UNIVERSIDAD REGIONAL AMAZONICA IKIAM
FACULTAD DE CIENCIAS DE LA TIERRA Y AGUA

CARRERA DE GEOCIENCIAS

ACUMULACIÓN Y ABUNDANCIA DE MICROPLÁSTICOS EN SEDIMENTOS: CASO DE ESTUDIO EN EL RÍO TENA

Proyecto de investigación previo a la obtención del Título de:

INGENIERA EN GEOCIENCIAS

AUTOR

MISHELL ESTEFANIA CABRERA JIMENEZ

Tena - Ecuador
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AUTOR: MISHELL ESTEFANIA CABRERA JIMENEZ

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Carrera de Geociencias

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DEDICATORIA

A mis amados padres, quienes con su amor incondicional y apoyo constante han sido mis guías en este viaje académico. Su dedicación y sacrificio son la inspiración detrás de cada logro alcanzado, con su ejemplo de perseverancia y determinación continuan impulsándome hacia adelante. A mis queridos hermanos, cuya complicidad y aliento han sido un faro en los momentos de desafío, aunque la distancia nos separe físicamente, su apoyo incondicional y sus palabras de aliento han estado siempre presentes en mi corazón. A mi estimado abuelo, cuya sabiduría y amor han sido una constante fuente de inspiración. Sus enseñanzas y valores han moldeado mi camino y me han guiado hasta este momento.

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TABLA DE CONTENIDO

ÍNDICE DE TABLAS

ÍNDICE DE FIGURAS

RESUMEN

La dependencia generalizada de los productos de plástico ha llevado a una preocupante contaminación global por microplásticos, partículas plásticas de 0.001 a 5 milímetros de tamaño. El objetivo de este estudio pretende determinar si la acumulación de microplásticos en los sistemas fluviales es una función de la granulometría. Los microplásticos a menudo, se utilizan como indicadores de contaminación. Se realizaron 30 muestras en seis zonas de trabajo con una pendiente del terreno inferior al 8%. Se utilizaron técnicas de muestreo con blancos para controlar la posible contaminación. Las muestras se secaron a 60 grados Celsius, se aislaron los microplásticos mediante flotación. Se realizó digestion a las muestras para eliminar la materia orgánica, y las muestras fueron teñidas con rosa de bengala para su posterior identificación. El análisis reveló 564 fibras de microplásticos, principalmente de colores rojo, negro, azul y transparente, con una longitud promedio de 612.603 µm y una mediana general de la longitud de 614.529 µm. Además, se realizó un análisis granulométrico de las muestras, empleando tamices con siete diferentes aberturas, donde se visualizó que las muestras mantenian una gran cantidad de lodos. Se observó que a medida que aumentaba la presencia de lodos (63 µm y <63 µm), se detectaba un incremento significativo en el número de partículas de microplásticos. En el análisis de datos se encontró una correlación positiva significativa entre microplásticos y lodos ($r=0.46$, $p=0.009$), y no significativa con sedimentos gruesos ($r=-0.11$, $p=0.54$).

Palabras clave: contaminación por microplásticos, río Tena, sedimentos, lodos, sedimentos gruesos.

ABSTRACT

Widespread reliance on plastic products has led to worrisome global pollution by microplastics, plastic particles from 0.001 to 5 millimeters in size. The objective of this study is to determine whether the accumulation of microplastics in river systems is a function of particle size. Microplastics are often used as indicators of pollution. Thirty samples were taken in six working areas with a ground slope of less than 8%. Blank sampling techniques were used to control for possible contamination. Samples were dried at 60 degrees Celsius, microplastics were isolated by flotation. Samples were digested to remove organic matter, and samples were stained with rose bengal for later identification. The analysis revealed 564 microplastic fibers, mainly of red, black, blue and transparent colors, with an average length of 612.603 µm and an overall median length of 614.529 µm. In addition, a granulometric analysis of the samples was carried out, using sieves with seven different openings, where it was observed that the samples maintained a large amount of muds. It was observed that as the presence of sludge increased (63 µm and <63 µm), a significant increase in the number of microplastic particles was detected. In the data analysis, a significant positive correlation was found between microplastics and muds (r=0.46, p=0.009), and not significant with coarse sediments (r=-0.11, p=0.54).

