Microplastic contamination in bathhouses in the middle Amazon region, Itacoatiara, Brazil

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Abstract

The number of investigations has increased worldwide about the abundance and distribution of microplastics in different water bodies and biota. This study investigated microplastic contamination in bathhouses in the Middle Amazon, in Itacoatiara, AM, Brazil. A total of 202 microplastic particles were recorded in the five investigated areas used for recreation. These results indicate no significant difference in the number of microplastic particles between bathhouses ($KW = 7.4805$; $P = 0.1126$). The size of the microplastic particles differed significantly between the bathhouses ($KW = 40.9582$; $P = 0.0001$). Both blue and red microplastic particles were recorded, with blue particles being the most abundant. The microplastic particles were in the form of fibers and fragments. The number of microplastic particles ($U = 7.4686$; $P = 0.0001$) was significantly different between the areas within and adjacent to the bathhouses; however, the size of microplastic particles were not significantly different in the areas within and areas adjacent to the bathhouses ($U = 0.6505$; $P = 0.5154$). There was no significant correlation in the bathhouses between their frequency of use and contamination (number of microplastic particles) ($r_s = 0.4472$; $P = 0.4502$). The results of this study indicate that microplastics are present in the bathhouses of the Middle Amazon and that contamination in areas used for recreation is significantly higher than in areas not used for this purpose.

Introduction

Despite a growing number of investigations around the world on the abundance and distribution of microplastics in different water bodies and biota, relatively few studies have been conducted in Latin America (Kutralam-Muniasamy et al. 2020). In Brazil, as in other countries, most studies are related to the marine environment (Nobre et al. 2015; Carvalho and Neto 2016; Olivatto et al. 2019). Although some studies have recently paid attention to other environments (Garcia et al. 2020; Santos et al. 2020; Bertoldi et al. 2021), the monitoring of microplastic contamination in freshwater ecosystems still needs more attention. (Castro et al. 2018).

Different factors are responsible for the composition, distribution, and number of microplastic particles in a given environment. For Jaubet et al. (2021), a high level of recreational activities is a factor that increases the number and morphotype of microplastics. In recent years, the use of water in Brazil for recreational activities has increased, mainly due to the interest in activities related to the natural environment, rather than modern life in the center of large cities (Porretti and Pessoa 2021). According to Lopes et al. (2014), recreational facilities lack research and monitoring plans to assess bathing conditions, especially in freshwater environments, which increases bathers' contact with contaminated water.

On the Atlantic coast of northeastern Brazil, marine debris with different concentrations and sizes was observed, indicating recreational activities as the second predominant source of its generation (Cavalcante et al. 2020). Wu et al. (2021) observed that recreational beaches have more microplastic particles, evidencing that the level of contamination by microplastic particles in these recreational areas is directly related to tourist activities. Jeyasanta et al. (2020) found a correlation between the concentrations of meso and microplastic and the degree of recreational activity. On a macrotidal beach on Brazil's northern coast, recreational tourist activities were found to be a contributing factor in the generation and distribution of microplastic particles along the coast (Martinelli-Filho and Monteiro 2019).

Microplastic particles are an environmental problem with unknown ecological impacts to small species in freshwater and marine ecosystems (Horton et al. 2017a). Negative effects include the penetration of these ingested particles into the circulatory system of the bivalve *Mytilus edulis* (Linnaeus, 1758) (Browne et al. 2008), in addition to the transport of microplastic from the stomach to the digestive gland causing tissue changes and inflation of the same bivalve (Von moos et al. 2012). The transmission of these particles in the food chain was also demonstrated by Farrell and Nelson (2013), who recorded microplastic particles in the stomach and tissues of the crab *Carcinus maenas*(1758) after feeding on contaminated bivalves. The negative effects of microplastics on the environment are numerous, even interfering with natural soil processes, such as nutrient cycling and the decomposition of organic matter (Lavelle 1997; Sampedro et al. 2006; Horton et al. 2017b).

