Bulletin of Environmental Contamination and Toxicology (2021) 107:45–51
https://doi.org/10.1007/s00128-021-03138-2

# Preliminary Assessment of Plastic Litter and Microplastic Contamination in Freshwater Depositional Areas: The Case Study of Puerto Misahualli, Ecuadorian Amazonia

Oscar Lucas-Solis[1] · Gabriel M. Moulatlet[1] · Jeniffer Guamangallo[2] · Naomi Yacelga[2] · Lipsi Villegas[2] · Emily Galarza[1] · Bryan Rosero[1] · Bryan Zurita[1] · Lizeth Sabando[1] · Marcela Cabrera[3] · Giovana Teixeira Gimiliani[4] · Mariana V. Capparelli[1]

Received: 30 September 2020 / Accepted: 1 February 2021 / Published online: 12 February 2021


## Abstract
We quantify plastic litter (PL, > 2 cm) and microplastics (MP, < 5 mm) from the sediments of a beach formed at a riverine depositional area, at the upper Amazon River basin, Ecuador. In the collection area (4400 $m^2$), the PL density was 0.045 items $m^{-2}$, where low-density polyethylene bags were the prevalent PL. The beach was classified as "very clean" (Clean Coast Index (CCI) of 1.3 items $m^{-2}$). Regarding MP, in 55 sampling stations, average MP concentrations ranged from 0 to 2200 items $kg^{-1}$ of dry sediment (0.5–2 mm), and 0–4200 items $kg^{-1}$ of dry sediment (2–5 mm). Blue fibers were the prevalent MP. Our results represent the first report to show the ubiquitous presence of PL and MP for the area. The monitoring and management of plastic disposal in freshwater beaches are necessary, as here we report a small part of an undocumented issue.

**Keywords** Plastic · LDPE · Littering and urban solid waste · Sewage treatment · Tropical rivers

Rivers are major pathways of plastic litter (PL; i.e. plastic items larger than 2 cm in length) and microplastics (MP; i.e., plastic particles between 1 and 5 mm in length) to the oceans (Lebreton and Andrady 2019). Given the increasing abundance of plastic transported by the fluvial pathway every year, research on the causes and sources of this type of contamination in estuarine and freshwater systems becomes necessary (Martinelli Filho and Monteiro 2019). When transported by rivers, part of the PL and MP may be deposited in areas of low flow energy in the river margins. Then, the fragmented PL can gradually become MP due to several factors, like photodegradation, oxidation and mechanical abrasion (Andrady 2017; Lebreton et al. 2017; Lebreton and Andrady 2019). The smaller the MP the easier it can be introduced into the trophic chain and become bioavailable, leading to detrimental effects on the biota (Andrady et al. 2019; Gerolin et al. 2020; Lebreton and Andrady 2019). Overall, estimations of PL and MP introduced into river systems and transported to the oceans are uncertain due to the lack of studies and standardized observations.

Based on the population size, applied waste management treatment, and hydrological modeling criteria, the Amazon River may be the 7th highest polluter river in the world (38.900 tonnes of plastic waste per year) and the first in South America (Lebreton et al. 2017). Until now, MP assessments in the Amazon basin have been limited to studies on marine and freshwater fish ingestion, and on transportation and deposition in riverine and coastal sediments near large urban centers in Central and Eastern Amazonia (Gerolin et al. 2020; Martinelli Filho and Monteiro 2019). The Amazon River basin drains 9 of the 13 South American countries, from the eastern hillside of the Andes to its mouth in the Atlantic Ocean, in northern Brazil, and hosts the largest forested area and biodiversity on Earth. Because of its flat relief and high volume of discharge, some of the large amazonian rivers form meanders with low-energy

✉ Mariana V. Capparelli
marivcap@gmail.com

1 Facultad de Ciencias de la Tierra y Agua, Universidad Regional Amazónica Ikiam, km 7, via a Muyuna, Tena, Napo, Ecuador

2 Facultad de Ciencias de la Vida, Universidad Regional Amazónica Ikiam, km 7, vía a Muyuna, Tena, Napo, Ecuador

3 Laboratorio Nacional de Referencia del Agua, Universidad Regional Amazónica Ikiam, Tena, Ecuador

4 Nuclear and Energy Research Institute, São Paulo, Brazil

sediment depositional areas where MP can accumulate. For instance, Gerolin et al. (2020) reported a high MP abundance (5869–8178 items $kg^{-1}$ of dry sediment) in the Negro River sediments near Manaus, Brazil. However, no data on PL and MP on sediments or surface water of deposition zones of the upper Amazon River basin have been reported yet.