Keywords: microplastic pollution, Tena River, sediments, muds, coarse sediments.

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ACCUMULATION AND ABUNDANCE OF MICROPLASTICS IN SEDIMENTS: CASE OF STUDY IN THE TENA RIVER

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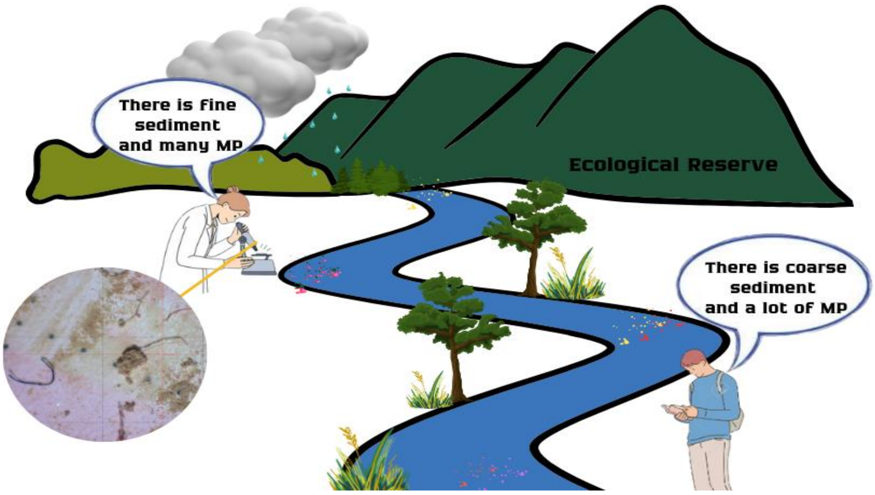
GRAPHICAL ABSTRACT



HIGHLIGHTS

- A positive correlation exists between the amount of microplastics and the increase in muds content (r=0.46, p-value=0.009).
- The variability in MP accumulation in coarse sediments indicates that coarse sediments is not a determining factor.
- The presence of microplastic fibers suggests atmospheric transport and highlights the need for effective environmental management.
- The most common form of microplastics found was fibers, with predominant colors being transparent, blue, and red.

INTRODUCTION

Plastics, also known as polymers, originate through synthesizing primary chemical compounds, mostly derived from natural gas and crude oil (Rios et al., 2007). About 95% of plastic particles captured in surface trawls consist of what is known as "microplastics"(Law, 2017). Plastic particles are usually classified into different categories according to their size: microplastics [hereafter MP] ranging from 1 um to 5 mm (Barnes et al., 2009). Secondary microplastics, whether particles or fibers originate from the decomposition of macroplastics due to mechanical, photolytic, or chemical degradation processes in aquatic environments (Mathalon & Hill, 2014). They are present in the lithosphere, hydrosphere, and even in the atmosphere (Cabrera et al., 2020). MP have been recorded in various bodies of water such as rivers, deep coastal areas or in deep sediments such as seas, beaches, aquifers, and remote areas such as glaciers(Cabrera et al., 2020; Van Cauwenberghe et al., 2015).

Plastics are environmental pollutants with higher accumulation in marine environments (Hale et al., 2020; Harris, 2020). Plastics are synthetic materials (polymers) easily transported as a function of slope, accumulating in riverbed sediments, implying long-term retention. High-energy stream channels mobilize the longest-distance deposited particles when the critical stress is exceeded and mobilize bed sediment, and at the same time, these channels can move MP deeper into the sediment (Robert, 1999).