In Brazil, recreational activities have been described as a contributing factor in the generation and the number of microplastic particles (Cavalcante et al. 2020), as well as in other countries such as Singapore (Ng and Obbard 2006), Uruguay (Lozoya et al. 2016), Iran (Naji et al. 2017), India (Dowarah and Devipriya 2019; Sathish et al. 2019; Jeyasanta et al. 2020), Finland (Scopetani et al. 2019), and China (Wu et al. 2021). Thus, to provide information on microplastic contamination in freshwater environments, this study analyzed microplastic contamination in sediments from freshwater bathhouses used for recreation in the middle Amazon, Brazil. In areas used for bathing and adjacent areas that are not used for recreation, the abundance, size, type, shape, and color of microplastic particles were compared. In addition, the packaging of plastic waste in the bathhouses was evaluated.

Material And Methods

Study area

This work was conducted between October and December 2021 in five areas used as bathhouses and adjacent areas not used for bathing in the middle Amazon, municipality of Itacoatiara, Amazonas, Brazil (S 03°08'19.9"; W 58°27'32 .5"). The bathhouses evaluated – Ada, Campo, Carú, Km-13, and Sofrência – are all located along Highway AM-010 (Fig. 1). These are in lowland areas, which periodically flood and dry out once a year (Bittencourt and Amadio 2007). The Km-13, Ada, and Campo bathhouses have partial damming of water for recreational activities, while the Carú and Sofrência bathhouses are open for water circulation, without damming the water of the river people bathe in.

Sediment collection and separation of microplastic particles

In each bathhouse, 30 samples with 50 grams of sediment were collected, 15 in areas used for recreation, called areas of use (AU) and 15 in areas that are not used for recreation located upstream the rivers at least 500 meters from areas used for recreation, called adjacent areas (AA). Collections were performed using a stainless-steel spoon (5 cm surface sediment), and the sediment was carefully placed in glass containers, sealed and labeled. In the laboratory, the sediment was separated from the microplastic particles as described below.

In a beaker containing 50 g of sediment, 200 mL of water solution saturated with NaCl was added, then it was shaken, and the supernatant transferred to another beaker. This process was repeated three times to ensure maximum removal of microplastics. After this procedure, 40 mL of H_2O_2 was added to degrade the organic matter. The solution was placed in an oven at 60 °C for 48 h and stirred twice a day to accelerate the degradation of the organic matter. After this procedure, the saline solution and the solution with H_2O_2 were vacuum filtered with filter paper (<5 μm), then dried at room temperature, following the methodology of Hanke et al (2013). After drying the filter paper, any particles with an unnatural appearance (due to color, shape, and dimensions) were counted and measured (mm) in a stereomicroscope coupled to a computer using the Motic 2.0 program. The color and shape of the particles were also recorded and classified according to Hanke et al. (2013).

The conditions of the bathhouses assessed in relation to the packaging of plastic waste

To verify the way in which plastic waste is disposed of in the bathhouses, a semi-structured questionnaire was applied to the owners of each bathhouse where the sediment was collected. The application of the questionnaire was approved by the Brazil platform, which is a unified national database of research records involving humans for the CEP/CONEP system, with Certificate of Ethical Appreciation Presentation – CAAE number 36331220.9.0000.5020. Altogether five people participated in the research, two men and three women between 37 and 70 years old. The questionnaire consisted of the following thirteen questions: 1- How often is the place open each week?; 2- Are there garbage cans? If “yes” answer question 3; 3- How many garbage cans?; 4- Is the solid waste (garbage) collection service done by the municipal government or the bathhouse?; 5- How often is the solid waste (garbage) generated on the site collected?; 6- Is recyclable waste separated from the garbage on site?; 7- Does the owner collect the solid waste (garbage) left in the sand?; 8- Does the owner collect the solid waste (garbage) left in the water?; 9- In your opinion, what is the most common waste generated at the bathhouse?; 10- In your opinion, does the frequent consumption of food and beverage products on site result in a greater amount of plastic waste?; 11- Are alcoholic beverages consumed on site?; 12- In your opinion, after drinking alcohol, do users throw more solid waste (garbage) into the environment?; 13- Where is the final disposal of the solid waste (garbage) generated at the bathhouse?.

