pinheiro *et al.*, 2023; Willis *et al.*, 2022; Xanthos; Walker, 2017). However, other ecologically and environmentally relevant ecosystems, that are equally vulnerable to PP, remain underexplored. One such example are mountain areas/ecosystems (Honorato-Zimmer *et al.*, 2021; Lasota *et al.*, 2023; Liro *et al.*, 2023; Mihai, 2018; Pastorino *et al.*, 2021; Senese *et al.*, 2023; Villanova-Solano *et al.*, 2023).

“Mountains are an essential component of the global life-support system [...]” and are highly vulnerable to anthropogenic threats.” (Schmeller *et al.*, 2022). These environments are characterized by complex terrain (in terms of topography, geology and soil), and by intense hydrological and meteorological dynamics. In tropical mountains, the combination of these factors results in a very high biodiversity, including the presence of endemic and/or threatened species see, for example, (Vilanova, 2025).

Mountains are also “[...] important tourism destinations worldwide and attract visitors for their scenic beauty, sports attractions, and rich cultural heritage (Food and Agriculture Organization of the United Nations; World Tourism Organization, 2021). However, according to FAO and UNWTO (2021), “[...] tourism is also associated with potentially

negative impacts on ecosystems, such as pollution and biodiversity loss [...]”.

This article reports a study on plastic pollution on a tourist route in the Serra da Mantiqueira Range, in which tourism/ecotourism activities are widely carried out. The Área de Proteção Ambiental da Serra da Mantiqueira (APASM) (Serra da Mantiqueira Environmental Protection Area) was created in 1985 and is considered one of the most important places of the world for the conservation of amphibians, birds, and mammals (Saout; Le *et al.*, 2013). Furthermore, the APASM is an important place for outdoor activities and tourism in Southeast Brazil.

The main objective of this study is to advance the understanding of how tourism promotes plastic pollution in APASM, through a case study in the Circuito Turístico do Gomerl (CTG) (Gomerl Tourist Circuit). The CTG receives tourists interested in ecotourism, outdoor sports (e.g. mountain biking and trail running) and religious tourism. It is one of the main pilgrim routes towards the National Sanctuary of Aparecida (A12, s.d.), one of the most important Catholic sanctuaries in Brazil.

The specific objectives of this study are: (1) to conduct a mapping of solid waste discarded in the CTG; (2) to classify the types of discarded waste by material; (3) to classify the types of plastic discarded among the waste; (4) to report the insights obtained during the fieldwork, in terms of plastic waste generation resulting from tourism activities; (5) based on the set of information previously described, to establish hypotheses regarding the type of tourism, behaviors, and physical environmental factors that could be used to mitigate the problem of plastic pollution in the CTG.

To the best of my knowledge, this is the first study on plastic pollution in APASM, which highlights the contribution and scientific relevance of the article.