It is estimated that between 2% and 5% of this production ends up polluting the marine environment (Jambeck et al., 2015). Recently, Harris (2020) has conducted studies of MP in sedimentary environments, finding a high concentration of MP. However, the distribution and quantification of MP are not accurate since there is no calibration of MP concentrations of the results, considering the same sedimentary environment in zones of accumulation and sediment erosion and, therefore, microplastics (Hidalgo-Ruz et al., 2012). For marine microplastics, analysis protocols have been developed in terms of pollution produced, types, and global impacts (Bollaín et al., 2019; Gola et al., 2021;

Hidalgo-Ruz et al., 2012; Hoellein et al., 2019).

Microplastics in headwater streams have been detected showing the widespread nature of riverine microplastic pollution (Emilie M. F. Kallenbach, 2021). What is particularly noteworthy here is that river hydrodynamics have a strong influence in the accumulation of microplastics in marine environments and their spatial distribution. Further studies suggest that freshwater systems are at great risk of contamination with MP (Emilie M. F. Kallenbach, 2021).

In order to maintain recent information on MP pollution, there is currently a high rate of MP research for the sole purpose of sampling protocols, analysis, and identification of MP (Hidalgo-Ruz et al., 2012). However, microplastic research has been conducted for almost two decades, and standards for sample collection, quantification, and identification have not yet been established (Prata et al., 2019). In several studies on MP pollution in waters, errors in the levels of analysis, identification, and classification of MP have been identified (Bai et al., 2022). According to Danopoulos et al., (2020) there have been few records of error studies where it is possible to identify the failure in the quantification of a comparison study to determine the MP in a landfill. The identification and comparison of MP in the flow rates, according to its granulometry of choice, provides information without margins of error.

This study aims to determine if microplastic accumulation in river systems is a function of granulometry. If true, estimate which granulometry size contains the most MP.

METHODOLOGY

Sampling site

The study area was carried out on the sediment bars along the Tena River, located on the eastern flank of the Andes in the Napo province, from coordinates (0°55'28.0” S, 77°52'35. 7“W) to (0°55'07.6” S, 77°52'49.9” W). The Tena River has a length of 23.40 km and a watershed of 40.95 km², of which 98.46 % (upstream) is within the Colonso Chalupas Biological Reserve. This river was selected for sampling because most of its watershed is in a protected area and because of its easy access.

To identify six catchment areas with slopes less than 8 degrees, a Digital Elevation Model (DEM) and the Van Zuidam slope classification (Rodriguez, 2016) were used (Figure 1). This methodology allowed the establishment of potential collection points prior to field work. In case sediments were not found in the areas identified by the DEM, we proceeded to collect samples in the nearest areas with suitable sediments.

Despite the fact that the morphology of the river is constantly changing, the analysis with the DEM was adequate, since sediments were found in the predicted areas. However, it is important to note that the DEM used does not accurately represent the morphology of the river at the time of collection, since the objective of the study is not to determine the exact morphology of the river, but to identify suitable areas for sediment collection.

This combined approach ensured greater accuracy in identifying areas of interest for sample collection, thus optimizing the sampling process.

