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Solid Waste and Environmental Impacts on Highways: A Systematic Literature Mapping

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ABSTRACT
Highways are integrated into the physical, biotic, and socioeconomic context, which is fundamental for proposing corrective actions that ensure balanced coexistence with the environment. This article aims to construct a critical reflection on solid waste and environmental impacts and draw a parallel with the presence of solid waste on highway SP-613 in Morro do Diabo State Park. The method consisted of a Systematic Literature Mapping (SLM) and textual analysis on solid waste and environmental impacts in electronic databases. This research was approved by the Research Ethics Committee under no. 4201. The publication survey reached a total of 551 references for articles in English and 105 in Portuguese. After applying exclusion criteria, 200 and 29 references were retained, respectively. Textual analysis revealed differences in thematic approaches. The impact of highways as environments for the propagation of waste due to transportation and the presence of landfills is highlighted. The SLM allowed establishing a situational diagnosis of the main publications, pointing out the actions of prevention, mitigation, and compensation of environmental damages that can affect the environmental and socioeconomic balance resulting from the disposal, management, transportation, deposition, and/or reuse of solid waste.

KEYWORDS: Systematic Analysis. Environmental Impact. Pontal do Paranapanema. Morro do Diabo State Park.

1 INTRODUÇÃO

It is known that the environmental impacts caused by the disposal of solid waste have become a global problem concerning environmental damage and pollution, especially when they are discarded without any treatment, affecting the soil, water, and air (MUCELIN & BELLINI, 2008).

Soil pollution can alter physicochemical characteristics, representing a serious threat to public health by promoting the presence and development of disease transmitters. Water pollution can alter the characteristics of the aquatic environment through the percolation of liquid generated by the decomposition of organic matter present in the waste (MUCELIN & BELLINI, 2008)

Air pollution can lead to the formation of natural gases in the waste mass due to the decomposition of waste with and without the presence of oxygen, causing risks of gas migration, explosions, and even respiratory diseases (MUCELIN & BELLINI, 2008).

Various studies in several countries address these issues, resulting in numerous publications that highlight problems, reflections, and diverse solutions on the subject at hand (CARVALHO & ORSINI, 2011).

Ricklefs (1996) stated that the environmental impacts caused by solid waste would increase, driven, among other things, by the world's population growth. It is noteworthy that currently (2019) there are approximately 8 billion human beings on Earth

A população do Brasil apresenta, como outros países desenvolvidos e em desenvolvimento, uma tendência de ocupação ambiental, privilegiando a área urbana.

Vários pesquisadores (GANDY, 1994; VISVANATHAN; TRANKLER, 2003; CHEN, 2008; GLAWE; VISVANATHAN; ALAMGIR, 2018; ASASE et al., 2009; TROSCHINETZ; MIHELCIC, 2009; UN-HABITAT, 2010; ZHANG et al., 2010) utilizaram diferentes métodos e geraram importantes conclusões sobre a comparação dos dilemas da gestão de resíduos em diferentes contextos urbanos de países desenvolvidos e em desenvolvimento.

The population of Brazil, like other developed and developing countries, shows a trend of environmental occupation, favoring urban areas.

Several researchers (GANDY, 1994; VISVANATHAN & TRANKLER, 2003; CHEN, 2008; GLAWE, VISVANATHAN & ALAMGIR, 2018; ASASE et al., 2009; TROSCHINETZ & MIHELCIC, 2009;

UN-HABITAT, 2010; ZHANG et al., 2010) have used different methods and generated important conclusions about comparing the dilemmas of waste management in different urban contexts of developed and developing countries.

Pereira and Maia (2012) confirmed in their study the hypothesis that there are enormous differences between cities in developed and developing countries in managing their municipal solid waste (MSW). They found that London has achieved constant improvement in solving its waste problem, contributing to social and environmental development. However, the MSW management system is expensive and relies on advanced technology provided by the private sector. In São Paulo, in addition to the growing volume of waste generated and the problem of proper disposal, there is also the issue of increasing informality. The amount of waste is enormous, growing year by year, and the socio-environmental issues are extremely complex.