METHODS

Study Area

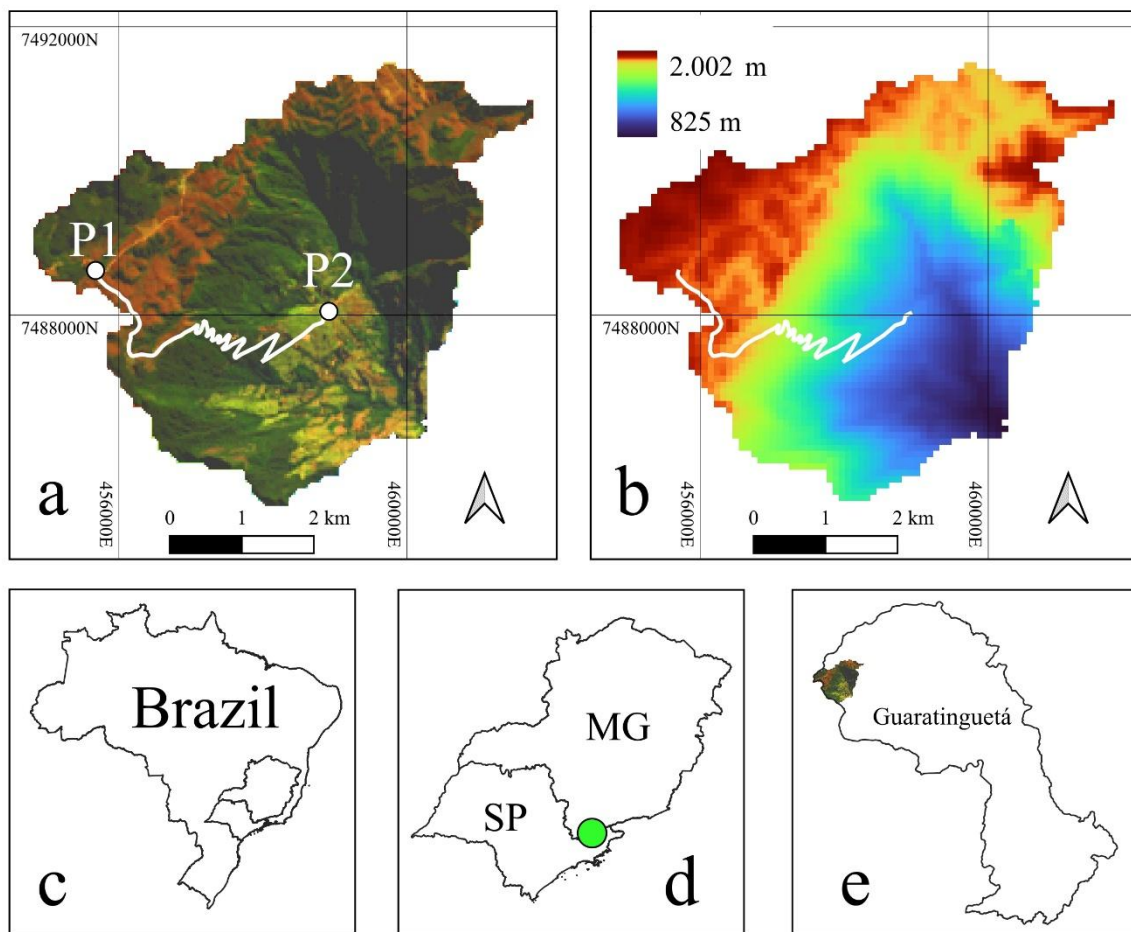
The CTG is in Guaratinguetá, São Paulo (SP) State, in the border with Minas Gerais (MG) State, Southeast Brazil (Figure 1). The study was conducted along a 7 km section of the Pedrinhas Road, from P1 (22°42'33.37"S, 45°25'52.97"W, altitude ≈ 1,910 m) to P2 (22°42'52.33"S, 45°24'0.23"W, altitude ≈ 1,230 m), as shown in Figure 1a. This section was chosen for its low anthropization and significant

native vegetation Atlantic Forest and altitude grasslands (Figure 2). The drainage area shown in Figures 1a and 1b corresponds to the section of the watershed where there is convergence of surface runoff (and, consequently, plastic waste carried by water) from the sub-basins traversed by Pedrinhas Road.

The studied section of Pedrinhas Road is unpaved. P1 is a convergence point of two roads/routes through which tourists from southern MG and Campos do Jordão access the CTG: the first (northwestern route) passes