The upper Amazon River system is one of the largest and most biodiverse aquatic systems in the Andean-Amazon region of Ecuador (Alexiades et al. 2019). The rivers of the upper Amazon basin, in contrast to the rivers of the central Amazonia, have been considered under low impact by rural, industrial, and domestic contamination due to its low population density, the presence of few medium-size urban centers (Anderson et al. 2018; Encalada et al. 2019). Nevertheless, the increasing population size, mostly living in the river margins, and the lack of proper waste management, have intensified environmental contamination risks, as much as the flexibilization of environmental protection and diversification of economic activities, like agriculture, fish farming, mining, and oil extraction (Capparelli et al. 2020; Galarza et al. 2021; Lessmann et al. 2019).

Hydrological and social factors have been proposed to explain the abundance of MP and PL in freshwater sediment (reviewed by Yang et al. 2021), including population density near water catchment, proximity to urban centers, hydrological dynamics (Gerolin et al. 2020), type of waste management used, sewage spillage and tourism (Martinelli Filho and Monteiro 2019). Thus, the conservation of freshwater ecosystems depends on both the investigation of the sources and occurrence of MP and PL in riverine sediments. The Puerto Misahualli river beach was chosen, as it is one of the most visited freshwater beaches in Ecuador (Marcinek and Hunt 2019) and it is located in a sediment depositional area subject to hydrological influence at the watershed outlet. The aim of our study was to present the first baseline assessment of PL and MP contamination in the surface sediments at deposition zones of the Misahualli River, at the upper Amazon basin, and set a precedent for its future environmental monitoring.

## Materials and Methods

The study area is the parish center of Puerto Misahualli located in the Napo Province of the Ecuadorian Amazonia (Fig. 1a). It is surrounded by a white sandy beach settled on the Misahualli riverbank, right where the Misahualli River meets the Napo River. The Misahualli beach is mainly formed by medium texture sand with the presence of gravels and large stones in both extremes of the beach (GPPM 2015). The Misahualli River drains a watershed of ca. 1.658 $km^2$, mainly covered by rainforest (70%) and where the larger urban centers are the cities of Tena (~ 44.000 inhabitants) and Archidona (~ 15.000 inhabitants). Misahualli River basin is located in a humid and tropical zone (relative humidity above 85% and mean annual temperature of 22.8°) with abundant bimodal rainfall (peaks occur in June and November). Precipitation is higher than 4000 mm/year throughout the year and there are no months with precipitation below 100 mm (Ikiam Hydrometeorological Service 2020). The study area is settled in a low topographic area that occasionally gets flooded when the level of Misahualli River increases due to intense rainfall over very short periods of time or by backwater effects, when the water level of the Napo River level increases and impedes the Misahualli River inflow.

Puerto Misahualli hosts nearly 6.600 inhabitants, being 75% self-identified from indigenous groups (Marcinek and Hunt 2019). Currently, the main source of economic income is based on community nature-oriented tourism. Tourist visits are higher in the months of February and July–August (GPPM 2015). The parish has a low coverage of public service, like sewerage (13.24%) and urban solid waste management (38.39%) (GPPM 2015). Thus, direct urban contamination sources to this watershed come from untreated discharges from domestic sewage systems and mismanagement of solid waste along the hydrographic basin. In addition, leachates outfall into tributaries of the Misahualli River from the landfills of Tena and Archidona, could be an important contamination source (Capparelli et al. 2020).

Sampling campaign was performed in February 2019. In a single day, eleven 20-m long sampling transects designated T-1 to T-11, were set perpendicularly to the shoreline, covering the full extension of the Misahualli beach (Fig. 1b). Transect length was measured with a measuring tape. Along each transect, five sampling stations (A, B, C, D and E) measuring 4 $m^2$ (2 m*2 m) were set every 4 m, starting from the shoreline, i.e., at 0 m, 4 m, 8 m, 12 m, 16 m and 20 m (Fig. 1c).

At each sampling station, 500 g of top beach sediment (10 cm deep) was collected from its center with a hand trowel manipulated by a team member who was positioned against the wind direction to avoid contamination. The hand trowel was rinsed after every sediment sampling. Samples were stored in pre-cleaned plastic bags for MP analysis. After collection, sediment samples were transported to the National Reference Water Laboratory housed at the Universidad Regional Amazónica Ikiam.