A study by Santos (2017) concluded that Brazil has made progress in terms of solid waste disposal. However, 10% of the waste collected in the country is disposed of improperly. In this process, more than 3,000 municipalities still do not dispose of waste correctly, characterizing an environmentally concerning situation regarding the collection, handling, and especially the transportation of waste, which often occurs inadequately and is deposited in dumps near highways.

According to Romanini (2005), the final disposal of solid waste generated on concession highways is an aspect that increasingly demands the involvement of different sectors of society to establish an adequate production-to-final-disposal cycle, both from a technical and socio-political perspective.

Thus, concerns about the topic transcend urban areas, as all the solid waste produced has a final destination that ends up impacting other regions, including those that should be protected.

An example of this is the Arlindo Bettio SP-613 highway, which was implemented in 1970 with the aim of developing the Pontal do Paranapanema region. This highway fragmented the Morro do Diabo State Reserve. It is important to highlight that at that time, there were no environmental concerns regarding the impact of the highway on the reserve due to the absence of specific legislation.

This work aims to construct a critical reflection through systematic mapping that addresses solid waste and environmental impacts, more specifically on the SP-613 highway in Morro do Diabo State Park in the municipality of Teodoro Sampaio-SP.

2 MATERIALS AND METHODS

The method of scanning and analyzing the existing bibliography was used through Systematic Literature Mapping (SLM) according to Maria (2019).

The necessary information for the search of publications is presented in Chart 1. The terms were searched in indexed scientific article databases (Capes Journal Portal, and Scielo Journal Portal) with a restriction to articles published between 2008 and 2022.

Between the two databases, there were significant differences in the formulation of the search string, as presented in Chart 2.

The exclusion criteria were: duplication of articles and lack of relevance to the research objectives. After analyzing the titles and abstracts obtained through the electronic search, the

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bibliographic references of the articles included in the review were analyzed in search of other studies relevant to the topic. IRAMUTEQ (LAHLOU, 2012; RATINAUD & MARCHAND, 2012) licensed under GNU GPL (v2), was used to perform statistical analyses on textual corpora and individual/word tables. Similarity Analysis, Word Cloud, and Descending Hierarchical Classification were selected as options. The word cloud and similarity analysis presented the graphical representation of the selected studies based on word frequency, as well as the representation structure of the studies

Chart 1 - Guidelines for Information Search in SLM.

TERMS FOR STRING FORMULATION	SEARCH RESTRICTIONS
Various combinations of terms: ("solid waste") OR ("solid residue") OR ("solid residues") AND ("environmental impacts") ("solid residue") OR ("solid residues") AND ("road" OR "roads") ("resíduo sólido") OR ("resíduos sólidos") AND ("impacto ambiental") OR ("impactos ambientais") AND ("rodovia") OR ("rodovias") AND ("Pontal do Paranapanema") **SELECTED DATABASES** Capes and Scielo	Abstracts in English and Portuguese. All published in indexed journals (excluding books and conference proceedings). **PUBLICATION AREAS** All

Source: The author (2022).

Chart 2 - Search Strings.

Database	Search Strings
Portal Capes	*("Solid Waste") OR ("Solid residue")OR "Solid residues" AND (environmental impact OR environmental impacts)* *("Solid residue")OR "Solid residues" AND (road OR roads)*
Scielo	*("Resíduo sólido") OR "Resíduos sólidos" AND (Impacto ambiental ou impactos ambientais) AND (Rodovia OR Rodovias) AND (Pontal do Paranapanema)*

Source: The author (2022).

3 RESULTS

The publication survey reached a total of 551 references. Of these publications, a total of 257 were excluded for being outside the selected research area. Of the remaining publications, another 94 were excluded after reading the titles, abstracts, and keywords for not being related to the research objectives. Thus, 200 articles were ultimately retained and subjected to textual analysis.