Data analysis

The size (mm) and number of microplastic particles obtained from sediment samples were submitted to the Shapiro-Wilk normality test. As the data did not obtain a normal distribution, non-parametric tests were used to compare data between areas. The Kruskal-Wallis (KW) test was used to compare the number and size of microplastic particles in the five bathhouses investigated. The Mann-Whitney (U) test was used to compare the number and size of microplastic particles in all bathhouses between areas of use and adjacent areas. The Spearman correlation (rs) was calculated to verify if there is a correlation between the number of microplastic particles and the frequency of use of the bathhouses. For all analyses, a significance level of $P<0.05$ was adopted.

Results

Contamination of bathhouses

A total of 202 microplastic particles were recorded in the five investigated areas used for recreation (Fig. 2). A greater number of particles were recorded in the bathhouses that dam the water (bathhouses: Km-13, Ada, and Campo) (Fig. 2). The average number of microplastic particles in the sediment samples of each bathhouse is provided in Fig. 3. In the bathhouses that do not retain water (Carú and Sofrência), the average number of microplastic particles was lower, although without a significant difference (KW = 7.4805; P = 0.1126). The size of the microplastic particles differed significantly between the bathhouses (KW = 40.9582; P = 0.0001), with the smallest mean size occurring in the Campo and Sofrência bathhouses and the largest in the Ada, Carú, and Km-13 bathhouses, regardless of whether the bathhouse had dammed water or not (Fig. 4). The smallest particle was recorded in the Campo bathhouse (0.150 mm) and the largest in the Ada bathhouse (4.909 mm).

Blue and red microplastic particles were recorded in the areas of use, with blue particles being the most abundant in all the bathhouses (Figs. 5 and 6). The shape of the microplastic particles were either fibers or fragments. In the Ada bathhouse, 48 fibers were found; in the Campo 30 fibers and 8 fragments; 31 fibers in the Carú; 51 fibers in the Km-13; and 34 fibers in the Sofrência bathhouse.

Comparing the areas of use and the areas adjacent to the bathhouses, the contamination by microplastics was higher in the areas of use (Fig. 7). In general, contamination was lower in adjacent areas (U = 7.4686; P = 0.0001) than areas used for recreation. There was no significant difference between the size of the microplastic particles in the areas within and adjacent to the bathhouses (U = 0.6505; P = 0.5154). In the adjacent areas, 2 red particles and 23 blue particles were registered, which were less abundant than in the areas of use. All particles from adjacent areas were fiber-shaped.

Evaluation of plastic waste packaging conditions

The interviews elucidated that the Ada, Campo, and Carú work from one to two days a week, Sofrência from two to three days, and Km-13 every day. There was no significant correlation between the frequency of use and contamination (number of microplastic particles) (rs = 0.4472; P = 0.4502) of the bathhouses.

The number of garbage cans used in each bathhouse is charted in Fig. 8, with the Carú bathhouse having the largest number of existing garbage cans, and only the Ada bathhouse had no cans. All the bathhouses reported that they collect waste left on the sand or in the water of the bathhouses. Every bathhouses except Campo separate the solid waste (recyclable waste) at the sites. The owners in the Ada, Campo, and Km 13 bathhouses collect the solid waste (garbage) left by bathers once a week, in Carú twice a week and in the Sofrência bathhouse three times a week. The municipality of Itacoatiara only collected the solid waste (garbage) directly at the Km-13 bathhouse. The owners of the other four bathhouses needed to take the waste to a municipal collection point.