PL (excluding organic material) was manually collected from the sand surface or when was partially buried within the area comprehended between T1 and T11 (20 m × 220 m or 4400 $m^2$). Collected PL was stored in large plastic bags of 50 L for posterior identification.

*Clean Coast Index*: To evaluate the level of PL cleanliness of the Misahualli beach we applied the Clean Coast index (CCI, Alkalay et al. 2007), which determines the state

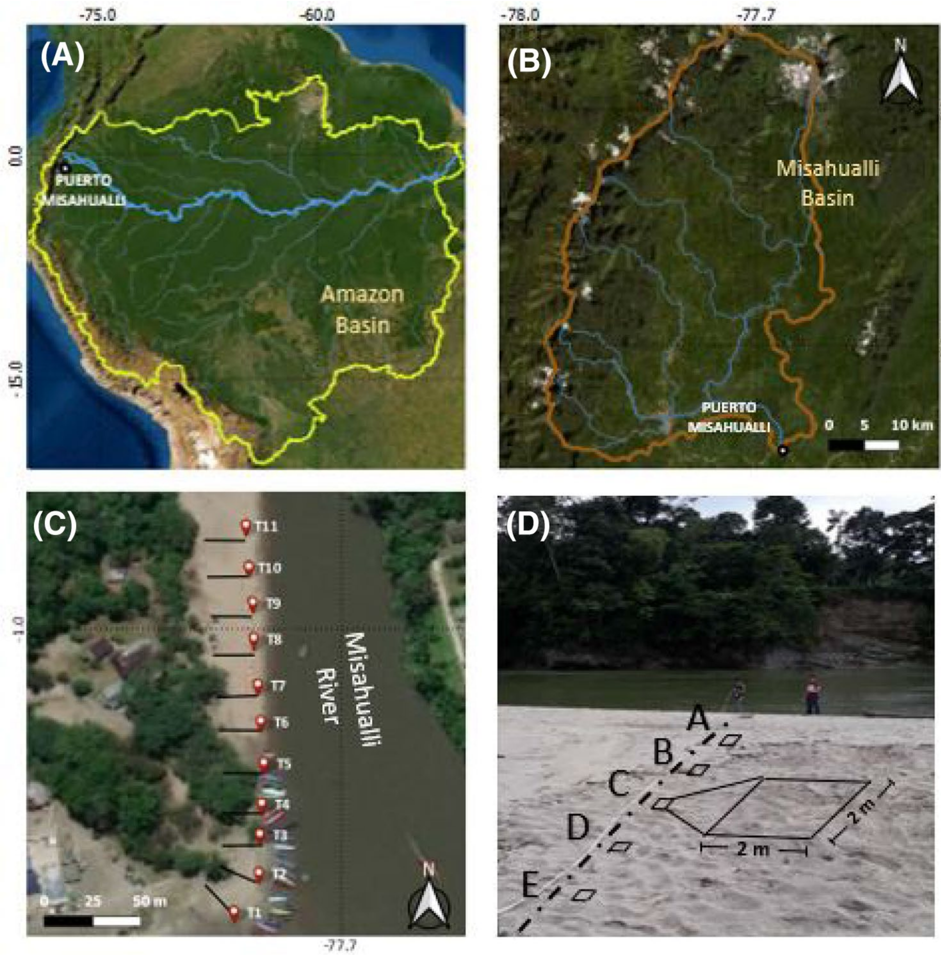


**Fig. 1** **a** The limits of the Amazon basin, highlighting the Amazon River and the geographic location of Puerto Misahualli, Ecuador (− 1.0344,− 77.665); **b** The Misahualli River basin and the location of Puerto Misahualli at the outlet of the basin; **c** Eleven 20 m-long transects along the extension of the beach, with a minimum distance of 20 m among the transects; **d** Representation of the distribution of sampling stations (A–E) along each transect (dashed line) perpendicularly to the river shoreline. Station A is the closest to the river and Station E is the closest to the vegetation line

of the sampling areas of being free of PL. CCI takes into account only plastic items, excluding organic items and other materials.This index is calculated using the formula: CCI = (Sum of Litter Items/Beach length*Beach width)*K, where K is a constant which value equals 20 (Alkalay et al. 2007). CCI values are given in items $m^{-2}$. When CCI values fall between 0 and 2, it indicates that no PL was found (“very clean”); between 2 and 5, it says that the beach is "clean"; when it is between 5 and 10, it indicates a beach with “moderate” litter; between 10 and 20, it indicates a “dirty” beach and CCI values higher than 20 indicate a greater presence of PL and the beach is classified as “extremely dirty”.

