GIS mapping of Allochthonous Marine Litter across the Brazilian Amazon Coast

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Abstract

The Amazon coast is vulnerable to solid waste pollution, which can lead to the degradation of its ecosystems and affect its biodiversity. The debris that reaches this coast has different origins and sources, with international waste coming from other countries through mainly sea-based sources. Characteristics and dynamics of litter have been studied through monitoring to establish mitigation strategies. However, there is still limited information on international waste in the region, so this work aims to map allochthonous marine litter using geographic information systems (GIS) to monitor its distribution in four municipalities of coast of Pará. The methodology includes the design of a georeferenced ArcGIS Survey123, international waste collection in the field, processing of the litter in the laboratory, and, finally, integrating the data obtained and designing an interactive map viewer. The online dashboard presents descriptive statistics of all data collected on the eight beaches of interest. In total 577 items were collected, and the characterisation led to the identification that the international litter comes mainly from Africa and Asia. There is a high incidence of plastic waste, especially mineral water bottles. The study gives visibility to a problem that affects the socio-cultural and environmental value of the region. The visual presentation of the data provides an engaging and simplified overview of allochthonous litter on beaches in Pará, allowing for adequate dissemination and awareness of international waste dynamics.

1. Introduction

Marine-coastal zones represent a areas of great interest for their capacity to provide diverse ecosystem services including provisioning, regulating, cultural, and supporting services (Solé Figueras et al., 2024). They are also of great scientific, commercial, and cultural value, owing to their biodiversity and because they are home to native communities with unique identities and knowledge (Ullah et al., 2024). However, they are vulnerable environments, threatened mainly by global climate change and environmental pollution.

The litter that reaches the seas and coasts is varied and comprises different materials (Andriolo and Gonçalves, 2024), however, around 80% of the litter is derived from plastic (Morales-Caselles et al., 2021). Litter is a major concern and negatively influences coastal marine environments by compromising the resilience of ecosystems to climate change, with the potential to increase adverse effects on biodiversity and ecosystem services (Lincoln et al., 2022). They also pose a risk to fisheries, and navigation and affect coastal landscapes, with the potential to impact tourism, heritage values, and therefore the economy of coastal communities (Beaumont et al., 2019).

Litter has different origins and sources, referring to where the debris originally came from before it became marine litter and the specific point at which it enters the environment (Assis et al., 2023). Most of the litter entering the oceans arrives mainly from land-based sources such as runoff, industrial, agriculture, and construction activities (Meijer et al., 2021; Santos et al., 2024),

and marine sources such as shipping, fishing, and offshore installations (IUCN, 2024). It is estimated that around 8 million metric tons of plastic are dumped into the ocean each year (Jambeck et al., 2015), constituting a threat that requires the implementation of mitigation strategies. Knowing the sources and origin of litter is of great importance to generate plans and establish strategies in favour of the conservation of marine-coastal ecosystems. This is where systematic monitoring acts as a tool that not only allows the identification of the origin, possibles sources and characteristics of marine litter but also serves to understand the dynamics and impacts on the different ecosystems.

Systematic monitoring of marine litter is often carried out using different traditional methods such as field-filled table forms (Rees and Pond, 1995). However, with technological advances, several studies propose the use of geographic information systems (GIS) and real-time dashboards to monitor coastal pollution. The implementation of GIS can facilitate the process of waste collection, identification, and geo-referencing. There is a guidance framework on the exclusive use of mobile applications in monitoring (Schattschneider et al., 2020). There is also a study analysing the sources and origin of waste using a mobile application in Vietnam (Bui et al., 2024). In addition, the proposal of an observation model would allow the detection, classification, and visualisation of plastic waste (Basthikodi et al., 2023).

In addition, several studies have been conducted to monitor environmental variables, using geo-referenced ArcGIS

Survey123 and real-time viewers in different research areas (Silva et al., 2021; Velastegui-Montoya et al., 2023). In this context, this study proposes a mapping methodology using GIS tools for the monitoring of international waste on the Brazilian Amazon coast. The information obtained will contribute to the scientific knowledge of the study area and the dissemination of the problem to local communities and decision-makers.