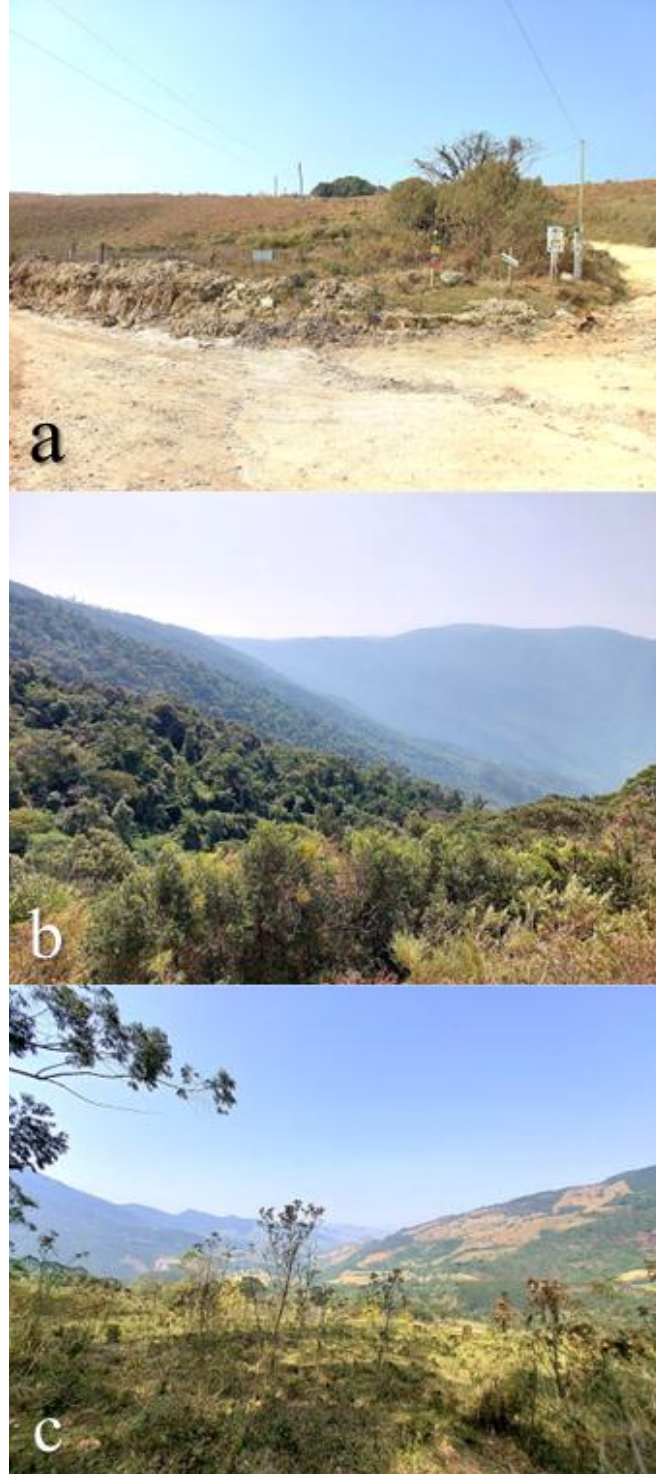
through the Parque Estadual de Campos do Jordão (PECJ) (Campos do Jordão State Park) PEC Jand is navigable by passenger vehicles, and the second (northeastern route) originates in Delfim Moreira (MG), passing through farms and trails. It is worth noting that Campos do Jordão is one of the main winter tourism destinations in Southeastern Brazil, which also results in an increased flow of occasional tourists (not associated with ecotourism, sports or religious tourism).

Figure 1 – Study Area. The white line in Figures a and b shows the section of Estrada da Pedrinhas analyzed: (a) composition of Landsat 8 satellite bands 4, 3, and 2; (b) SRTM digital elevation model; (c) locations of SP and MG States in Brazil; (d) study area regional location; and (e) study area within Guaratinguetá municipality



Source: INPE (2025); MIRANDA (2005). Prepared by the author (2025).

Figure 2 – Landscapes of the study area: (a) P1 and altitude grasslands; (b) native forest; and (c) transition zone between native forest and anthropized area



Source: The author (2025).

Field Work

The solid wastes mapping campaign occurred on September 9, 2024, two days after the September 7 holiday (Brazilian Independence Day). This date was selected due to the high number of tourists at the CTG during the holiday, which was indicated by local entrepreneurs. The selected road section was

covered on foot and car, from approximately 9:30 am to 2:00 pm. The weather conditions on the day were sunny and dry. It is important to highlight that, during the period in which the campaign took place, Southeast Brazil faced heat waves and low rainfall. This fact is important, considering the possibility of solid waste being carried away by the runoff produced by the rain.