*Visual inspection of plastic litters and microplastics*: PL were classified according to the polymeric type, following a modified version of the method of Uneputty and Evans (1997). Whenever possible, each polymer was identified based on the description of the product label. When it was not possible to do this verification, the product was searched in the official brands webpages to confirm the polymeric type. The results of PL are presented as items per square meter (items $m^{-2}$). Color classification was done as: colorful items (mix of colors in one material), transparent items (when it is possible to see through the item) and opaque items (single color composite item).

Quantification and isolation of MP from freshwater sediment samples were carried out based on the methodology proposed by Gimiliani et al. (2020). Sediment samples were first homogenized with the aid of a shovel. Then, a subsample of 100 g was taken from each sample and dried at 50°C during 24–48 h, until its complete drying. The subsamples were passed through a sequence of sieves with pore sizes of 2.0 mm and 0.5 mm to separate samples into decreasing size fractions (2–5 mm and 0.5–2 mm). Then, 20 g of the sediment retained in each sieve was transferred to Petri dishes and dried for the second time at 50ºC for 12 h.

The Petri dishes containing the dry material extracted from each sieve were examined under a stereomicroscope at ×5.0 magnification, in order to count the number of plastic fibers and fragments present in the samples. Petri dishes were divided into four quadrants. The counting was done in a single quadrant and then extrapolated to the total sample (i.e. 20 g). The patterns used to identify types of microplastics were based on the descriptions provided by Mohamed Nor and Obbard (2014) and Masura et al. (2015), as well as on visual inspection. Two observers used stainless steel tweezers to actively search for microplastics and to separate them from other sediment fragments. The plastic fragments were visually categorized by color (blue, transparent, red, yellow, white, orange, light blue, light brown, violet, black and mixed) and shape (fibers and fragments). Under the stereomicroscope, the fragments were manipulated or dragged around with the aid of tweezers to confirm the makeup of the plastic particles. If the materials crumbled or were easily crushed, they were not considered plastic compounds. If the particles kept their shape, they were included in the counting (Mohamed Nor and Obbard 2014).

## Results and Discussion

We collected 200 items of PL within the area comprising the transects at the Misahualli beach. This results in the CCI value of 1.3 items $m^{-2}$, which indicates that the beach is classified as "very clean" and of low density of PL items. Our CCI value (1.3 items $m^{-2}$) was lower than those calculated for 27 central Caribbean beaches of Colombia that ranged from 2.8 (clean) to 574 (extremely dirty) items $m^{-2}$, and 25 of 26 Israel beaches, that ranged from 1.14 (very clean) to 36.29 (extremely dirty) items $m^{-2}$ (Rangel-Buitrago et al. 2020; Alkalay et al. 2007). The amount of PL collected denotes an absolute predominance of colorful LDPE bags over the other plastic products with a relative abundance of 54.5% (Table 1). LDPE is the polymer used in disposal plastic bags, which is higher in the Amazonia than in other parts of Ecuador (Zambrano-Monserrate and Ruano 2020) and represent near 50% of the items reported in other freshwater beaches (Blettler et al. 2019). PL studies in river sand beaches in Amazonia are still scarce to provide fair comparisons of our results with other parts of the Amazon basin. When compared to other South American rivers, our results showed lower PL amount (~0.045 items $m^{-2}$) compared to those found in a floodplain lake (~1.15 items $m^{-2}$) and one riparian zone (~2.27 items $m^{-2}$) of the Paraná River (Blettler et al. 2017, 2019).

The average MP concentration found in the 55 stations along the transects of the Puerto Misahualli beach was 987 (0–4200) items $kg^{-1}$ of dry sediment for particles of size between 0.5 and 2 mm and 761(0–2200) items $kg^{-1}$ of dry sediment larger than 2 mm and smaller than 5 mm. Our results are similar to what was reported to Central Amazonia (417–8178 items $kg^{-1}$ of dry sediment), being the highest MP (size: 0.063–5 mm) concentrations found near to the metropolitan region of Manaus (Gerolin et al. 2020). MP distribution in the sediment was variable at different sections along the beach extension (Fig. 2a). Higher MP concentration was found at transect T4 for MP items of size between 0.5 to 2 mm and at T6 for items of size between 2 to 5 mm length (Fig. 2a). The MP distribution at the sampling stations aligned perpendicular to the river (Fig. 2b) shows that the MP concentration of items of both 0.5–2 mm and 2–5 mm was greater near the vegetation line (sampling station E). This could be explained by accumulation of MP in the barrier formed by the vegetation line during floodings (Jayasiri et al. 2013). Fibers represent 97% of the total MP found in the study area (Fig. 2c). This is in agreement with other studies that report the prevalence of fibers in freshwater sediments (Yang et al. 2021), most likely originated from clothing and other fiber products. We reported that blue fibers were the most abundant ones (Fig. 2a and b), followed by transparent and black fibers. Blue fibers are commonly