2. Study Area

This study considers beaches on the Atlantic coast of the state of Pará, located in the municipalities of Augusto Corrêa, Bragança, Salinópolis, and Viseu, located in the northeast of the state (Figure 1). According to the Köppen-Geiger climate classification system, the region experiences a tropical monsoon climate (Am), characterised by two well-defined seasonal seasons, the dry season and the rainy season. In the state of Pará, the rainy season occurs between January and May, while the dry season occurs between July and December (Corrêa-Neto et al., 2024). Air temperature values range between 22 °C and 34 °C (Cordeiro et al., 2017) and the accumulated annual rainfall is between 2250 and 2500 mm, depending on the intensity of climatic events (Assunção and Quinteiro, 2023).

The selected sites are characterised by sandy beaches, rocky outcrops, dunes, tidal channels, mudflats, and typical coastal vegetation such as herbaceous restinga, and mangroves (Lopes et al., 2024; Pedrini et al., 2021). The selected sites are under different levels of protection, Vila de Perimirim beach (Augusto Corrêa), Vila dos Pescadores beach (Bragança), and Apeú Salvador beach (Viseu) are located within Marine Extractivist Reserves (RESEX in Portuguese) and are considered rural beaches with limited access and little tourist traffic. The beaches of Ajuruteua, Farol (Bragança), Atalaia, Maçarico, and Corvina (Salinópolis) are outside the RESEX and have a greater anthropogenic influence, especially during the holiday season.
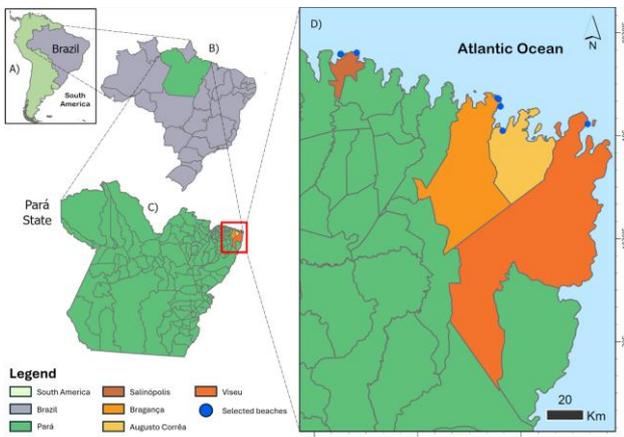

Figure 1. Study area with A) South America; B) Brazil States C) Pará State; D) Municipalities and beaches selected for the Paraense coastline.

3. Materials and Methods

The methodology of the study (Figure 2) was structured in three sections: 1) ArcGIS Survey123 construction and design; 2) Fieldwork and processing of the collected data; and 3) Import of the processed data to generate the dashboard.
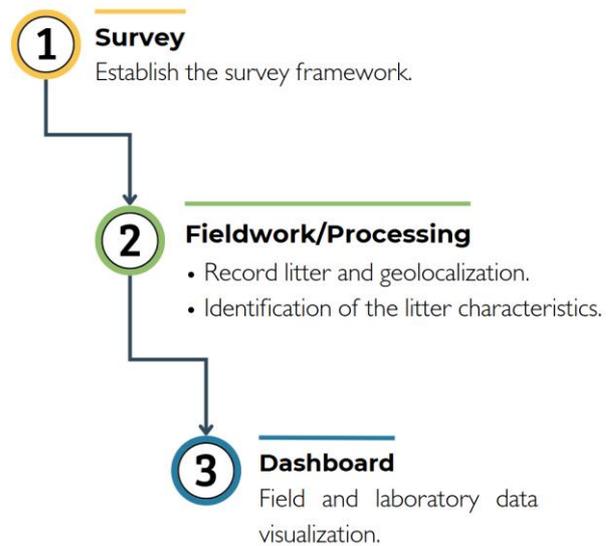

Figure 2. Methodological approach.