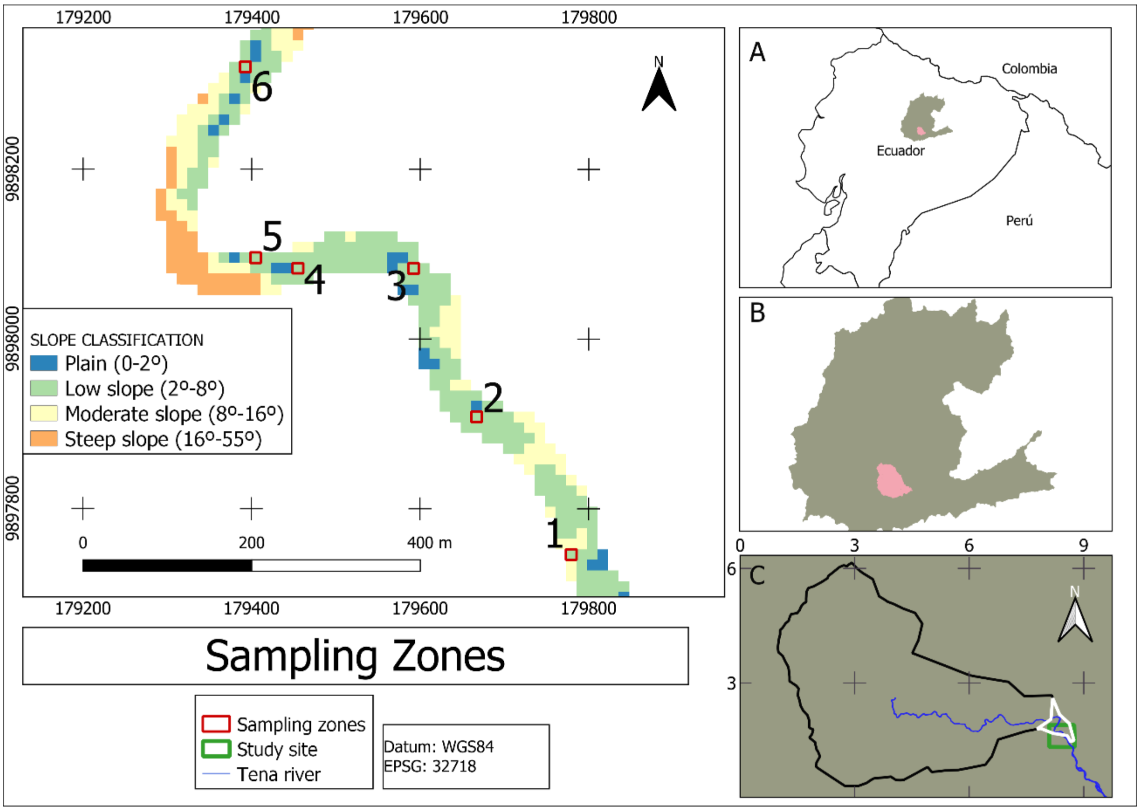


Figure 1. Sampling site map. The figure shows the location of the six sampling zones marked with numbered red squares. Slopes along the river were categorized in plain (blue), low (green), moderate (yellow), and Steep (orange). Insets A and B show the geographic location of Ecuador and the Napo province, respectively. Inset C shows the Tena River watershed subdivided into a protected area (black polygon) and a non-protected area (white polygon). The green rectangle represents the location of the main map, and the blue line is the Tena River (Decentralized Autonomous Municipal Government of Tena (2022). Shapefile of the basins of Tena). The slope classification in the Tena Basin with a scale of [1:5000].

A 3 by 12-meter plot was traced within each zone over sediment bars. The plot was subdivided into 1.20 m grids, and five of them were randomly selected using R to ensure that each point had the same probability of selection.

Samples were collected after a precipitation event strong enough to raise the river flow and remove previously deposited sediment. Following the episode, the downstream flow deposited new sediments that were sampled when they were exposed.

Surface sediment samples were collected in accumulation zones of the river. In each sampling zone, five samples were collected where 250 grams of sediment were collected with a metal shovel, specifically in beach-type areas and along selected riverbanks.

Samples were carefully obtained to ensure an accurate representation of the sedimentary conditions in these depositional zones. Therefore, during sample collection, a clean empty bag (control) was placed upwind to estimate direct contamination during sampling. The bag was cleaned with filtered distilled water.