In the English-language approach, the highlighted words reveal: "waste" followed by "environment" and "waste management," which mostly detailed concerns with recovery actions for environmental preservation.

Similarly, when applying the similarity analysis (Figure 1), the co-occurrences between words and their connectedness are observed, identifying the representation structure.

By including articles from various countries and regions to support the discussion and

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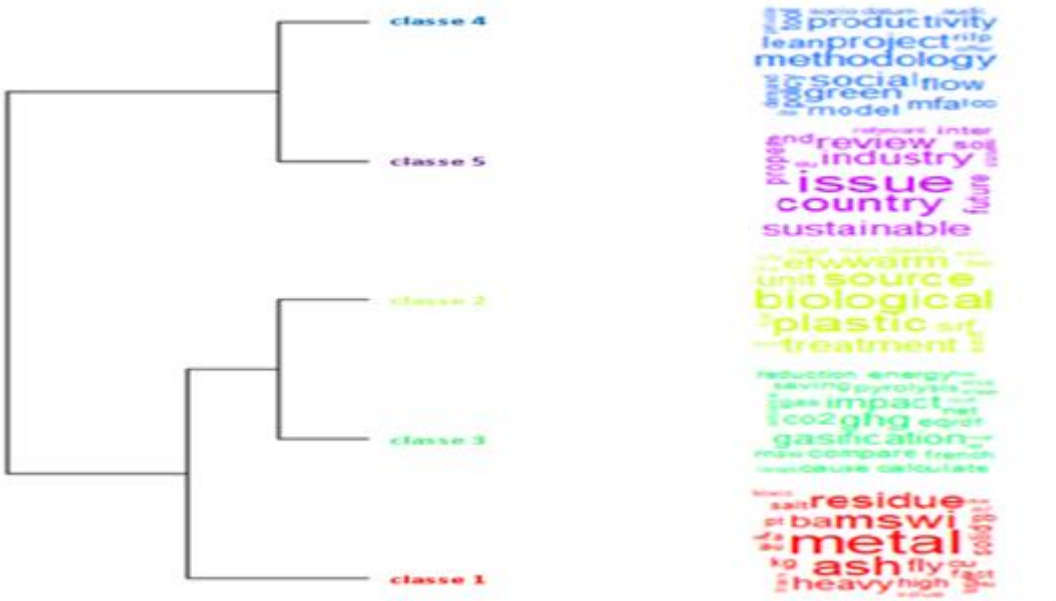
compare the results found, a total of 12 articles were selected: 02 from Denmark, 01 from Germany, 01 from France, 01 from the European Community, 01 from the United States of America, 01 from Mexico, 02 from Colombia, 01 from Cuba, 01 from Bangladesh, and 01 from Chile.

The analysis of the descending hierarchical classification (Figure 1) reveals the characteristics of the main scientific publications in each group. The group with the highest frequency depicts sustainability issues, followed by the approach of projects and teaching methodologies. The intermediate classes address sources such as plastics and metals and the resources for treatment. The last classification specifically dealt with gas production and the impacts on energy production.

Figure 1 - Current situation of school meal management in Presidente Bernardes-SP.



Source: Prepared by the author.

3.1 Solid Waste and Environmental Impacts in Urban Areas and National Highways, Including SP 613 Arlindo Bettio Highway

The survey of national publications reached a total of 105 references. Of these publications, a total of 79 were excluded for being outside the selected research area. Of the remaining, another 14 were excluded after reading the titles, abstracts, and keywords for not being related to the research objectives. Thus, 12 articles were ultimately retained and subjected to textual analysis. The word cloud (Figure 2) presented the graphical representation of the selected studies based on word frequency.