3.1 Survey design

A field form was created in the ArcGIS Survey123 platform to record the field data with their respective georeferencing. The survey included the details of the researcher who conducted the collection, a unique code for each residue collected, and photographic evidence of the litter for later identification. Additionally, the survey was configured to capture the geolocation of the debris automatically once the questionnaire was completed. The questionnaire fields are detailed in Figure 3.
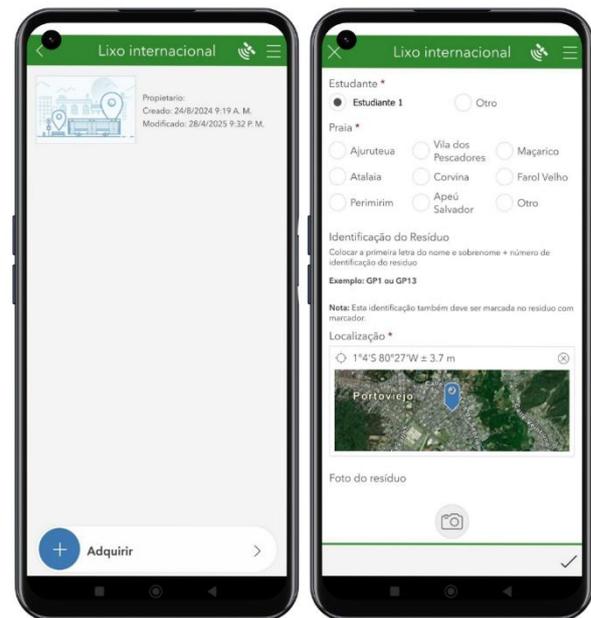

Figure 3. Screens of the ArcGIS Survey123 in the application

3.2 Fieldwork and data processing

In order to characterise the international waste on the beaches of northeastern Pará, several field trips were carried out with a group of researchers who collaboratively collected the characteristics of the litter found using their smartphones. During the field trips, the litter was collected, recorded, and stored for subsequent analysis in the laboratory.

In the area of interest, litter was collected covering at least 1 kilometre of the beach from the most recent tide line to the vegetation closest to the shore, as litter tends to get trapped in vegetation (Brennan et al., 2018). The use of the ArcGIS Survey123 application on the smartphone meant that it was not necessary to rely on an internet connection for data collection, however, the pre-designed form must be downloaded onto the smartphone before the field trip. All collected litter was transported to the laboratory for characterisation.

The characterisation process consisted of the visualisation of the visible identifications on the labels, specific reliefs, or markings present on containers and lids, which allow the continent and country of origin of the waste to be recognised. Additionally, the waste was categorised according to its material, type of content, and product brand. If none of the above variables could be identified, the waste was categorised as unknown. The information processed in the laboratory was added to a matrix recorded in Excel (Version 2504).

Finally, the georeferenced data captured in ArcGIS Survey123 and the characterisation data recorded in Excel were imported into ArcGIS Pro (Version 3.5) for merging. As a result, all the data were obtained in a single matrix (Table 1), this matrix was exported to a web layer in the ArcGIS cloud.

Field	Detail
COD	Specific code for the residue
Date	Day of data collection
Photo	Photographic evidence of the litter
Location	Municipality
Specific site	Beach of interest
Continent	Manufacture continent of the residue
Country	Manufacture country of the residue
Brand	Product brand registered of the residue
Content	Type of content of the litter
Material	Type of material of the litter

Table 1. Variables and details obtained after merging field and laboratory data

3.3 Dashboard

To facilitate the visualisation and interaction of researchers with the international waste data, a dynamic map viewer was designed and linked to the data hosted on the Web Map containing the information in Table 1. The map viewer was created in the ArcGIS Dashboards application, which allows visualisation and filtering of the project data, as well as free navigation of the international waste map, without the need for the user to be an expert in GIS (Geographic Information Systems), allowing the entire community interested in this information to interact with the information presented on the dashboard (Mora-Araus et al., 2021).

In this way the dashboard allows internal and external users of the project to: 1) select the municipality and the specific beach for which the data will be analysed; 2) visualise the distribution of international litter along the beaches using the base map; 3) distinguish the abundance of litter. The information is available in a general and specific format for each municipality and beach; 4) explore the quantitative representation regarding continent, countries, type of material, type of content, and markings on each of the beaches.