Laboratory analysis

In the laboratory, the sediment samples were placed in aluminum containers and dried at 60 degrees Celsius for three days. After drying, the samples weighed between 100 and 200 grams. To estimate possible MP contamination during weighting and sample drying, a cleaned petri dish (control) was kept open in the working area. The dried samples were homogenized, quartered and divided in two fractions of 2.5 and 100 grams respectively. The hundred-gram fraction was sieved to estimate the granulometry and the 2.5 grams fraction was processed to estimate the microplastic content. The 2.5 grams of dried sediment were placed in 100 ml beakers containing 20 ml sodium metatungstate solution ($H2Na6O40W12$; 2g/ml) with a specific density of 2.0 grams per ml. The samples were shaken for 3 min and allowed to rest for 48 hours. The sample supernatant was isolated and filtered through a 0.45 um pore-size membrane. The filtered samples were digested with hydrogen peroxide for 24 hours to eliminate the organic matter that hinders MP counting. The digestion was done in 50 ml beakers filled with 5 ml of hydrogen peroxide ($H2O2$, 30%) mixed with 0.5 ml of the Fenton's solution. Subsequently, the samples were filtered a second time through a 0.45 um nitrate-cellulose membrane, washed with distilled water and deposited in a petri dish. Six milliliters of Rose Bengal (200 mg/L) were applied to dye the samples. Finally, the samples were taken to the oven for 1 hour at 60 degrees Celsius. After drying, MP samples were ready for quantification.

Identification of microplastics

The MP identification and quantification was carried out using an Motic stereo microscope equipped with a camera (Motic SMZ-171, 10X/Total magnification 3.5/ Zoom 0.4/ total magnification 3.5). Images were captured using MotiConnect software. The

Rose Bengal dye, stained in pink the organic particles that remained after the digestion in hydrogen peroxide and allowed to differentiate them from the microplastics (MP) that retained their original color (Kosuth et al., 2018). Microplastic dimensions were estimated using ImageJ software.

The shape and color of the MP particles was recorded, and they were divided into five groups: white, blue, transparent, black and red. All the materials used were previously washed with filtered distilled water.

Granulometry

The 100-gram fraction of sediment was dry sieved using a series of sieves with specific sizes, classified according to the Udden-Wentworth scale into coarse sediments and muds (Nichols, 2009). The sieve sizes used were: 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, and for muds 63 µm and <63 µm. Once sieved, each fraction was accurately labeled and weighed.

This classification allowed us to obtain a detailed correlation between grain size and the amount of microplastics (MP) present in the samples.

RESULTS

Granulometric Analysis

The results of the granulometric analysis reveal a detailed distribution of grain sizes in the sediment samples. The seven fractions obtained after sieving showed significant variations in their relative weight and percentage. The most abundant corresponded to the fraction (63 µm) with a maximum weight of 50 grams and a percentage of (52%). In contrast, the least represented fraction was (2 mm), with a maximum weight of 12.84 grams and a percentage of (13%). See Table 1.

Most of the samples showed a predominance of muds, which was reflected in the high percentages of the smaller fractions. On the other hand, coarse sediments showed significantly lower weights, indicating a lower presence in the analyzed samples. These data suggest sediment dynamics where muds are dominant, which has important implications for the retention of microplastics in these fractions.

Table 1. Weight in grams (gr) and relative percentage of the seven different fractions obtained after sieving for particle-size analysis

Sample	**2 mm (gr)**	**Percentage**	**1mm (gr)**	**Percentage**	**500 mm (gr)**	**Percentage**	**250 mm (gr)**	**Percentage**	**125 mm (gr)**	**Percentage**	**63 µm (gr)**	**Percentage**	**> 63 µm (gr)**	**Percentage**
M_01	1.1	1%	1.9	2%	17.0	17%	36.2	36%	23.6	24%	18.5	18%	1.8	2%
M_02	0.1	0%	0.2	0%	1.5	2%	9.8	10%	23.6	24%	44.0	44%	20.8	21%
M_03	0.2	0%	0.2	0%	3.6	4%	10.0	10%	26.1	26%	43.6	44%	16.2	16%
M_04	0.6	1%	3.3	3%	12.5	13%	17.7	18%	25.0	25%	32.0	32%	8.9	9%