All visible solid waste along the road were photographed with a smartphone and georeferenced for later analysis. For health and safety reasons, none of the wastes were handled and/or moved.

Waste Analysis

Georeferenced photographs were analyzed to quantify and classify general and plastic waste. We aimed to minimize the subjectivity of visual classification, but it can't be entirely avoided. In

this sense, the natural environment posed challenges such as dust, sunlight, and precipitation, complicating identification due to: (1) degradation and fragmentation of some waste; (2) dirt/dust accumulation; (3) agglomeration of different waste types. First, the photographs were grouped by location (according to the 500 m sections established). After that, for each section, they were categorized by material and further subcategorized by type (when applicable), as illustrated in Table 1.

Table 1 – Categories and types of solid wastes that were considered in the study

Category (material)	Type
Plastic	Drinking straws; Cigarettes; Cups; Packaging; Packaging or bag fragment; Bottles; Polystyrene foam; Jars and containers; Lines and ropes; Other; Bags and sacks; Utensils.
Metal	General; Beverage cans
Paper	-
Cartonboard packaging	-
Glass	General; Beverage bottles
Undetermined	-

Source: The author (2025).

The grouping process involved three rounds to correct errors and refine the classification. Elements that remained unclassified were placed in the "Undetermined" category.

Waste identifiable as a single element was considered a "unit". Fragmented elements or those too small for visual identification were disregarded. Elements disposed together, like stacked disposable cups, were also considered a unit.

In the classification of plastics, the following types were considered: (1) packaging: original wrapping placed by the product manufacturer, typically smaller in size, used for protection/storage of products, whether individual or in small portions; (2) bag or sack: wrapping not placed by the product manufacturer, generally larger in size, used for protection/storage or transportation of products. "Fragments of bags and sacks, and packaging" were included as a third type, when the level of degradation/fragmentation made it difficult to classify the plastic into the first two categories.

Plastic bottles, caps, and labels were counted as separate units when discarded individually.

"Jars and containers" included both the containers and their separate caps, also when discarded individually.

Cigarette packaging was classified as "Cigarette" due to the filter, despite being made of plastic and paper.

Plastic medicine vials found at the study site were classified as "Jars and containers".

The application of these methods and

guidelines allowed for a more accurate classification of the solid wastes found. Nevertheless, a degree of subjectivity remains unavoidable in many studies of plastic pollution, as acknowledged by current protocols and scientific literature.

RESULTS

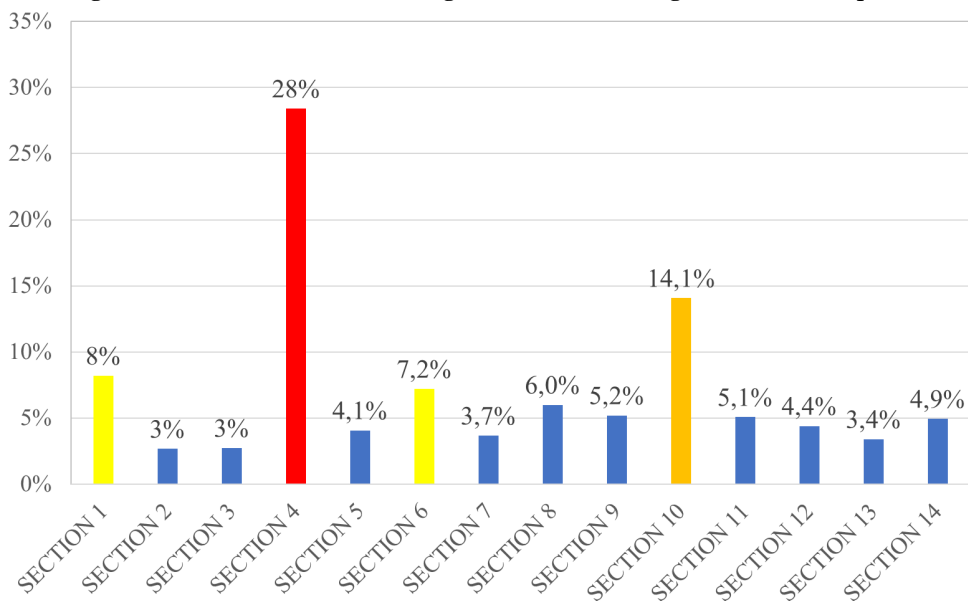
Spatial Analysis

In the studied sections, 1,502 units of solid waste were identified, resulting in a waste abundance of 214.5 units per km. Figures 3 and 4 present the results of this sampling, in terms of the quantity of waste disposed of in each section of the road.

