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Quick analysis of the influence of the monsoon on the concentration of microplastics in the air

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Abstract

Microplastic particles are found in various aquatic environments, and numerous studies are being conducted to understand their spatial distribution. However, the amount of microplastics in the air is even greater than that found in these environments, posing a risk to human health and an important primary source of contamination. Rainwater is an important carrier of these contaminants, as they are incorporated into water droplets and can further increase their toxicity when in contact with acid rain. To test the potential for removing microplastics particles from the air by rain, rainwater was collected three times during the rainy season in the municipality of Macapá, Amapá State, Brazil. Chemical digestion and filtration protocols were used to identify the particles. A total of 225 ml of rainwater and 194 inorganic particles (microplastics) were collected, the vast majority of which were classified as fibers (96,9%). Comparing the data obtained with local meteorological data, it was observed that the amount of microplastics collected tends to increase with the number of previous days without rain, indicating that this phenomenon may be serving to eliminate these particles from the air, since the collections that had rain events the previous day presented lower amounts of microplastics.

1. Introduction

Plastic pollution is one of the most pressing environmental and social issues of the 21st century (Brahney et al. 2021). Many researchers have studied the abundance of microplastics (MPs), plastic particles less than 5 mm in one dimension (Hartmann et al. 2019), in numerous environmental mediums to understand their spatial distribution (Allen et al. 2021; Curren et al. 2021; Yang et al. 2022). Much is already known about microplastics in the marine environment and now also in the freshwater, but we need to consider that MPs are also atmospheric pollutants, their primary sources being the industrial processing of plastic products, deficient sewage systems, plastic waste, etc. (Riaz et al. 2024). The percentage of microplastics in the air is comparatively higher than in any other medium, which indicates that all humans are susceptible to inhaling such harmful particles. However, monitoring the abundance of MPs in certain areas is considered insufficient in assembling preventative measures that reduce and prevent MP pollution because MPs travel globally through various routes (Ross et al. 2021).

Microplastics are not inert (Illuminati et al. 2024); they react with atmospheric oxidants like oxygen, ozone, hydroxyl radicals, and nitrogen oxides (Bianco et al. 2020; Vicente et al. 2009), producing harmful organic compounds. These compounds pose risks to ecosystems and can accumulate in aquatic organisms, causing internal injuries, and behavioral changes (Cole et al. 2011).

Meanwhile, studies of rainwater, which is one of the major transportation routes of MPs, remains scarce (Hitchcock 2020). When it rains, airborne MPs are collected and concentrated by rain droplets and become what is so-called “plastic rain” (Brahney et al., 2020). Pignattelli et al. (2021) demonstrated that MP toxicity may increase when MPs are coupled with acid rain. These rainfall events therefore impact not only the spatial distribution of MPs but the health of the general public by direct MP contact (Li et al. 2018). This emphasizes the need for global monitoring and test studies of MPs in rainwater.

This study focuses on the atmospheric component of MPs and investigates its potential as a vector of plastic pollution.

2. Methodology

The rainy phase of a seasonally shifting pattern is commonly known as the monsoon. In the Brazilian State of Amapá, the monsoon occurs between December and July, with a peak in March.

Following the protocol of Do et al. (2023), rainwater was collected during three rainfall days (June and July 2024) in an environment with low urban density (0°1'26.43"S, 51°4'41.38"W) near the Amazon River in the municipality of Macapá, state of Amapá, Brazil (Fig. 1). Meteorological data for the collection days were provided by the Center for Hydrometeorology and Renewable Energy (NHMET), Institute of Scientific and Technological Research of the State of Amapá, Macapá, AP, Brazil.

The atmospheric precipitation was collected during the first 15 minutes of discharge (first-flush effect) by standardized glass containers with a mouth diameter of 60 mm and previously washed with distilled water. As proposed by Do et al. (2023), the glass containers were placed one-meter above the surface to prevent additional input of MPs originating from the ground surface. The amount of water collected ranged from 55 to 100 mL according to the intensity of the rain.

The collected water was transferred to sterile beakers and, to remove organic matter, enough KOH was added to form a 10% solution. The beakers were covered with aluminum foil to prevent possible contamination and evaporation. The samples were then heated at a temperature of 60°C for 24 hours (Suwartiningsih et al. 2020), which according to Dehaut et al. (2016) is the most effective protocol for the digestion of organic matter and preservation of microplastics (MPs). After digestion, the remaining solution was poured through 50 µm pore size filters in the Ichthyology Laboratory of the Instituto de Pesquisas Científicas e Tecnológicas do Estado do Amapá (IEPA). Before each use, the filters were inspected under microscope to ensure the absence of MP contamination. After filtering, the filters were placed onto sterile petri dishes for microscopic examination of microplastics. Finally, the plastics were visually assessed and categorized by color, size, and shape (i.e., fiber/line, fragment, pellet, film, or foam) (GESAMP 2019). After the entire chemical digestion process, it is expected that only inorganic matter will be present in the final solution. Therefore, we assume that all fibers found were plastic fibers or potential microplastics, since FTIR or Raman spectroscopy was not conducted to confirm the polymer composition (Miranda et al. 2025).