4. Results and Discussion

The dashboard (Figure 4) shows the distribution of international waste along seven beaches located in three different municipalities on the Amazonian coast of Brazil. The data collected allows us to identify the abundance and possible areas with the highest incidence of international waste, as well as to classify the litter according to region of origin, main compositional materials, and manufacturing brands. In the seven selected beaches, 577 wastes were collected, corresponding to 550 full containers and 27 lids.

The analysis of the results shows that the main contributors of litter are the continents of Africa and Asia, with all the beaches sampled showing litter from these two continents. In addition, there was no data on litter originating from Oceania and some of the beaches (Atalia, Ajuruteua, Farol, Maçarico, Perimirim) did not present waste originating in America or Europe. Also, one of the most important contributors was China, which could be associated with its wide distribution of ships around the world and its raw material production capacity. All bottle caps collected belong to the continent of Africa. The relationship between the proportion of waste coming from the African continent, especially from West Africa such as Mauritania, Senegal, and Morocco, could be because the debris travels through the currents of the Atlantic Ocean until it reaches the coast of Brazil (Assis et al., 2023; Brabo et al., 2024).

In the pie chart showing the distribution by material type, it can be seen that more than 90% is single-use plastic residues and there are few samples of glass, cardboard, and metal, which is associated with the high durability and low degradability of plastic (Twagirayezu et al., 2024). In addition, the higher presence of plastic may be due to its developed global manufacturing and consumption (Balu et al., 2022; Geyer et al., 2017). This material is widely used in different industries, especially in product packaging (Babaremu et al., 2023).

More than 80% of the waste found corresponded to PET bottles of mineral water. Additionally, most of the litter corresponds to products from the food industry (juices, soft drinks, tea, etc.). Globally, approximately 60% of the plastic produced for packaging is used in the packaging of food and beverage products (Groh et al., 2019). Although plastic is a great ally of this industry, effective measures need to be put in place to mitigate its negative effects. However, some companies have a limited approach to the life cycle of plastic and their perception of plastic pollution (Phelan et al., 2022).

The five most abundant brands are Nongfu Spring and Master Kong from China and Tijirit, Tayba, and ES-SAVI from Mauritania, which correspond to mineral water bottles. These five brands were found at all collection sites. Chinese marks have been observed in other studies in different regions of the world such as South Africa, the Chagos Archipelago, and the Galapagos Archipelago (Benito-Kaesbach et al., 2024; Ryan et al., 2021; Savage et al., 2024). One of the main exporters of water in the world is China, however, imports to South America are insignificant (Ryan et al., 2019), therefore, it is inferred that the source of contamination is maritime due to the remoteness of these two continents.

The percentage of litter that is marked as unknown are those that did not present identifiers, so no origin, brand, or content could be attributed to them. However, they were collected as an international waste as they did not present the manufacturing characteristics of the national market. On the Amazonian coast of
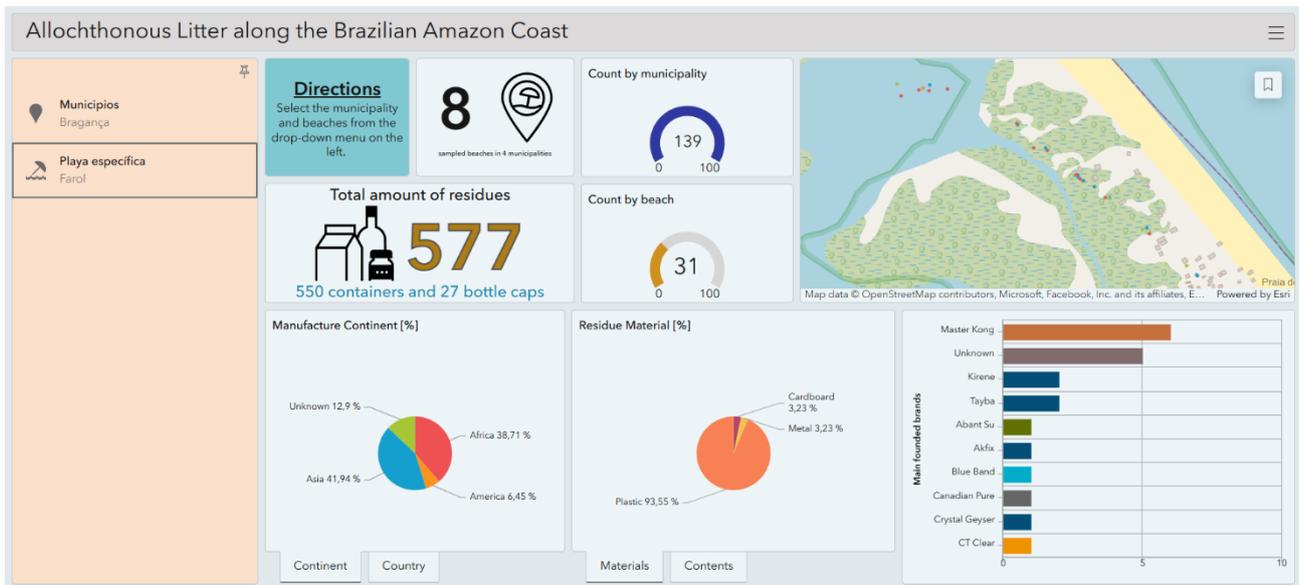
Figure 4. Dashboard of Allochthonous Marine Litter along the Brazilian Amazon Coast (https://www.arcgis.com/apps/dashboards/394af38bb1e6461faa8f695a38606880)