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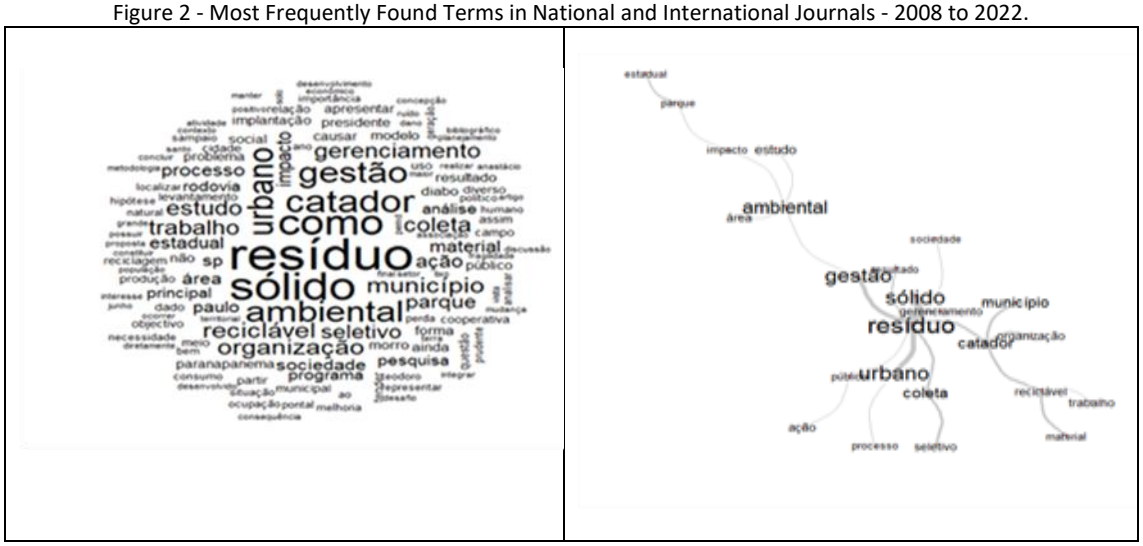
Figure 2 - Most Frequently Found Terms in National and International Journals - 2008 to 2022.

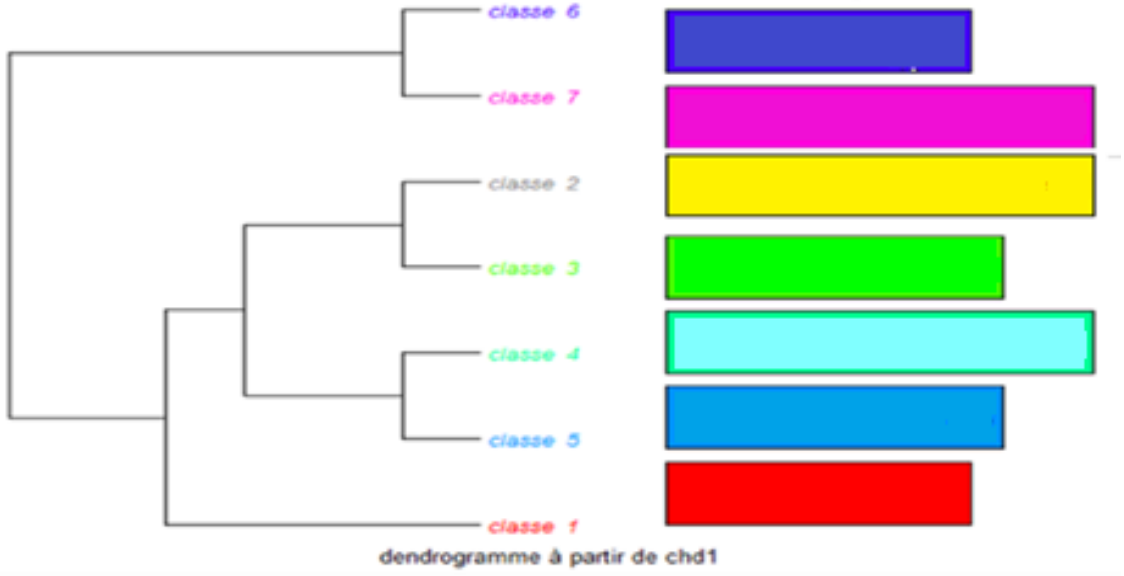


Source: Prepared by the author.