All laboratory procedures involved necessary precautions to avoid possible contamination of the samples. For example, laboratory personnel always wore nitrile gloves and cotton lab coats during analysis. Laboratory surfaces and digestion equipment were cleaned with purified water before and after each dissection. Control blanks were made for each day of analysis and before beginning the sample digestion. For control blanks, a beaker was filled with 50 ml of the same KOH solution and covered with aluminum foil; these blanks were exposed to the same protocol applied to the samples.

To standardize the results across samples, we report MPs per 100 mL of rainwater collected (Table 1). The data were analyzed using descriptive statistics as well as a Spearman correlation analysis between the amount of PM and precipitation (Siegel 1975).

3. Results and discussion

We found a total of 194 microplastic particles in 225 mL of total analyzed rainwater, corresponding to 0.86 MP particles per milliliter and an average of 64.6 particles per day of collection. These results revealed that a rain event washes out MPs from the atmosphere. Regarding the type of MPs found, 96.9% were classified as fibers, followed by pellets (2.6%) and 1 foam particle (0.5%). Ross et al. (2023) also found fibers to be the most abundant MP in their work on rainwater in Alberta, Canada.

The majority of fibers found were black (54%), followed by blue (25%), red (13%), green (9%) and pink (6%) (Fig. 1). These colors and their proportions are generally similar to those found in aquatic environments or in the gastrointestinal tract of fishes, indicating that air may be an important source of MPs that reach these environments. For examples, the most common colors were blue, black and red in fishes from the floodplain lake of the Curiaú River in Macapá (Miranda et al. 2025), black, white and blue among microplastics reported by Khan and Setu (2022) in freshwater fishes in Bangladesh, black in demersal fish from the Spanish Coast and Mediterranean Sea (Bellas et al. 2016) and pelagic and demersal fish in Indonesia (Aunurohim et al. 2023), and black, blue and red in serrasalmid fishes from Xingu River, Brazil (Andrade et al. 2019).

Dris et al. (2016) similarly found a significant amount of fibers in atmospheric fallout in urban areas of France, and 29% of those fibers contained petrochemicals. Martinson and Thomas (2005) explained that the initial rainwater during the rain event (first-flush phenomenon) can remove up to 85% of particles accumulated on the ground surface. Thus, the airborne MPs flushed by rainwater and the MPs already on the ground are both drained into water bodies during rain events.

Our results constitute a snapshot of the atmospheric concentration of MPs at the time of sampling. Since rainwater washes the air, MPs are expected to accumulate in the air over time between rains. Thus, more MPs are expected in rain events that occur over longer periods of dryness. Our results were consistent with this (Table 1), as we found a greater amount of MPs in rainwater after two dry days vs. rain on the day before sampling occurred. This suggests that atmospheric MP contamination is constant because MPs were found in the following day's rain, however, in smaller quantities. In this way, the rainy season will contribute to cleaning MP from the air but will increase the arrival of this contaminant in the bodies of water that receive this flow.

Table 1
MPs found in the collections and respective meteorological data, where PP – Precipitation; AT - Average daily temperature; RAHmax – maximum relative air humidity.

Collection (2024)	MPs	ml	MP/100ml	PP (mm^3)	TA (°C)	RAH max	Previous PP
1 June	69	100	69	27,6	29	94	1,2mm on 31 May (day before)
24 July	82	70	117	12,4	28	90	1,2 on 21 June (3 days before)
30 July	43	55	78	7,4	29	90	30,2mm on 29 July (day before)

We found no relationship between the amount of PMs found and the daily temperature or relative humidity. These factors possibly affect the persistence of PMs in the air, but longer studies are needed to establish this possible relationship.

We found a predominance of 1- and 2-mm fibers in the rainwater. The size distribution of the fragmented MPs showed a higher number of smaller particles (Fig. 2). This greater number of smaller particles, as also noted by Dris et al. (2016), in the air likely because larger MP particles are more easily captured during the first 10 minutes of a rain event (Abbasi 2021), and also because the atmospheric floating time (air sustention) increases for smaller particles according to Stokes' law (Van Sebille et al. 2020), so probably we do have more smaller MP particles in the air. Furthermore, as plastic particle size decreases, they release more mobile and bioavailable chemicals (MacLeod et al. 2021), leading to more severe and poorly reversible pollution than that produced when they first entered the environment (Wang et al. 2025). The aerodynamic shape of MP particles is also important for understanding atmospheric residence time but is still poorly understood for fibers and other asymmetric shapes (Brahney et al. 2020).