Section 4 (Figure 3 and Figure 4, S4) exhibited the highest quantity of irregularly disposed waste, accounting for 28% of the total. Section 10 (Figure 3 and Figure 4, S10) was the second worst among those studied, representing 14% of the total disposal, while Sections 1 (Figure 3 and Figure 4, S1) and 6 (Figure 3 and Figure 4, S6) contributed with 8% and 7%, respectively.

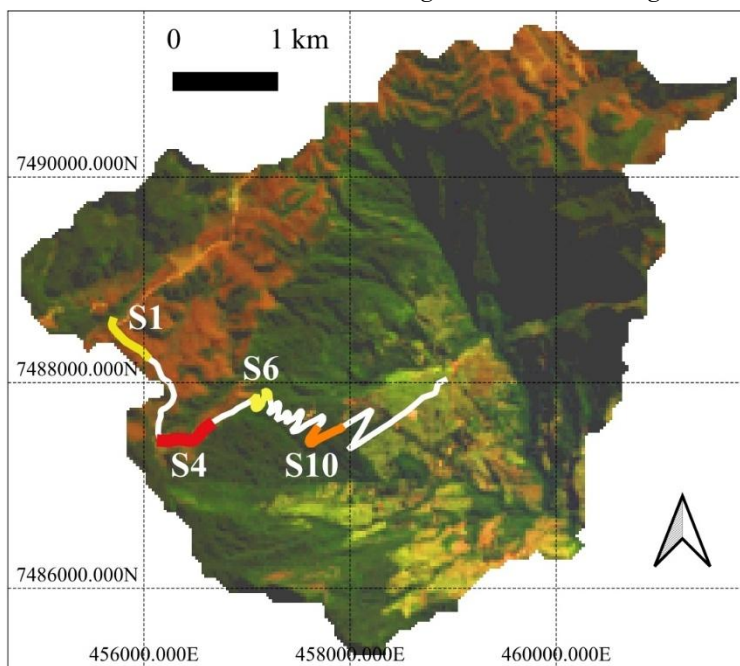
A discussion regarding the characteristics of the sections with the highest levels of irregular waste disposal is presented in the section "What makes a location more prone to irregular waste disposal on a tourist route?"

Figure 3 – Sections with the highest levels of irregular waste disposal



Source: The author (2025).

Figure 4 – Location of the sections with the highest levels of irregular waste disposal