**Table 1** The relative abundance of plastic litter (PL) and the proportion of polymeric types in the sediments of the Misahualli beach

| Plastic litter (PL) | Absolute number of items | Relative abundance (%) | Colorful items (%) | Transparent items (%) | Opaque items (%) | Polymeric type Type (Total number) |
|---|---|---|---|---|---|---|
| Bag | 109 | 54.5 | 88.5 | 20.9 | 39.2 | LDPE (101) HDPE (8) |
| Cup | 28 | 14.0 | 0.0 | 65.1 | 0.0 | PP (28) |
| Straw | 17 | 8.5 | 0.0 | 0.0 | 21.5 | PP (17) |
| Bottle cap | 8 | 4.0 | 0.0 | 0.0 | 10.1 | PP (8) |
| Label | 8 | 4.0 | 10.3 | 0.0 | 0.0 | PVC (8) |
| Bottle | 7 | 3.5 | 0.0 | 11.6 | 2.5 | PET (7) |
| Spoon | 7 | 3.5 | 0.0 | 0.0 | 8.9 | PS (7) |
| Container | 5 | 2.5 | 1.3 | 2.3 | 3.8 | PET (2) HDPE (1) PP (1) PET(1) |
| Plate | 4 | 2.0 | 0.0 | 0.0 | 5.1 | PS(4) |
| Fork | 3 | 1.5 | 0.0 | 0.0 | 3.8 | PS(3) |
| Lollipop stick | 2 | 1.0 | 0.0 | 0.0 | 2.5 | PP(2) |
| Tube | 1 | 0.5 | 0.0 | 0.0 | 1.3 | PVC (1) |
| Shoe | 1 | 0.5 | 0.0 | 0.0 | 1.3 | PVC (1) |
| Sum (∑) | 200 | 100.0 | 100 | 100 | 100 | All (200) |