Plastic was confirmed as the main type of waste in four of the bathhouses. However, in the Carú bathhouse, the most generated waste was metal, according to the bathhouse owners. Those responsible for each bathhouse stated that the frequent consumption of food and beverages on site results in more plastic waste. Alcoholic beverages are consumed at all bathhouses, and the interviewees from the Ada, Km-13, and Sofrência bathhouses stated that after the consumption of alcoholic beverage users throw more solid waste (garbage) into the environment. The owners of the Campos and Carú bathhouses responded that, in their understanding, users do not dispose of solid waste (garbage) in the environment with greater frequency. The final disposal of solid waste (garbage) generated in most of the bathhouses is the municipal dump. Only the Carú bathhouse conducts waste disposal in an open deposit in the local surroundings.

Discussion

Dammed water can be a potential source of microplastic accumulation (Zhang et al. 2015), and contamination can be significantly higher in these dammed areas than in open water (Watkins et al. 2019). In the present study, similar to the results of Watkins et al. (2019), all the bathhouses were contaminated with microplastic. The Km-13, Ada, and Campo bathhouses with dammed water were more contaminated than the Carú and Sofrência bathhouses, which were not dammed.

Although the bathhouses with dammed water contained more microplastics, there was no significant difference in the number of microplastic particles between the bathhouses investigated. This result may be related to several factors, such as the frequency of operation and the flow of people in each bathhouse. Furthermore, the number of microplastic particles can vary according to the hydrodynamic characteristics that define the erosive and depositional behavior of the sampled areas (Gerolin et al. 2020). All the bathhouses investigated in the present study are located in floodplain areas. The periodic flooding and seasonal drought that occurs once a year in these areas in the Amazon region (Bittencourt and Amadio 2007) is probably the main factor influencing contamination by microplastics and could decrease the number of particles in the environment. Hurley et al. (2018), who investigated riverbeds, reported up to 70% of microplastics stored in the bed were exported during the flood period.

In the bathhouses investigated, the size of the microplastic particles differed significantly. In other studies, high daytime temperatures (Zhang et al. 2016) and erosion (Gerolin et al. 2020) influenced particle size. Although not tested in the present study, the high temperatures in the Amazon region could contribute to the fragmentation of microplastic particles. However, the difference in size between the bathhouses may not have an exact explanation, as this phenomenon can occur in a variety of ways in the investigated areas without a specific reason for the different sizes recorded.

Red and blue microplastic particles were found, and the color may be related to different sources of anthropic generation. Microplastic particles can be identified by color and shape, which is why they differ from the prevailing environment (Alam et al. 2019). The most abundant fiber colors were blue and in a lesser quantity red, as also described by Piñon-Colin et al. (2018), who studied microplastics from sandy beaches of the Baja California Peninsula, Mexico.

Microplastic particles can have different shapes and are more often found in a specific shape (Waldschläger and Schüttrumpf 2020). The sediment samples analyzed in the present study had fibers and fragments, with the fiber format found more frequently. In another study on the sediments of Amazonian rivers, the fiber format was present not only in greater numbers, but in all samples analyzed (Gerolin et al. 2020). In the River Thames, UK, higher occurrences of fibers were also found, and this shape may be related to anthropogenic activities (Horton et al. 2017b). For Di and Wang (2018), the proportion of fibers in the sediments is relative, ranging from 33.9 to 100%, corroborating the results of this study. Almroth et al. (2018) stated that a common type of microplastic found in environmental samples is fiber, which is believed to originate from textile fabric. As bathing is a primary recreational activity in the bathhouses, the results observed in this study could come from clothing. Scopetani et al. (2020) said that contamination by textile fabrics is possible in different environmental matrices such as snow, ice, and sediment. The fragments found may come from breakage of larger plastic items such as packaging (Thompson et al. 2004; Ng and Obbard 2006; Zhang et al. 2016) but were found in smaller numbers and proportions than fibers in this study.

Recreational activities contribute to the generation of microplastic particles (Cavalcante et al. 2020), and these activities are related to the prevalence of microplastic, as observed by Dowarah and Devipriya (2019). The areas of use were considerably more contaminated than the adjacent areas that are not used for recreation, proving the anthropic effect in the contamination of microplastics in the bathhouses of the Central Amazon. As noted by Wu et al. (2021) at recreational beaches in Haichow Bay, China, where these activities were a potential factor in the release of microplastic particles.