It is noteworthy that in contrast to what was found in the English-language articles, which highlighted the words "waste," followed by "environment" and "waste management," the main words here are "solid waste," "environmental," "collector," "recyclable," and "collection," indicating a relationship between waste production, handling, and processing. The similarity analysis clarifies these aspects by depicting a figure that presents three distinct sets of correlation.

At the center is the group "waste" connected to the groups "management," "urban," and "collector." The descending hierarchical classification distributed the articles into 2 groups with 7 distinct classes (Figure 3).

Figure 3 - Dendrogram of National Articles.



Source: Prepared by the author.

Thus, the analysis of the descending hierarchical classification (Figure 4), despite the

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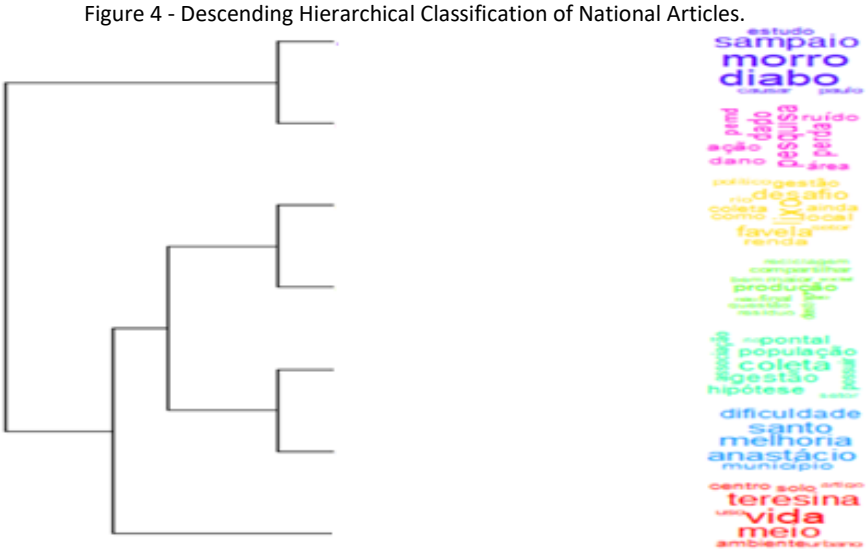
small number of articles, reveals the characteristics of the scientific publications, corroborating the findings in the word cloud and similarity analysis. The 2 groups generally address issues related to waste management linked to collection processes and the challenges posed by municipalities, specifically in the Pontal do Paranapanema region and Morro do Diabo State Park.

The solid waste found on the Arlindo Bettio highway was classified by type, characteristics, and frequency of occurrence (Chart 3). In addition to the type, the location of the highest incidence of deposition was determined, both in the right-of-way and in the direct influence area of the highway (buffer zone). This zone was considered as the area reached by waste that was thrown, left, or dumped by users.

The most commonly found waste was Class III, such as plastic packaging, beverage cans, and plastic containers.

Figure 4 - Descending Hierarchical Classification of National Articles.



Source: Prepared by the author.

Chart 3 - Strings de Busca.

Waste	Characteristics and Incidence Locations	Classification	Waste Found on SP-613
Class I	Present risks to the environment and human health due to high levels of flammability, corrosivity, reactivity, toxicity, pathogenicity. **Location** – shoulder and traffic lane	Hazardous Waste	Cigarette butts (Low occurrence)
Class II A	Non-inert, may present combustibility, biodegradability, or solubility; typically, characteristics of domestic waste. **Location** – near the shoulder	Non-hazardous Waste	Cigarette butts (Low occurrence)

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Class II B	Inert waste that does not destroy or decompose when disposed of in the environment. **Location** – between the shoulder and the buffer zone	Non-hazardous Waste	Food packaging, beverage cans, plastic containers, tires, treated wood, and rubber fragments. (High occurrence)

Source: Prepared by the author based on NBR:10004/2004.