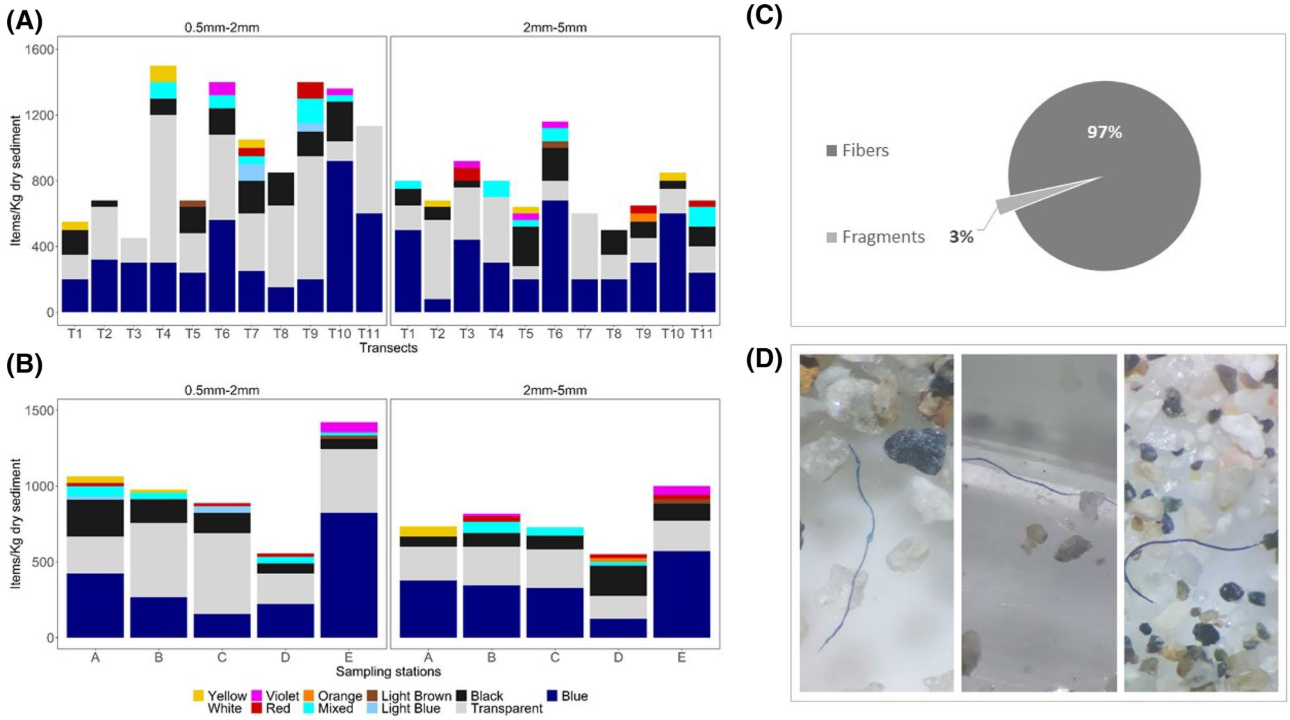


**Fig. 2** Quantification of Microplastic (MP) along the Misahualli freshwater beach. MP was classified by color, shape (fibers and fragments) and size range (0.5–2 mm and 2–5 mm). **a** MP average concentration by transects. **b** MP average concentration by sampling station. **c** MP shape classification. **d** Pictures of MP fibers found in the sediments in the study area

found in freshwater systems affected by sewage spillage and low wastewater treatment plant effluents (Leads and Weinstein 2019).

Although Tena and Archidona cities are provided with three wastewater treatment plants, their efficiency in MP removal is unknown. At both cities the sewage network does not cover all urban and surrounding rural areas, and there are several sewage spillages that flow into the rivers. Moreover, neither Tena nor Archidona are provided with effective landfills. The mismanagement of solid wastes in landfills results in high levels of contamination of nearby rivers caused by leachate, including the presence of metals in high concentrations (Capparelli et al. 2020). As such, urban streams become important contributors in the dissemination of several contaminants, including both PL and MP, downstream. This can result in constant load of domestic waste outfall into the Misahualli River and its tributaries that are transported to the Misahualli beach, which is the outlet of the Misahualli River watershed.

We associated the presence of MP in the Misahualli beach to plastic input upstream, that is transported by the Misahualli River and deposited in the sediments of the beach during occasional flooding. MP pollution in riverine sediments can be more influenced by hydrological dynamics than other factors, such as the proximity of dense population zones, industrial activity or the location of wastewater treatment plants (Klein et al. 2015; Yang et al. 2021). Amazonian rivers are subject to high variability in the water flow caused by rainfall patterns. Extreme rainfall events lead to an increment in the river flow that occasionally inundates areas located in low topographic positions, such as the river beaches (Salo et al. 1986). Thus, due to the small size, MPs get deposited in low energy environments after flooding, a phenomenon that has been reported in other areas (Gündoğdu et al. 2018). Depositional areas may also become sources of MP, as MP deposited in sediments can be exported downstream (Hurley et al. 2018). Hydrological dynamics could also explain the prevalence of LDPE litter items in the study area, as they are of low density ($0.91 \pm 0.03$ g/cm$^3$) and easier to be transported downstream during floods and be retained in depositional areas.

Our assessment of the plastic contamination at Puerto Misahuallí provides a baseline information of PL and MP distribution in sediments in one sand beach at the upper Amazon basin, Ecuador. The presence of PL in the sediment requires controlling efforts to diminish the disposal of these elements. If PL can be transported downstream, it will reach depositional areas along the Amazonian wetlands and may gradually become MP. Similarly, the presence of MP in Puerto Misahualli raises a concern about the occurrence of MP and its magnitude in comparison with more contaminated areas. MP concentrations seem to be clearly related to the distance to the river, showing higher concentrations in the sampling stations near to the vegetation line. Conservation actions to control plastic disposal into Amazonia freshwater ecosystems are urgently needed, as we here report a small part of an undocumented issue. This includes further studies on the MP removal capacity of wastewater plants and management actions towards global sewage treatment. The absence of residual management in Amazonian cities may result in pervasive MP and PL contamination of freshwater and potential adverse effects to the biota. We suggest the continuous monitoring of the contamination in several freshwater beaches at the upper Amazon basin by taking into account hydrological dynamics.