Garbage cans used in natural environments are adaptations of urban models that aim to provide adequate places to dispose of solid waste, facilitating its handling for collection (Pontes and Mello 2013). All the bathhouses, with the exception Ada, had garbage cans, which demonstrates that most of the bathhouse owners were concerned with the cleanliness of the places. For Perrone (2021), the garbage can is the user's first contact with the collection system and is an item for collective use. It is important for sustainable attitudes, such as the proper disposal of solid waste (Lima et al. 2022), because solid waste generated daily and improperly stored is a risk factor for environmental contamination and to human health (Pozzetti and Caldas, 2019).

The collection of solid waste helps clean the environment subjected to anthropic activities and mitigates environmental impacts (Pujara et al. 2019). The owners of the bathhouses reported that they collect the solid waste left by bathers in the water and sand of the bathhouses. This action positively reflects in the visual aesthetics of the bathing areas and contributes to the collection of discarded solid waste, reducing the sources of contamination.

The separation of recyclable solid waste is another way to improve the management of useful materials and practice a circular economy (Gundupalli et al. 2017). In the bathhouses study, only the Campo bathhouse did not separate their waste. This can lead to the loss of recyclable materials, which could have been reintroduced into the production chain. The highest frequency of solid waste collection conducted by the owner during the week was observed at the Sofrência bathhouse, indicating the frequent consumption of food and beverages at this bathhouse. For Ribeiro and Mendes (2018), the consumption of single-use products is attractive due to the ease of disposal; however, associated with the incorrect disposal of solid waste, they are one of the world's greatest environmental problems.

Transport and collection of solid waste by public agencies are important and costly processes, due to the substantial use of vehicles and the intensity of labor (Jacobsen et al. 2013). In the KM-13 bathhouse, collection takes place in the bathhouse itself, which was accessible for the entry of the collection trucks, which facilitates the collection of solid waste compared to other bathhouses. Plastic is currently an environmental problem at a local and global level (Chen et al. 2021). In four of the five bathhouses investigated, plastic was the most generated waste, due to the frequent use of plastic packaging. These plastics can break down into smaller fragments, generating secondary microplastics that can be contaminants easily dispersed in the environment (Binetti et al. 2020).

The destination of municipal solid waste is an issue of increasing concern in society (Xue et al. 2015). It is also urgent that policymakers find efficient and sustainable ways to collect and dispose of the growing amount of solid waste (Salazar-Adams 2021). In the Carú bathhouse, the final disposal of solid waste takes place in a specific area far from the bathing area, as the municipality does not collect solid waste in the area this bathhouse. However, even if this solid waste was collected by the municipal collection truck, they would not go to a suitable location, since the municipal garbage dump in the open air is not an adequate alternative and the National Solid Waste Policy (PNRS) in Brazil indicates the choice of landfills as an environmentally adequate final disposal, having specific operational norms, to guarantee the protection of the environment and public health (Brazilian Solid Waste Policy 2010).

Conclusion

The results of this study indicate that microplastic particles are present in the bathhouses of the middle Amazon associated with recreational activities. Greater contamination was probably not found due to the characteristics of the sites, where periodic flooding occurs once a year and the particles are carried to other environments. Comparison of the areas used for bathing and adjacent areas not used for recreation indicated that recreation activities significantly increase the number of microplastic particles in the bathhouses. Authorities must inspect and order the proper disposal of solid waste, especially plastics in these bathhouses to suitable places that do not contaminate the environment. In addition, environmental education campaigns should be promoted to prevent the population from disposing garbage on the banks of the bathhouses.

Declarations

Ethical Approval

The development of this research, which had questionnaires applied to human, was approved by the regulatory body of Brazil, denominate "Plataforma Brasil", certificate of presentation of ethical assessment - CAAE number 36331220.9.0000.5020.

Consent to Participate

All the people involved in the research consented to the use of data from the questionnaires in this work.