4 DISCUSSION

Cities have been facing serious problems related to waste generation, and consequently, this lack of knowledge about alternatives for the disposal of urban solid waste causes considerable disturbances to the population and the environment (GOUVEIA, 2012).

However, it is worth noting that several authors (GANDY, 1994; VISVANATHAN & TRANKLER, 2003; CHEN, 2008; GLAWE, VISVANATHAN & ALAMGIR, 2018; ASASE et al., 2009; TROSCHINETZ & MIHELCIC, 2009; UN-HABITAT, 2010; ZHANG et al., 2010) affirm that a large portion of waste consists of recyclable materials and, when properly disposed of, can be transformed into a resource-generating industry with the full capacity for the productive scale to coexist with the environment.

The studied articles indicated the need to implement integrated solid waste management mechanisms that respect regional particularities and their socioeconomic, cultural, geographical, educational, and political characteristics (DUTHIE, 2001; RAMJEAWON & BEEDASSY, 2004; JHA-THAKUR, FISCHER & RAJVANSHI, 2009; KOSAMU, 2011; QUEIROZ et al., 2014).

The results highlight that both in Germany and Denmark, selective collection and recycling are operationalized based on laws approved at the national and European Community levels (GEHRMANN, HIEBEL & SIMON, 2017; BHANDER et al., 2010).

The article by Gehrmann, Hiebel, and Simon (2017) from the class 3-green, presents a study on waste treatment in Germany for landfill disposal without a plan for energy recovery, such as the use of biogas. According to the author, the treatment of solid waste depends on certain objectives for defining its treatment, and one of them should be the possibility of obtaining energy to conserve resources.

Another possibility is the recycling of paper, plastics, metals, and glass, as well as the incineration of other products, ensuring the protection of humans and the environment (PENTEADO, 2011; LANDIN et al., 2016)

Bhander et al. (2010), from class 4-blue, present a computational model for solid waste management that assists the user in making decisions involving the separation and disposal of waste. This system evaluates waste collection, transportation, and treatment technology with greater ease.

Another study presented by Merrild, Larsen, and Christensen (2012), from class 5-pink, highlights that the results of the solid waste management system show environmental benefits when recycling paper, glass, steel, and aluminum instead of incinerating them. For cardboard and plastic, the results were more uncertain, depending on the level of energy recovery at the incineration plant.

In contrast, the results of the textual analysis of the selected articles regarding Bangladesh, Mexico, Colombia, Cuba, and Chile (ROFIQUL ISLAM, HANIU & FARDOUSHI, 2009;

SILVA et al., 2006; ARIAS & AGUDELO, 2005; GOICOCHEA-CARDOSO, 2015; MOVILLA-QUESADA et al., 2017) demonstrate that the topics are more related to aspects of deposition, decomposition, classification, awareness campaigns, and solid waste management.

Also from class 4-blue, we highlight the article on solid waste management by Goicochea-Cardoso (2015) in Cuba, which presents an environmental management model for the handling of domestic solid waste in the city of Havana, taking into account the life cycle of waste, environmental management instruments, and the socioeconomic context.

On the other hand, the work by Silva et al. (2006), from class 2-yellow, in Mexico, highlights the need for defining environmentally safe areas for waste disposal, such as sanitary landfills.

Regarding the types of landfills, Albuquerque (2011) highlights common landfills, or open dumps, and controlled landfills. Common landfills, or open dumps, are those where solid waste is disposed of improperly, that is, it is dumped on the ground without any treatment. Therefore, they are the most harmful to the environment and human health.

According to Costa and Ribeiro (2013), sanitary landfills can be summarized as "a technique for disposing of urban solid waste on the ground without causing harm to public health and safety, minimizing environmental impacts."