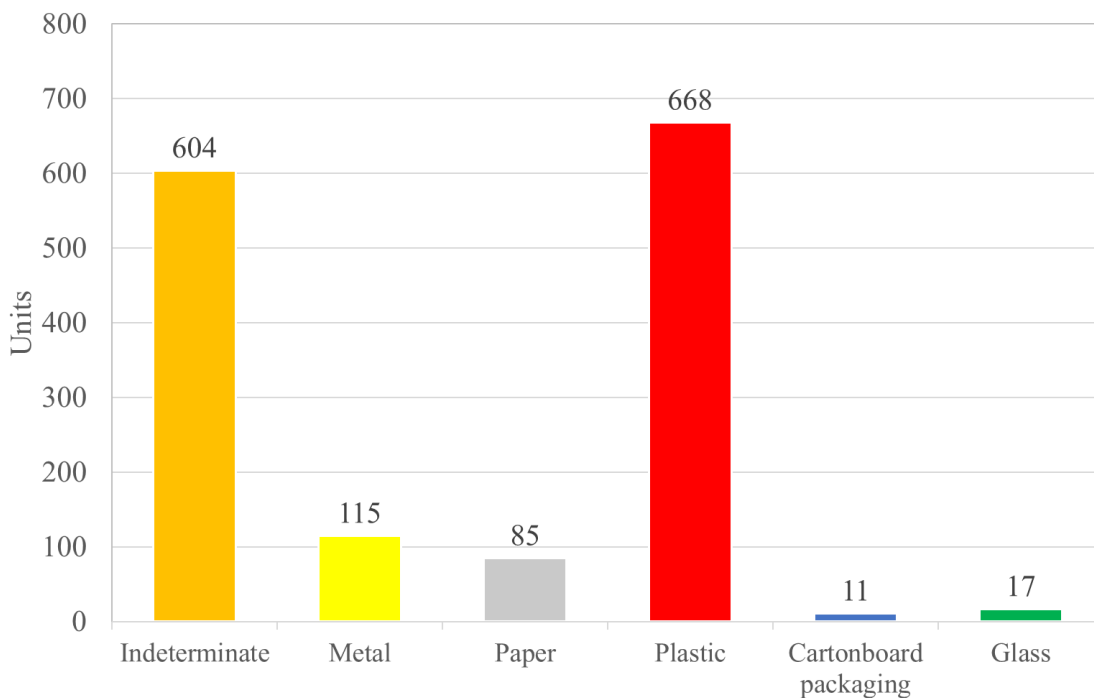
Source: The author (2025).

Waste Assessment

Plastic constitutes the predominant type of waste in the examined road section (Figure 5), representing 44% of the total waste identified. Food packaging and food transport-related waste constitute most of the discarded material.

Approximately 40% of the waste found was not identified due to its high level of degradation. Based on fieldwork observations, a significant portion of this unidentified material appears to be paper products (toilet paper, tissues, and napkins), which explains the high level of degradation.

Figure 5 – Classification of waste materials/categories identified (units found)



Source: The author (2025).

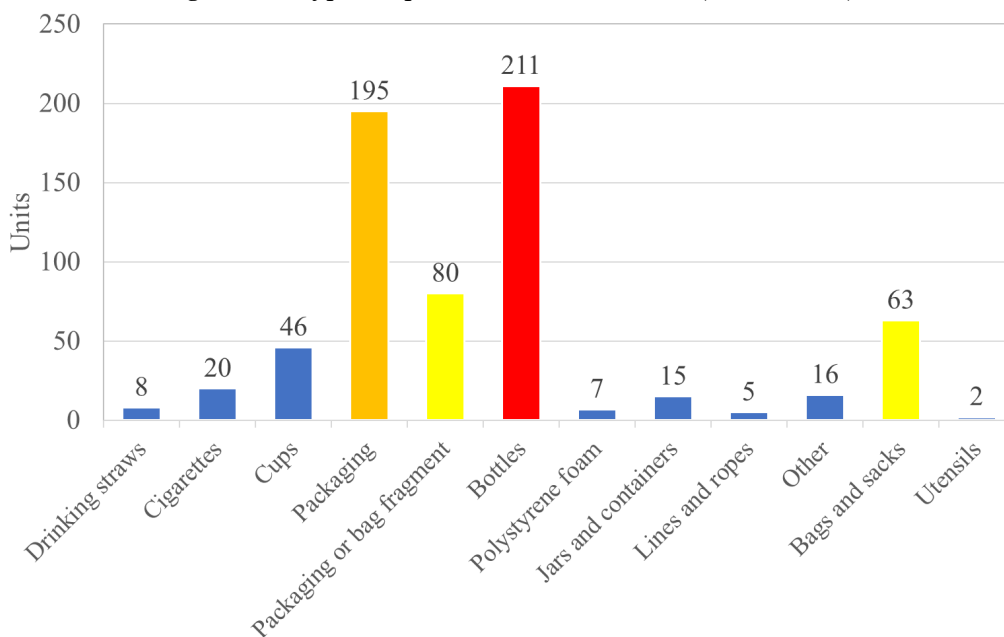
Metals comprised 8% of the identified waste. These metals are almost exclusively aluminum cans, especially beer cans, which have significant potential for recycling. Beer and other alcoholic beverages are the main source of most glass bottles, which represent a minor contribution to the overall composition of waste (1%).