Consent to Publish

Publication of data was also consented to by all participants.

Author contributions

All authors contributed to the study conception and design. The sample design and the general management of the research, as well as part of the scientific writing was prepared by the author Bruno Sampaio Sant'Anna. Data collection, analysis and scientific writing were performed by the author. The author Gustavo Yomar Hattori participated in the writing of the manuscript.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose

Availability of data and materials

All data and materials as well as software application or custom code support their published claims and comply with field standards.

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Figures

Figure 1

Location map of study areas. The Ada, Campo, Sofrência, Km-13, and Carú bathhouses, in the municipality of Itacoatiara, Amazonas, Brazil.

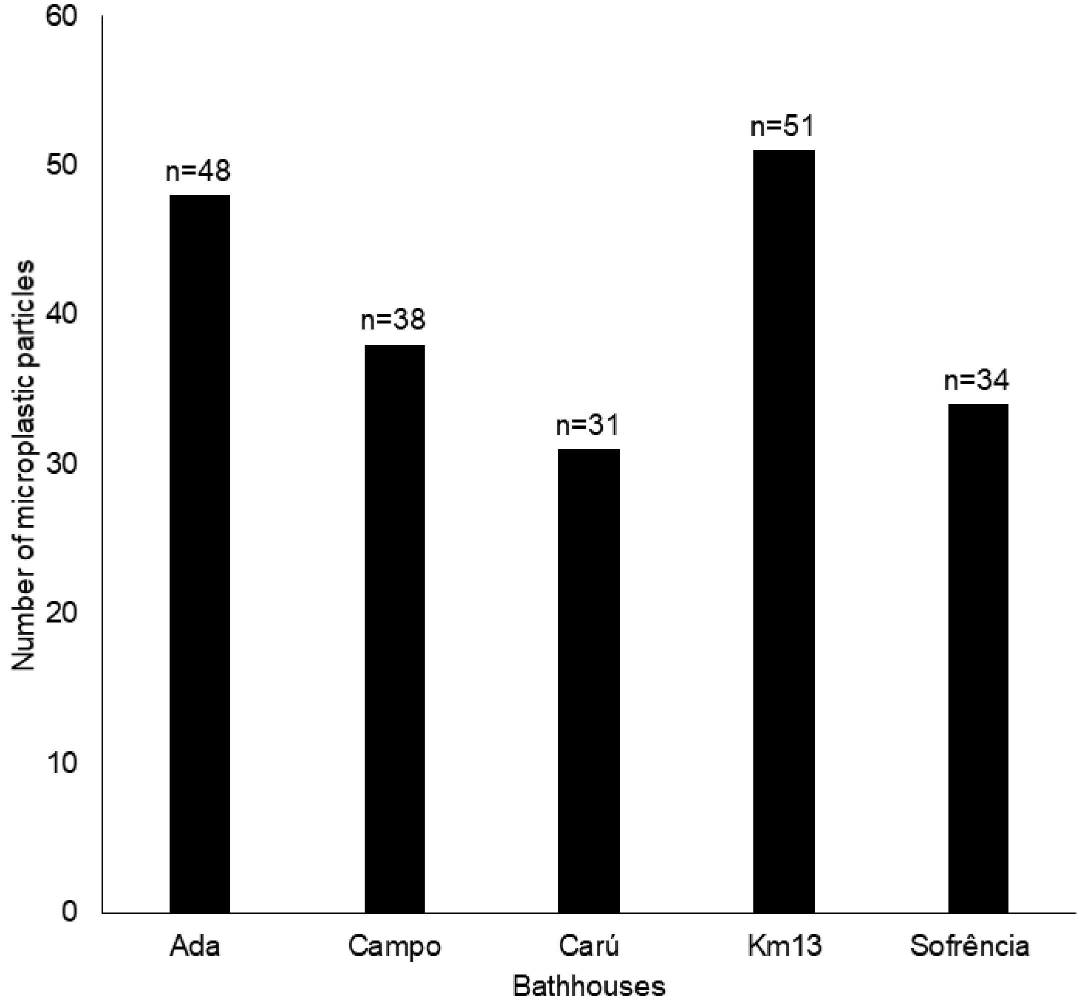

Figure 2

Number of microplastic particles from sediments collected at each sampling site at the bathhouses in Itacoatiara, Amazonas, Brazil.