However, sanitary landfills also have some disadvantages, such as the generation of characteristic odors, the possibility of exposure and risks to workers, the need for large areas for the project, and resistance from the surrounding community, a phenomenon internationally known as Not in My Back Yard (NIMBY) (PORTELLA & RIBEIRO, 2014).

Among the works selected in our study, the one by Arias and Agudelo (2005), from class 2-yellow, in Colombia specifically addresses the decomposition and stabilization of solid waste. This study demonstrated that environmental factors, including the moisture present at the site, are responsible for the stabilization of waste, but do not interfere with the acceleration of decomposition. The study also emphasized the importance of covering exposed waste to prevent the generation of leachate.

Another highlight of our results is the work by Gulloso and Vega (2011), which dealt with the collection and classification of solid waste, class 1-red. This study observed that environmental management not only involves the discussion and classification of solid waste but, above all, focuses on awareness campaigns that can contribute to minimizing the problem and mitigating environmental impacts.

Environmental education constitutes a process that contributes to the development of skills, allowing the modification of attitudes towards the environment (MINISTÉRIO DO MEIO AMBIENTE, 2019). It can contribute to changing human behavior towards nature, aiming to meet current and future needs, in order to promote a sustainable development model (VIANA, BARROS & SOARES, 2016).

According to Damato and Romanini (2010), from class 2-yellow, there are numerous landfills along the highways of São Paulo state (SP-157 Mogi Mirim Sanitary Landfill; SP-191 Araras Sanitary Landfill, SP-352 Itapira Sanitary Landfill, SP-147 Mogi-Mirim, Limeira, and Piracicaba Sanitary Landfill, SP-215 Casa Branca, Porto Ferreira, and São Carlos Sanitary Landfill, SP-330 Araras, Pirassununga, and Porto Ferreira Sanitary Landfill), which cause significant environmental impact in the regions where they are located.

Grimberg (2004), from class 4-dark green, discusses that in solid waste management, it is necessary to distinguish three groups of social actors that are interconnected in solving the problem: 1) the public authorities, who can establish public policies for waste management and taxation of the production chain; 2) the population, which needs to be made aware of the benefits of reducing discarded waste and recycling; and 3) the production chain, which can develop strategies and tactics for managing the process of returning packaging to the production cycle.

Regarding the Pontal do Paranapanema, no specific studies on solid waste disposal on highways were found. However, five studies involved waste disposal management in cities within the Pontal do Paranapanema region (LEAL et al., 2002; GONÇALVES, 2009; CANTÓIA & LEAL, 2011; SAMPAIO, TROMBETA & LEAL, 2014; MARIA et al., 2014)

Our results also revealed that the key points of mitigation, prevention, and compensation actions referred to specific municipal legislation, incentives for cooperatives, the implementation of selective collection, and public awareness, indicating the need for optimization of research in this area.

The research by Maria et al. (2014) highlights the absence of a master plan, environmental zoning, and lack of environmental awareness. Supporting this study, the research by Sampaio, Trombeta, and Leal (2014), from class 5-blue, conducted an evaluative study with technical visits to waste disposal areas, using a questionnaire for municipal government managers and interviews with urban cleaning system employees. Their results highlighted the existence of a Plan that provides for the implementation of selective collection with the inclusion of recyclable material collectors; however, so far, there are no actions to realize the proposal. Thus, according to Maria et al. (2014), it is necessary to plan actions with all the steps for the implementation of the Plan in order to improve environmental management and socio-environmental quality.

These results indicate that environmental management on highways should consider planning aligned with the municipality's master plan as an important tool to evaluate alternatives and local characteristics, optimizing less harmful scenarios for the environment.

Currently, many public and private initiatives recognize and seek more sustainable measures in their actions, aiming to achieve development that meets present needs without compromising the ability of future generations to meet theirs—a widely used definition of sustainable development (HOLZMANN, 2019).

The implementation of cooperatives and/or selective collection programs are mechanisms that integrate the community and optimize environmental protection actions. Additionally, they are essential for social development, improving the working conditions of waste pickers, who are the agents of this process, as the income obtained from the work is divided equally among the members, fostering socialization and cooperation (FROTA et al., 2015).