**Acknowledgements** This investigation received financial support from the European Union in coordination with the Spanish Cooperation International Agency for Development (AECID), granted to MVC. We are thankful to Ikiam driver Pablo Neris "Don Tito" Paz Andrade of the Universidad Regional Amazónica Ikiam.

## Compliance with Ethical Standards

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

Alexiades AV, Encalada AC, Lessmann J, Guayasamin JM (2019) Spatial prediction of stream physicochemical parameters for the Napo River Basin, Ecuador. J Freshw Ecol 34(1):247–261. https://doi.org/10.1080/02705060.2018.1542353

Alkalay R, Pasternak G, Zask A (2007) Clean-coast index—a new approach for beach cleanliness assessment. Ocean Coast Manag 50(5–6):352–362. https://doi.org/10.1016/j.ocecoaman.2006.10.002

Anderson EP, Jenkins CN, Heilpern S, Maldonado-Ocampo JA, Carvajal-Vallejos FM, Encalada AC, Rivadeneira JF, Hidalgo M, Cañas CM, Ortega H, Salcedo N, Maldonado M, Tedesco PA (2018) Fragmentation of Andes-to-Amazon connectivity by hydropower dams. Sci Adv 4(1):eaao1642. https://doi.org/10.1126/sciadv.aao1642

Andrady AL (2017) The plastic in microplastics: a review. Mar Pollut Bull 119(1):12–22. https://doi.org/10.1016/j.marpolbul.2017.01.082

Andrady AL, Pandey KK, Heikkilä AM (2019) Interactive effects of solar UV radiation and climate change on material damage. Photochem Photobiol Sci 18(3):804–825. https://doi.org/10.1039/C8PP90065E

Blettler MCM, Ulla MA, Rabuffetti AP, Garello N (2017) Plastic pollution in freshwater ecosystems: macro-, meso-, and microplastic debris in a floodplain lake. Environ Monit Assess 189(11):581. https://doi.org/10.1007/s10661-017-6305-8

Blettler MCM, Garello N, Ginon L, Abrial E, Espinola LA, Wantzen KM (2019) Massive plastic pollution in a mega-river of a developing country: sediment deposition and ingestion by fish (*Prochilodus lineatus*). Environ Pollut 255:113348. https://doi.org/10.1016/j.envpol.2019.113348

Capparelli MV, Moulatlet GM, de Abessa DMS, Lucas-Solis O, Rosero B, Galarza E, Tuba D, Carpintero N, Ochoa-Herrera V, Cipriani-Avila I (2020) An integrative approach to identify the impacts of multiple metal contamination sources on the Eastern Andean foothills of the Ecuadorian Amazonia. Sci Total Environ 709:136088. https://doi.org/10.1016/j.scitotenv.2019.136088

Encalada AC, Flecker AS, Poff NL, Suárez E, Herrera-R GA, Ríos-Touma B, Jumani S, Larson EI, Anderson EP (2019) A global perspective on tropical montane rivers. Science 365(6458):1124–1129. https://doi.org/10.1126/science.aax1682

Galarza E, Cabrera M, Espinosa R, Espitia E, Moulatlet GM, Capparelli MV (2021) Assessing the quality of amazon aquatic ecosystems with multiple lines of evidence: the case of the Northeast Andean foothills of Ecuador. Bull Environ Contam Toxicol. https://doi.org/10.1007/s00128-020-03089-0

Gerolin CR, Pupim FN, Sawakuchi AO, Grohmann CH, Labuto G, Semensatto D (2020) Microplastics in sediments from Amazon rivers, Brazil. Sci Total Environ 749:141604. https://doi.org/10.1016/j.scitotenv.2020.141604

Gimiliani GT, Fornari M, Redígolo MM, Willian Vega Bustillos JO, Moledo de Souza Abessa D, Faustino Pires MA (2020) Simple and cost-effective method for microplastic quantification in estuarine sediment: a case study of the Santos and São Vicente Estuarine System. Case Stud Chem Environ Eng. https://doi.org/10.1016/j.cscee.2020.100020

GPPM (2015) Actualización del plan de desarrollo y ordenamiento territorial: Parroquia Puerto Misahuallí Cantón Tena – Provincia de Napo. Gobierno Parroquial de Puerto Misahualli. http://app.sni.gob.ec/sni-link/sni/PORTAL_SNI/data_sigad_plus/sigadplusdiagnostico/1560507250001_PDOT_2015_PMisahualli_15-05-2015_09-11-36.pdf