Pará, the market for water and other beverages is dominated by industry in the region, which leads to the inference that these wastes are not generated locally. Some of the beaches in Pará have limited access or are remote; nevertheless, they hold significant environmental, cultural, and economic importance. Therefore, the presence of international litter could amplify the impacts produced by environmental pollution.

As marine litter is an international issue and spreads across different environments, it is possible to find it in areas where there is little or no anthropogenic influence. Therefore, debris monitoring using GIS applications for capturing geo-referenced data aids data collection in rural areas or remote and deserted islands, as these are areas of difficult access and limited internet coverage. Furthermore, the spatial representation of the data through a dashboard allows for simplified data visualisation without the need to be a GIS expert (Figure 4) (Ching-Ávalos et al., 2021). This factor can help communities and decision-makers in establishing waste management strategies and support the dissemination of results regarding international waste.

The implementation of online questionnaires or mobile applications (apps) to monitor marine litter is widely used to enhance the data collection process. Various global initiatives promote citizen science through mobile apps, enabling efficient data collection on marine pollution (Peacock et al., 2025). In Brazil, the *Mar Limpo* (Oceânica) app allows users to classify and quantify the type of litter they find on beaches, as well as validate other users' records to map the waste that reaches the Brazilian coast (Oceânica, 2025). At the global level, *Clean Swell* and *Marine Debris Tracker* apps enable users to record waste and monitor its characteristics (Marine Debris Tracker, 2025; Ocean Conservancy, 2025). These apps also help users to explore data obtained by others through graphs, expanding local knowledge about marine pollution. For this study, a specific ArcGIS Survey123 and ArcGIS Dashboard were designed to summarize the information about international litter. The survey recorded specific variables to reduce post-processing time by georeferencing the waste collected by the team and subsequently providing an interactive visualization of the main findings.

5. Conclusions

This study has developed a dashboard to analyse and visualise data associated with the incidence of international litter on the Amazonian coast in the northeastern region of the Brazilian state of Pará. The dashboard integrates data from field monitoring and data from laboratory processing. In addition, it includes functions such as a drop-down box to select the municipality and beaches studied and present quantitative graphs on the different variables (origin, type of waste, brands). Users can use the map viewer to observe the distribution of waste along the beach. The results of the characterization and processing are displayed on a page published online to provide a more interesting and easy-to-understand visualisation, which can also be updated with new study areas.

Future studies can explore the application of georeferenced ArcGIS Survey123 to integrate the data collection and litter characterisation phases in the field. In addition, citizen participation approaches to data collection could be implemented, so that there would be continuous sample acquisition, with greater spatial and temporal coverage. This strategy would allow for the direct involvement and participation of coastal communities, which would strengthen the strategies for the conservation of marine and coastal ecosystems.

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