4. Conclusions

The presence of microplastics in rainwater highlights the presence of these particles in the atmosphere, which are carried to the ground when incorporated into raindrops. The results show the importance of evaluating rainwater and its runoff as a means of MP transmission to aquatic environments.

Rainy periods will provide an atmosphere with a lower amount of suspended MP.

These results show a significant number of MP fibers in rainwater, meaning that atmospheric MPs should not be neglected as a source of microplastics in aquatic habitats.

Declarations

Conflict of interest

The authors declare that they have no potential conflict of interest to disclose.

Financial interests

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

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Author contributions

CSG contributed to the study conception and design. Material preparation, data collection and analysis were performed by GGJ and ASA and supervised by CSG. The statistical analysis and interpretation were carried by LMAS. The digestion of the samples was carried by GGJ and ASA and supervised by CSG. Meteorological data and analysis were provided and performed by JESV. The first draft of the manuscript was written by CSG and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Map

Map 1 is available in the Supplementary Files section.

Figures

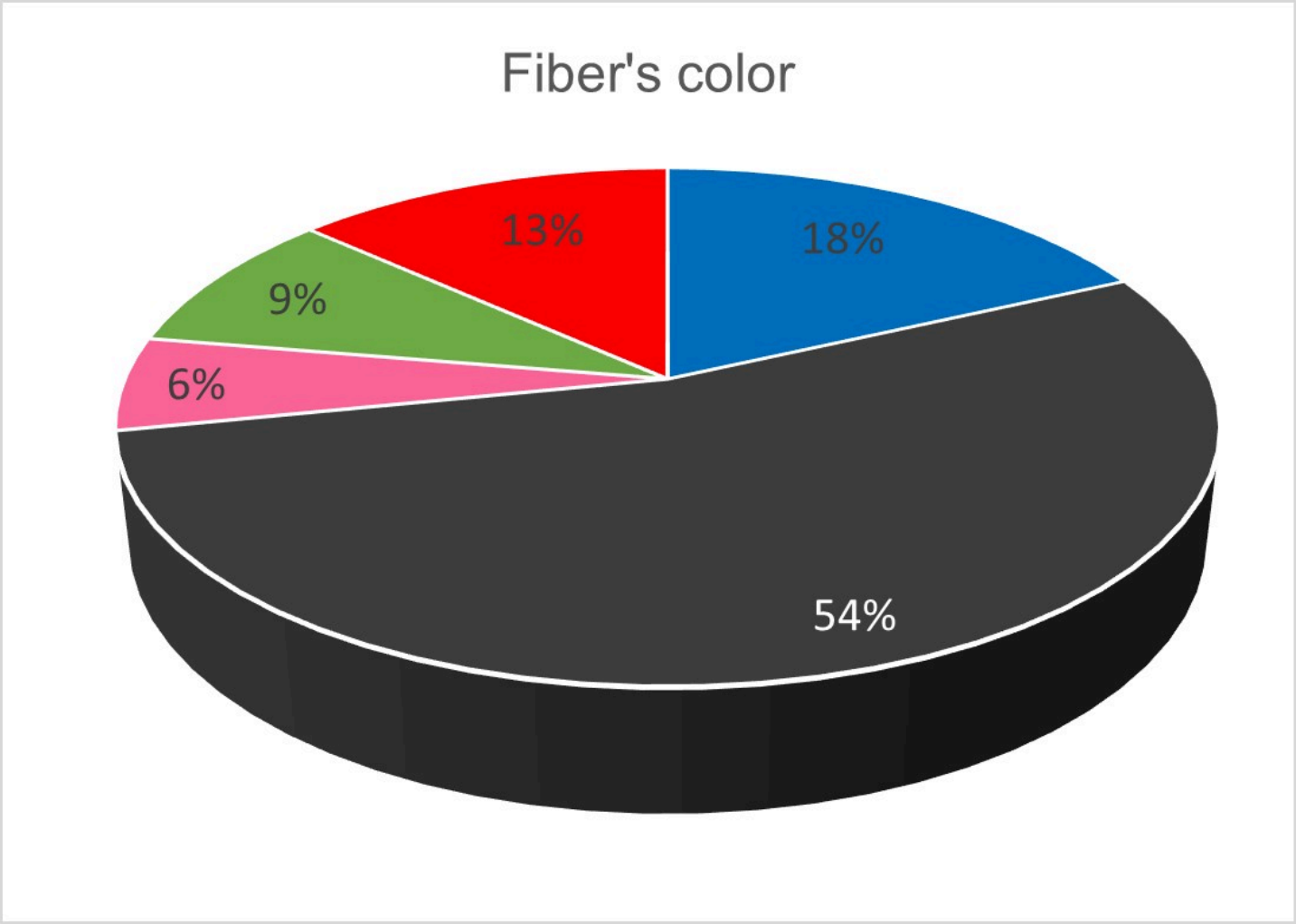

Figure 1

Distribution of fiber colors found.