Figure 3

Mean and standard deviation of the number of microplastic particles per sample taken in the bathhouses in Itacoatiara, Amazonas, Brazil.

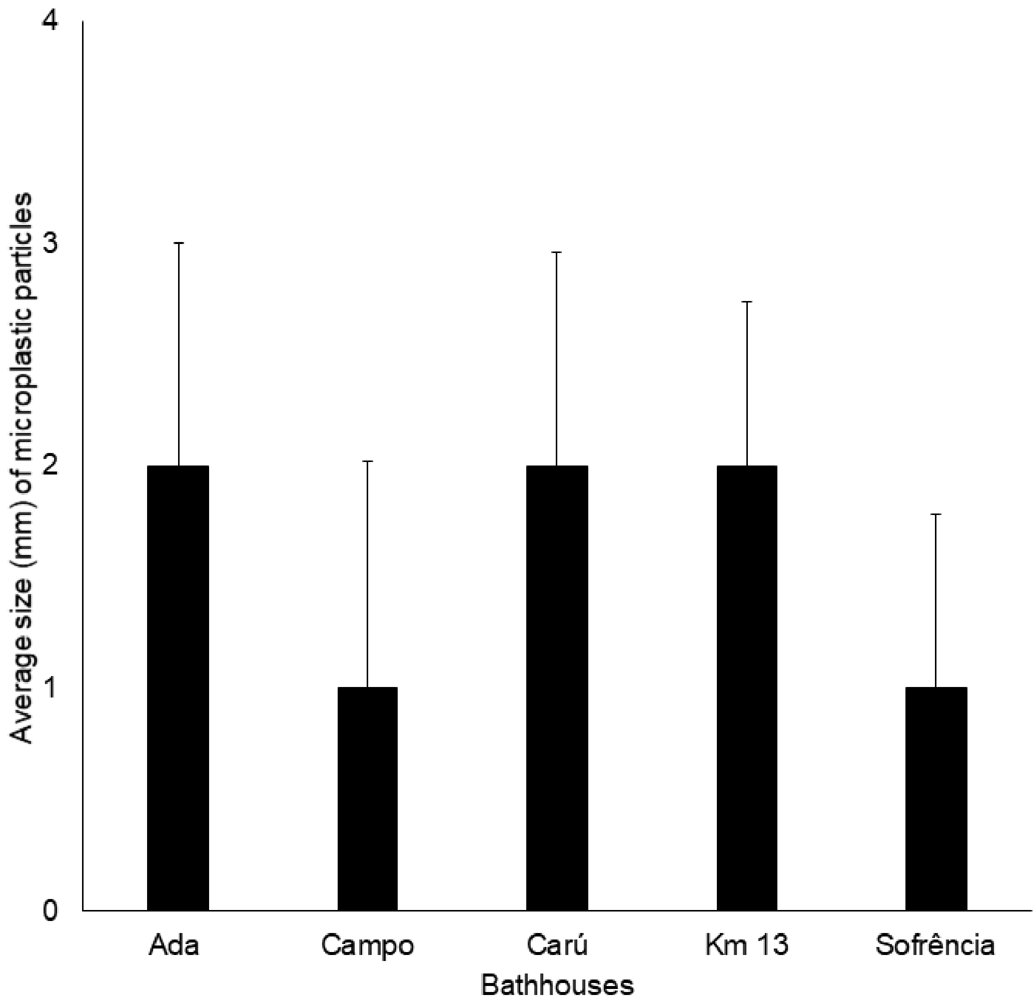

Figure 4

Mean and standard deviation of the size of microplastic particles in each bathhouse investigated in Itacoatiara, Amazonas, Brazil.