M_05	7.0	7%	12.7	13%	30.7	31%	34.2	34%	10.1	10%	4.2	4%	1.1	1%
M_06	4.4	4%	3.2	3%	8.1	8%	11.7	12%	20.3	20%	33.4	33%	18.9	19%
M_07	0.2	0%	2.2	2%	16.5	17%	27.8	28%	16.2	16%	27.8	28%	9.3	9%
M_08	9.8	10%	24.0	24%	24.7	25%	9.9	10%	5.7	6%	16.5	16%	9.4	9%
M_09	0.6	1%	2.7	3%	5.0	5%	33.4	33%	42.5	43%	12.7	13%	3.0	3%
M_10	0.3	0%	0.3	0%	3.2	3%	22.0	22%	30.5	30%	32.5	32%	11.2	11%
M_11	1.4	1%	2.7	3%	12.9	13%	42.9	43%	31.3	31%	8.3	8%	0.5	0%
M_12	1.8	2%	5.3	5%	20.6	21%	33.9	34%	19.7	20%	16.3	16%	2.5	3%
M_13	0.1	0%	1.2	1%	11.6	12%	43.2	43%	24.9	25%	15.3	15%	3.8	4%
M_14	0.5	0%	5.0	5%	27.0	27%	36.8	37%	17.3	17%	11.3	11%	2.2	2%
M_15	0.4	0%	3.2	3%	24.2	24%	33.6	34%	22.8	23%	12.8	13%	3.0	3%
M_16	8.4	8%	13.4	13%	30.4	30%	24.7	25%	14.6	15%	8.2	8%	0.4	0%
M_17	0.8	1%	3.6	4%	19.6	20%	41.0	41%	20.5	20%	12.5	13%	2.0	2%
M_18	0.0	0%	0.8	1%	3.4	3%	51.0	51%	31.3	31%	11.9	12%	1.5	2%
M_19	0.1	0%	1.4	1%	8.3	8%	16.6	17%	28.7	29%	34.8	35%	10.2	10%

M_20	0.8	1%	3.5	4%	18.9	19%	21.9	22%	19.2	19%	27.2	27%	8.5	9%
M_21	0.1	0%	0.8	1%	6.0	6%	41.1	41%	30.6	31%	16.6	17%	4.8	5%
M_22	0.0	0%	0.3	0%	2.9	3%	23.2	23%	41.5	41%	26.1	26%	6.1	6%
M_23	0.1	0%	0.2	0%	2.7	3%	16.8	17%	40.4	40%	35.2	35%	4.7	5%
M_24	0.1	0%	0.2	0%	1.1	1%	9.0	9%	30.7	31%	50.3	50%	8.7	9%
M_25	4.4	4%	2.5	2%	12.3	12%	29.5	30%	31.7	32%	15.8	16%	3.7	4%
M_26	4.2	4%	11.2	11%	10.5	10%	9.5	9%	41.6	42%	21.1	21%	2.0	2%
M_27	6.6	7%	7.3	7%	11.4	11%	23.5	23%	40.5	40%	10.0	10%	0.7	1%
M_28	12.8	13%	16.5	17%	26.0	26%	17.1	17%	12.5	12%	11.7	12%	3.3	3%
M_29	2.2	2%	3.7	4%	14.5	14%	25.7	26%	26.2	26%	20.6	21%	7.2	7%
M_30	1.1	1%	4.4	4%	11.7	12%	21.4	21%	29.4	29%	24.4	24%	7.7	8%

Abundance of MP

A total of 564 MP particles were identified from 30 sediment samples collected along the Tena River. Abundances per sample are depicted in Table 2. Microplastics tallied in the contamination controls blanks were 5 particles representing 0.1% of all MP particles found in the sediment samples.

Table 2. This table includes information on the number of sampling zone of each sediment sample, the number of microplastics particles (MP) found in each sample, the slope value of each sample (indicating the slope of the land where the sample was taken) and the transformed weight for statistical analysis in grams (gr) of the sediment collected in each granulometric fraction after sieving.