The article by Nascimento et al. (2018), from class 1-red, presents that planning instruments capable of promoting development with economic growth and ecological prudence were implemented at the study site.

Additionally, our study analyzed the research by Contóia et al. (2011), from class 4-dark green, who collected data in a municipality of the Pontal do Paranapanema to identify the

Waste Quality Index (WQI) and the Compost Quality Index within a cooperative. Their results demonstrated that there is heterogeneity in the information regarding the organization and functioning of cooperatives.

Cantóia and Leal (2011) further assert that this fact is closely linked to the model of management and administration of urban solid waste adopted by the municipalities. This results in improved waste collection and disposal conditions, as well as generating work and income for former workers who lived in dumps, making them essential agents in this process.

Another study we analyzed was developed by Leal et al. (2012), from class 7-pink, which revealed the importance of the organization of cooperatives aiming to analyze part of the municipal management of urban solid waste, with an emphasis on a cooperative of workers handling recyclable materials. The study concluded that the greatest weakness of this process was related to the informality of the work, difficulty in receiving payments, and the lack of appreciation for the workers.

Among the studies developed in the municipalities of Pontal do Paranapanema (LEAL et al., 2002; CANTÓIA & LEAL, 2011; SAMPAIO, TROMBETA & LEAL, 2014; MARIA et al., 2014), the study by Gonçalves (2009), from class 3-light green, stands out. It involved the daily monitoring of sorting activities carried out in a cooperative to observe the procedures used in selective waste disposal. Essential points revealed included the need for support to the cooperative, planning of new selective collection sectors, implementation of educational campaigns and an internal management system, as well as increasing the number of positions for waste pickers.

Our findings revealed that three specific studies on environmental management have already been conducted on other highways in the country, not those of Pontal do Paranapanema, indicating the importance and relevance of the topic for this region. In this regard, the three studies, from class 7-pink, addressed environmental management as a tool for prevention and handling of solid waste.

Menezes et al. (2016) conducted solid waste collection along the margins of the BR-116 highway (km 91, 97, and 98) in the State of Rio de Janeiro, highlighting the need for investment in monitoring and permanent maintenance, as well as the execution of essential works to mitigate impacts. This somewhat corroborates the key points of mitigation actions found in the studies of the Pontal do Paranapanema region, which emphasized the implementation of selective collection and public awareness.

On the same highway (BR-116) but now in the State of Rio Grande do Sul, BR-040 in Juiz de Fora, and BR-122, and on the Anchieta-Imigrantes System, Mellone, Santos, and Shibao (2013) highlighted the use of asphalt mix incorporating ground tire rubber as an environmental management strategy that combines economy and safety with environmental benefits due to recycling.

Finally, the work by Damato and Romanini (2010) on highways in the State of São Paulo, managed by the Concessionária Intervias, evidenced a significant increase in the volume of waste in the months of January, February, and July, influenced by school holidays, with an increase of more than 100% in the waste collected over a year, indicating the need for public awareness.

5 CONCLUSION

The Systematic Literature Mapping (SLM) method proved to be effective in establishing the situational diagnosis of the publications, and it can be an initial strategy for further in-depth study of the subject through the Systematic Review method. It should be noted that the Textual Analysis method also proved to be an excellent research tool by providing integrated and visual construction of results.

The analysis revealed that highways have many impacts as environments for waste propagation due to transportation and the presence of landfills. The SLM allowed for the establishment of a situational diagnosis of the main publications, highlighting actions for the prevention, mitigation, and compensation of environmental damages that can affect the environmental and socioeconomic balance resulting from the disposal, management, transportation, deposition, and/or reuse of solid waste.

More environmental studies on highways are necessary. These studies can become tools for technically evaluating the prevention, mitigation, and compensation of environmental damages that may affect the ecological and socioeconomic balance resulting from highway implementations.

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