Figure 5

Number of blue and red microplastic particles in each bathhouse in Itacoatiara, Amazonas, Brazil. Blue (B) and red (R).

Figure 6

Images of microplastic particles recorded in the study areas, a- blue fragment, b and c-red fibers, and d-blue fiber. Scale bar = 0.5 mm.

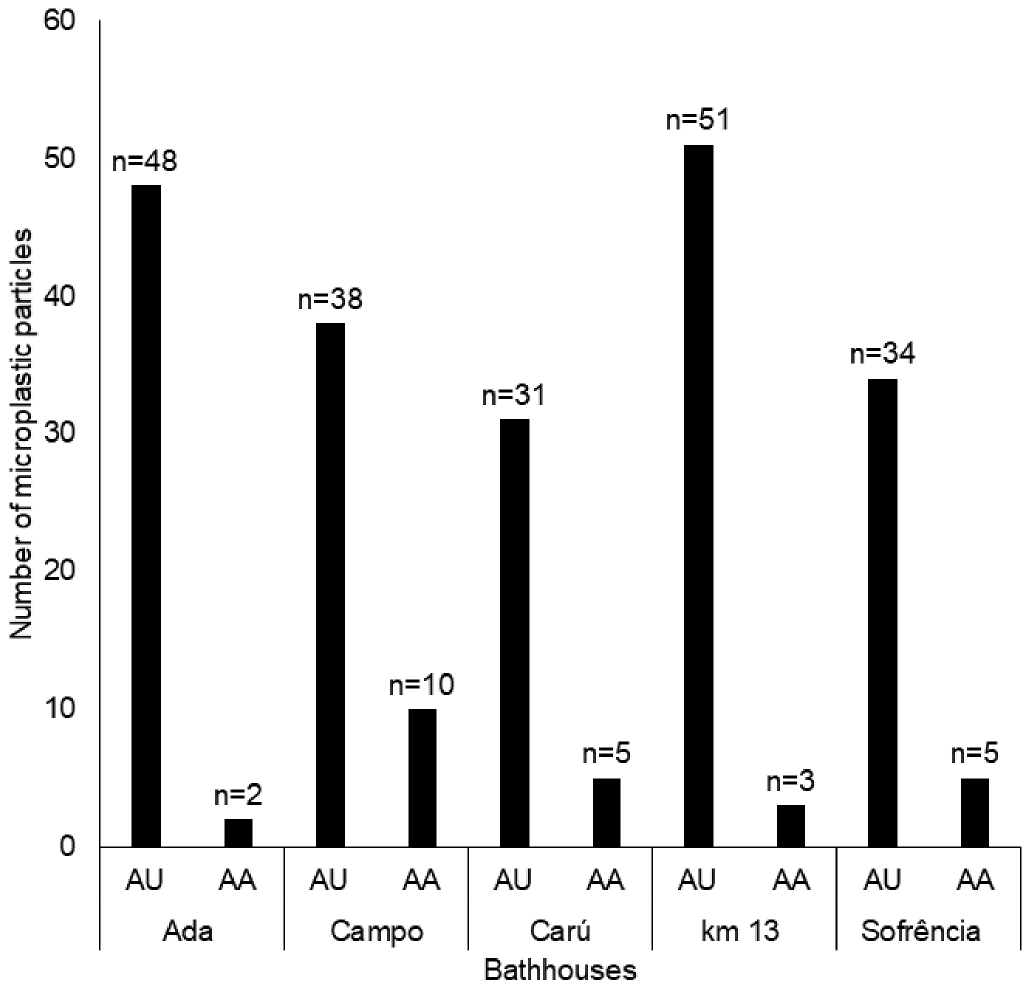

Figure 7

Number of microplastic particles recorded in sediment samples from areas of used for recreation (AU) and adjacent areas (AA, not used for recreation) from the bathhouses investigated in the municipality of Itacoatiara, Amazonas, Brazil.

Figure 8

Number of dumps in bathhouses in Itacoatiara, Amazonas, Brazil.