Zone	Sample	Number of MP found	Slope	2 mm (gr)	1mm (gr)	500 µm (gr)	250 µm (gr)	125 µm (gr)	63 µm (gr)	> 63 µm (gr)
Zone 6	M_30	16	4.62	1	1.4	1.8	2.1	2.3	2.2	1.7
Zone 6	M_29	10	4.62	1.2	1.4	2	2.3	2.3	2.1	1.6
Zone 6	M_28	8	4.62	1.9	2	2.3	2	1.9	1.8	1.3
Zone 6	M_27	3	4.62	1.6	1.6	1.8	2.2	2.5	1.8	0.9
Zone 6	M_26	24	4.62	1.4	1.8	1.8	1.8	2.5	2.1	1.2
Zone 5	M_25	40	6.85	1.4	1.3	1.9	2.3	2.4	2	1.4
Zone 5	M_24	20	6.85	0.5	0.7	1	1.7	2.4	2.7	1.7
Zone 5	M_23	14	6.85	0.5	0.7	1.3	2	2.5	2.4	1.5
Zone 5	M_22	9	6.85	0.4	0.7	1.3	2.2	2.5	2.3	1.6
Zone 5	M_21	10	6.85	0.5	0.9	1.6	2.5	2.4	2	1.5
Zone 4	M_20	12	5.71	0.9	1.4	2.1	2.2	2.1	2.3	1.7

Zone 4	M_19	10	5.71	0.6	1.1	1.7	2	2.3	2.4	1.8
Zone 4	M_18	8	5.71	0	0.9	1.4	2.7	2.4	1.9	1.1
Zone 4	M_17	3	5.71	0.9	1.4	2.1	2.5	2.1	1.9	1.2
Zone 4	M_16	7	5.71	1.7	1.9	2.3	2.2	2	1.7	0.8
Zone 3	M_15	8	4.62	0.8	1.3	2.2	2.4	2.2	1.9	1.3
Zone 3	M_14	19	4.62	0.8	1.5	2.3	2.5	2	1.8	1.2
Zone 3	M_13	48	4.62	0.5	1	1.8	2.6	2.2	2	1.4
Zone 3	M_12	31	4.62	1.2	1.5	2.1	2.4	2.1	2	1.3
Zone 3	M_11	6	4.62	1.1	1.3	1.9	2.6	2.4	1.7	0.8
Zone 2	M_10	29	5.71	0.7	0.7	1.3	2.2	2.3	2.4	1.8
Zone 2	M_09	24	5.71	0.9	1.3	1.5	2.4	2.6	1.9	1.3
Zone 2	M_08	16	5.71	1.8	2.2	2.2	1.8	1.5	2	1.8
Zone 2	M_07	11	5.71	0.7	1.2	2	2.3	2	2.3	1.7
Zone 2	M_06	63	5.71	1.4	1.3	1.7	1.8	2.1	2.4	2.1
Zone 1	M_05	17	5.94	1.6	1.9	2.4	2.4	1.8	1.4	1

Zone 1	M_04	29	5.94	0.9	1.3	1.9	2.1	2.2	2.4	1.7
Zone 1	M_03	26	5.94	0.7	0.7	1.4	1.8	2.3	2.6	2
Zone 1	M_02	27	5.94	0.5	0.7	1.1	1.8	2.2	2.6	2.1
Zone 1	M_01	16	5.94	1	1.2	2	2.5	2.2	2.1	1.2

Shapes, colors and sizes of microplastics

Fibers were the only MP shape found in the 30 samples analyzed. The most common colors were transparent (74.4%), blue (18.8%), red (4.5%), black (1.3%), and other (0.8%). The average length of the fibers was 613 µm and the median length of 615 µm.

Sediment grain size

Sediment analysis was performed by classifying the grain size into 7 fractions, from (2 mm) to (<63 µm), which were divided into two groups: coarse sediments and muds. The results indicate that samples with a higher proportion of fine sediments had a significantly higher concentration of microplastics (MP). This pattern is visualized in Figure 2, while Figure 3 visualizes the concentration of microplastics in coarse sediments for both groups and shows the relationship between grain size and the amount of microplastics found. The figures reveal that as the proportion of muds in the samples increases, the amount of microplastics also increases. This behavior can be explained by the greater capacity of muds to retain microplastics due to their higher specific surface area and higher adsorption capacity. The results suggest that a higher presence of muds is associated with a higher concentration of microplastics, which is relevant for the evaluation of microplastic contamination in different environments.