All multilayer cartonboard packaging found originated entirely from beverage consumption, mainly dairy products.

Plastic Waste Assessment

In the surveyed sections, 668 plastic waste units were identified, resulting in an abundance of 95.5 plastic waste units per km. Figure 6 illustrates the composition of the identified plastic waste. Bottles (32%) and packaging (29%) constitute most of the plastic waste found. Packaging fragments, bags, and sacks accounted for 12% of the plastic waste, while bags and sacks contributed 10%.

Figure 6 – Types of plastic waste identified (units found)



Source: The author (2025).

Hydration (mainly drinking/mineral water, isotonic drinks, and soft drinks) is responsible for most discarded plastic bottles. Most of these bottles are composed of poly (ethylene terephthalate) (PET) code 1 according to (ABNT, 2008; ASTM International, 2020).

In terms of packaging, the products most associated with this waste are peanut candy, cookies/biscuits, cereal bars, carbohydrate gels, savory snacks, banana candy, chocolate-coated wafers, and candies. Most of these packages are composed of polypropylene (PP) code 5, according to (ABNT, 2008; ASTM International, 2020), and a small number of these items are made from other resins code 7, (ABNT, 2008; ASTM International, 2020).

DISCUSSION

Proposed Management Strategies for Reducing Solid Waste and Plastic Pollution in the CTG

Some preliminary solutions are proposed to mitigate plastic and general solid waste pollution in the CTG resulting from tourist activities:

(1) Continuous environmental education campaigns (for example, using social media) aimed at fostering responsible behaviors prior to participation in tourist activities (see section “The role of behavior and environmental education”);

(2) On-site environmental education initiatives within the CTG, such as the installation of informational banners, to reinforce the importance of proper waste management practices during tourism, especially at locations with higher rates of improper disposal (see sections “What makes a location more prone to irregular waste disposal on a tourist route?” and “The role of behavior and environmental education”);

(3) Placement of waste collection receptacles at strategic points along the route (see section “What makes a location more prone to irregular waste disposal on a tourist route?”).

What Makes a Location More Prone to Irregular Waste Disposal on a Tourist Route?

As previously described, some sections of the road showed a high concentration of improperly discarded solid waste. Here, it is presented some common features of these sections that may explain this concentration of waste.

The concentrated waste disposal occurs at tourist stop locations, which manifest in various forms: (1) places with religious symbols (such as chapels, altars, and prayer caves), (2) locations with buildings that can serve as support bases where, apart from finding shade and protection from the sun, tourists can rest and replenish with water, for example; (3) viewpoints and other tourist attractions. These locations are, therefore, strategic for the installation of solid waste management infrastructure (such as trash bins) and environmental education initiatives (for example, banners and posters).

In the studied location, the terrain seems to influence the concentration of large waste disposals. The average slope of the section studied is 9.7%, and during the fieldwork, there was a clear perception that large disposals occur in flatter sections. Some of these flat areas coincide with the previously described stopping points. When this is not the case, the greater presence of waste in flat terrain may be related to the biomechanics of walking and the reduced speed of cyclists: in both situations, the lower slope facilitates the consumption of food and beverages while moving.

Regarding indeterminate and paper waste, fieldwork clearly demonstrated that the rustic drainage systems (Figure 7) along the road are being used by tourists as toilets for physiological needs, as evidenced by the large amount of these wastes found in these systems. This is a critical issue for water pollution in the region, given that the significant runoff concentrated in these systems can carry the wastes downstream. It is important to note that the studied section is within the the Ribeirão Guaratinguetá Watershed, the main water source for the municipality of Guaratinguetá.

Figure 7 – Rustic drainage systems



Source: The author (2025).