Gündoğdu S, Çevik C, Ayat B, Aydoğan B, Karaca S (2018) How microplastics quantities increase with flood events? An example from Mersin Bay NE Levantine coast of Turkey. Environ Pollut 239:342–350. https://doi.org/10.1016/j.envpol.2018.04.042

Hurley R, Woodward J, Rothwell JJ (2018) Microplastic contamination of river beds significantly reduced by catchment-wide flooding. Nat Geosci 11(4):251–257. https://doi.org/10.1038/s41561-018-0080-1

Ikiam Hydrometeorological Service (2020) Meteorological and hydrological stations network: Meteoviewer, version 3.4. Universidad Regional Amazónica Ikiam. http://hidrometeorologia.ikiam.edu.ec/meteoviewer/. Accessed 24 Dec 2020

Jayasiri HB, Purushothaman CS, Vennila A (2013) Plastic litter accumulation on high-water strandline of urban beaches in Mumbai, India. Environ Monit Assess 185(9):7709–7719. https://doi.org/10.1007/s10661-013-3129-z

Klein S, Worch E, Knepper TP (2015) Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. Environ Sci Technol 49(10):6070–6076. https://doi.org/10.1021/acs.est.5b00492

Leads RR, Weinstein JE (2019) Occurrence of tire wear particles and other microplastics within the tributaries of the Charleston Harbor Estuary, South Carolina, USA. Mar Pollut Bull 145:569–582. https://doi.org/10.1016/j.marpolbul.2019.06.061

Lebreton L, Andrady A (2019) Future scenarios of global plastic waste generation and disposal. Palgrave Commun 5(1):6. https://doi.org/10.1057/s41599-018-0212-7

Lebreton LCM, van der Zwet J, Damsteeg J-W, Slat B, Andrady A, Reisser J (2017) River plastic emissions to the world's oceans. Nat Commun 8(1):15611. https://doi.org/10.1038/ncomms15611

Lessmann J, Troya MJ, Flecker AS, Funk WC, Guayasamin JM, Ochoa-Herrera V, Poff NL, Suárez E, Encalada AC (2019) Validating anthropogenic threat maps as a tool for assessing river ecological integrity in Andean-Amazon basins. PeerJ 7:e8060. https://doi.org/10.7717/peerj.8060

Marcinek AA, Hunt CA (2019) Tourism and cultural commons in the Ecuadorian Amazon. J Tour Cult Change 17(4):449–466. https://doi.org/10.1080/14766825.2019.1591711

Martinelli Filho JE, Monteiro RCP (2019) Widespread microplastics distribution at an Amazon macrotidal sandy beach. Mar Pollut Bull 145:219–223. https://doi.org/10.1016/j.marpolbul.2019.05.049

Masura J, Baker J, Foster G, Arthur C (2015) Laboratory Methods for the Analysis of Microplastics in the Marine Environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48. https://repository.library.noaa.gov/view/noaa/10296

Mohamed Nor NH, Obbard JP (2014) Microplastics in Singapore's coastal mangrove ecosystems. Mar Pollut Bull 79(1–2):278–283. https://doi.org/10.1016/j.marpolbul.2013.11.025

Rangel-Buitrago N, Velez-Mendoza A, Gracia CA, Neal WJ (2020) The impact of anthropogenic litter on Colombia's central Caribbean beaches. Mar Pollut Bull 152:110909. https://doi.org/10.1016/j.marpolbul.2020.110909

Salo J, Kalliola R, Häkkinen I, Mäkinen Y, Niemelä P, Puhakka M, Coley PD (1986) River dynamics and the diversity of Amazon lowland forest. Nature 322(6076):254–258

Uneputty PA, Evans SM (1997) Accumulation of beach litter on islands of the Pulau Seribu Archipelago, Indonesia. Mar Pollut Bull 34(8):652–655. https://doi.org/10.1016/S0025-326X(97)00006-4

Yang L, Zhang Y, Kang S, Wang Z, Wu C (2021) Microplastics in freshwater sediment: a review on methods, occurrence, and sources. Sci Total Environ 754:141948. https://doi.org/10.1016/j.scitotenv.2020.141948

Zambrano-Monserrate MA, Ruano MA (2020) Do you need a bag? Analyzing the consumption behavior of plastic bags of households in Ecuador. Resour Conserv Recycl 152:104489. https://doi.org/10.1016/j.resconrec.2019.104489