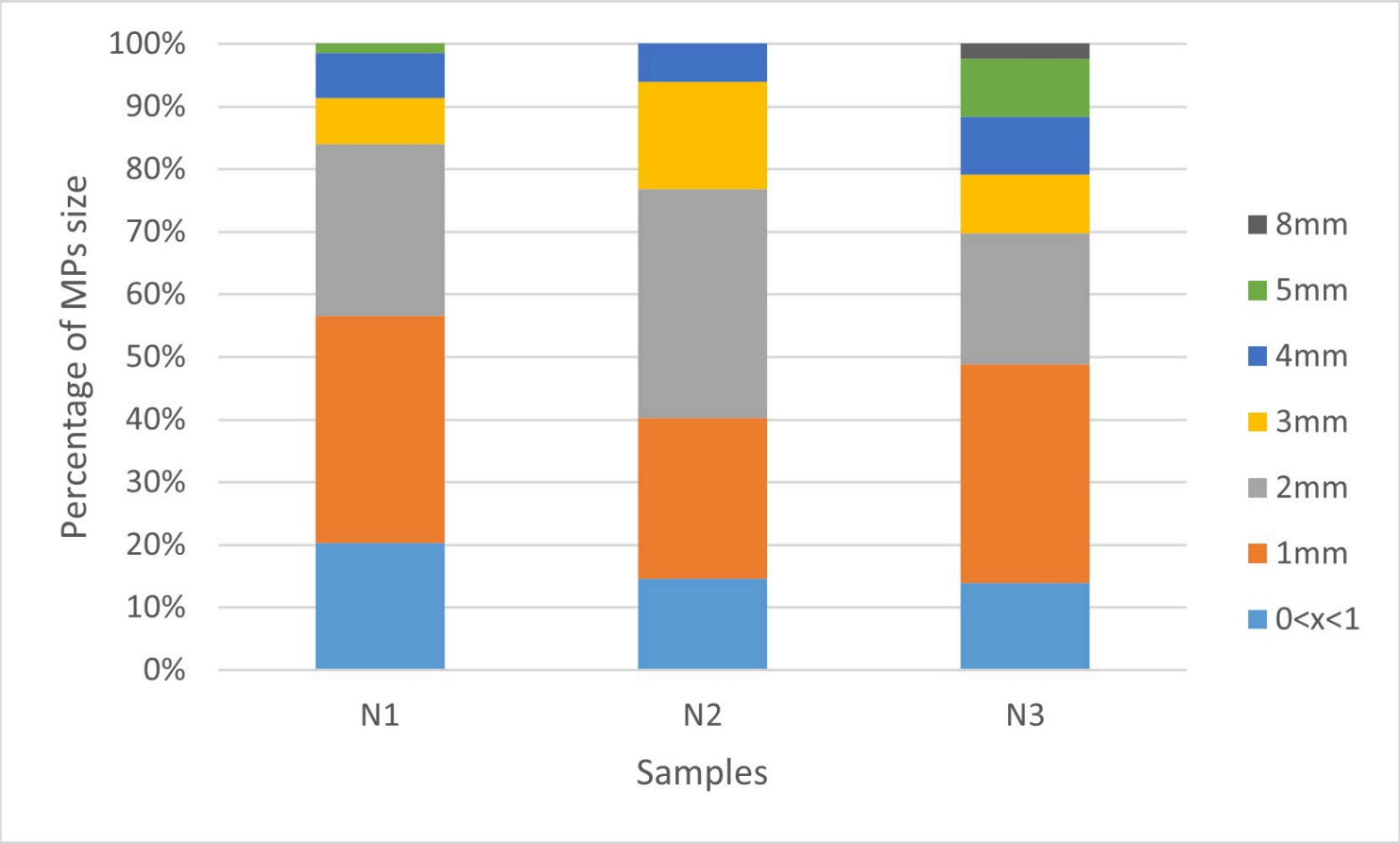

Figure 2

Size distribution of MP particles during the three collections.

Supplementary Files

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- Map.jpg