The Role of Behavior and Environmental Education

Some specific types of waste allow hypotheses to be raised about their origins. The large quantity of alcoholic beverage packaging (aluminum cans and bottles, mostly beer) suggests that this type of waste is not associated with sports activities conducted in the CTG – it is unreasonable to assume that hikers and cyclists consume such beverages during these activities. On the other hand, the various carbohydrate gel packages and bottles of isotonic drinks are probably discarded by these athletes.

This example allows us to address a key aspect of solid waste management in tourist routes: environmental education and tourist behavior. Different types of tourists have different motivations and interests for visiting a tourist circuit, which reflects their individual and collective values (since many activities, such as pilgrimages, occur in groups). These factors tend to be reflected in the behaviors and practices of individuals and groups, as well as in their willingness to adopt environmentally responsible practices. In this sense, the strategies for educating, communicating, and raising awareness among tourists must be specific and targeted at the intended audience.

According to Pooley and O'Connor (2000),

“[...] environmental attitudes may be based on different sources of information, and therefore attitudes toward specific environmental issues may be predicted by both cognition (beliefs) and affect (emotions or feelings).”

Some behavioral aspects associated with mitigating waste pollution in mountain tourism destinations were addressed by Hu *et al.* (2019), based on a study of the Zero Litter Initiative in a mountainous tourism area of Huangshan National Park, China. The main results of Hu *et al.* (2019) are presented below. Firstly, tourists' personal norms (PN) were identified as the most important factor influencing tourists' intention to participate in the Initiative. The PNs considered were based on previous studies and refer to the following Hu *et al.* (2019): (1) engaging in the initiative makes the tourist feel environmentally responsible; (2) participating in the initiative makes the tourist feel they are contributing to the protection of the park; and (3) participating in the initiative makes the tourist feel proud. Demographically, younger tourists and male tourists showed lower intentions to participate in the initiative (Hu *et al.*, 2019). Other factors that influenced tourists' intention to participate in the initiative included (Hu *et al.*, 2019): attitude toward the behavior (i.e. tourists' positive or negative opinions regarding the act of carrying their own waste

out of the mountain); subjective norms (opinions of people who are important to the tourist about the act of carrying their own waste out of the mountain); perceived behavioral control (the ease/difficulty and/or convenience assessed by the tourist regarding their personal ability to carry waste out of the mountain); and past behavior (whether the tourist has previously performed actions and exhibited behaviors aligned with the initiative).

Although the findings of Hu *et al.* (2019) pertain specifically to a particular type of tourist in a specific country - and therefore cannot be generalized to other locations, such as the region studied in this article - their results emphasize that subjective factors can have a significant impact on environmental education initiatives aimed at reducing plastic pollution in mountainous areas. Understanding these factors allows, for example, the application of frameworks to promote pro-environmental behavior, as proposed by Steg and Vlek (2009), which includes: (1) identifying the behavior that needs to be changed, (2) examining the main factors underlying this behavior, (3) designing and applying interventions to alter the behavior to reduce environmental impact, and (4) evaluating the effects of these interventions.

Finally, Hu *et al.* (2019) also stated that preventing waste generation by tourists may be more effective than managing or handling pollution, given that the logistics and infrastructure in mountainous regions make it difficult to collect, transport, and properly dispose the wastes. Ultimately, avoiding or reducing waste generation through changes in tourist behavior can simplify this management and handling. In this regard, the promotion and dissemination of environmental awareness and education prior to tourist activities can play a role as significant as on-site management actions.

CONCLUSIONS

This research demonstrated that plastic pollution is the main form of improper solid waste disposal along a mountain tourist route located within the Área de Proteção Ambiental da Serra da Mantiqueira (APASM) (Serra da Mantiqueira Environmental Protection Area), one of the most important protected areas in Brazil and worldwide. Most of the plastic waste identified was associated with food and

beverages consumed by tourists.

Rest and stopover areas along the studied road were identified as the primary locations for improper waste disposal, making them strategic sites for implementing management measures and waste handling interventions, including environmental education initiatives.

In this context, the type of tourist (pilgrims, athletes, and occasional visitors) is directly related to the type of discarded material, as well as to the most effective environmental education strategies for mitigating this issue.

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Mateus Vilanova: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing.

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