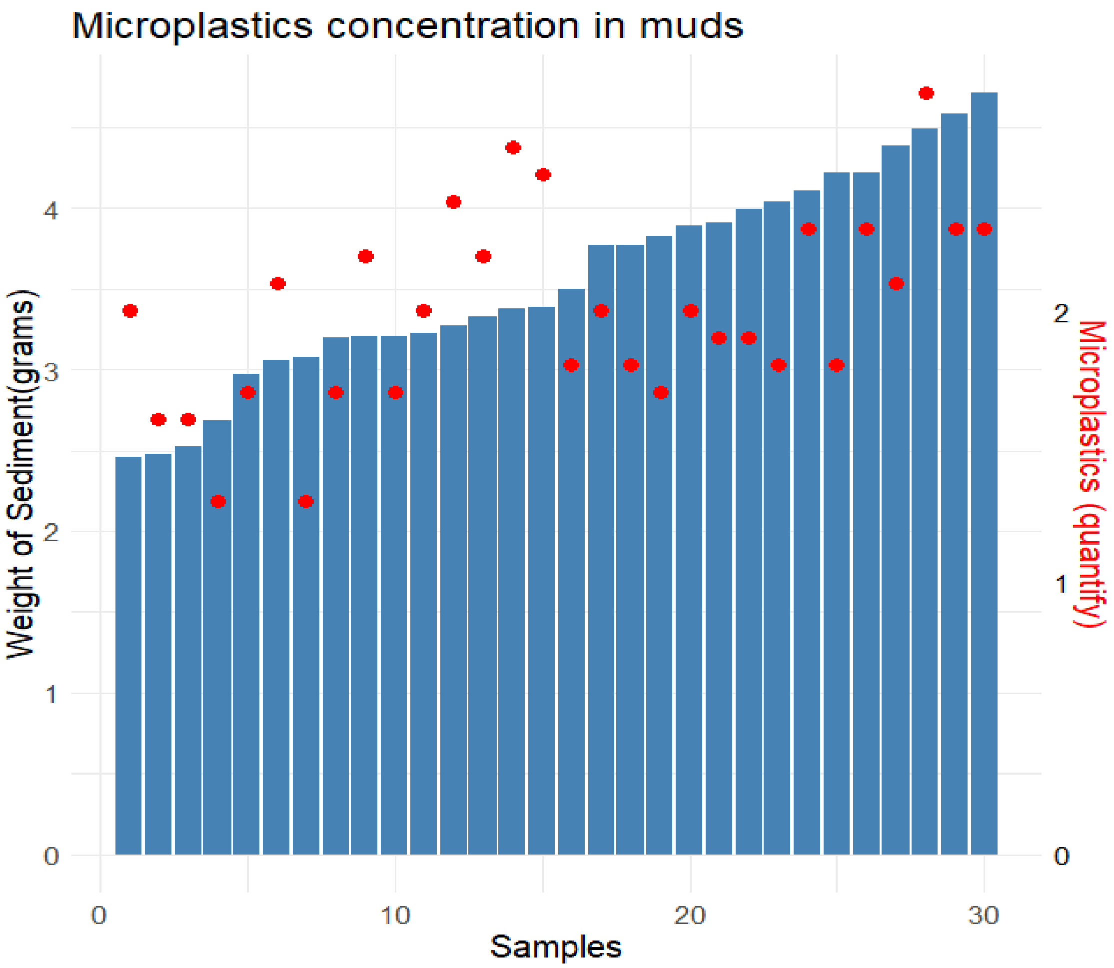


Figure 2. It shows the concentration of microplastics (amount) VS the amount of muds (grams) in the different samples ordered from the lowest to the highest amount of muds. The X axis shows the number of samples while the Y axis on the left shows the amount of muds (grams), on the other hand the Y axis on the right shows the amount of microplastics found in each sample.

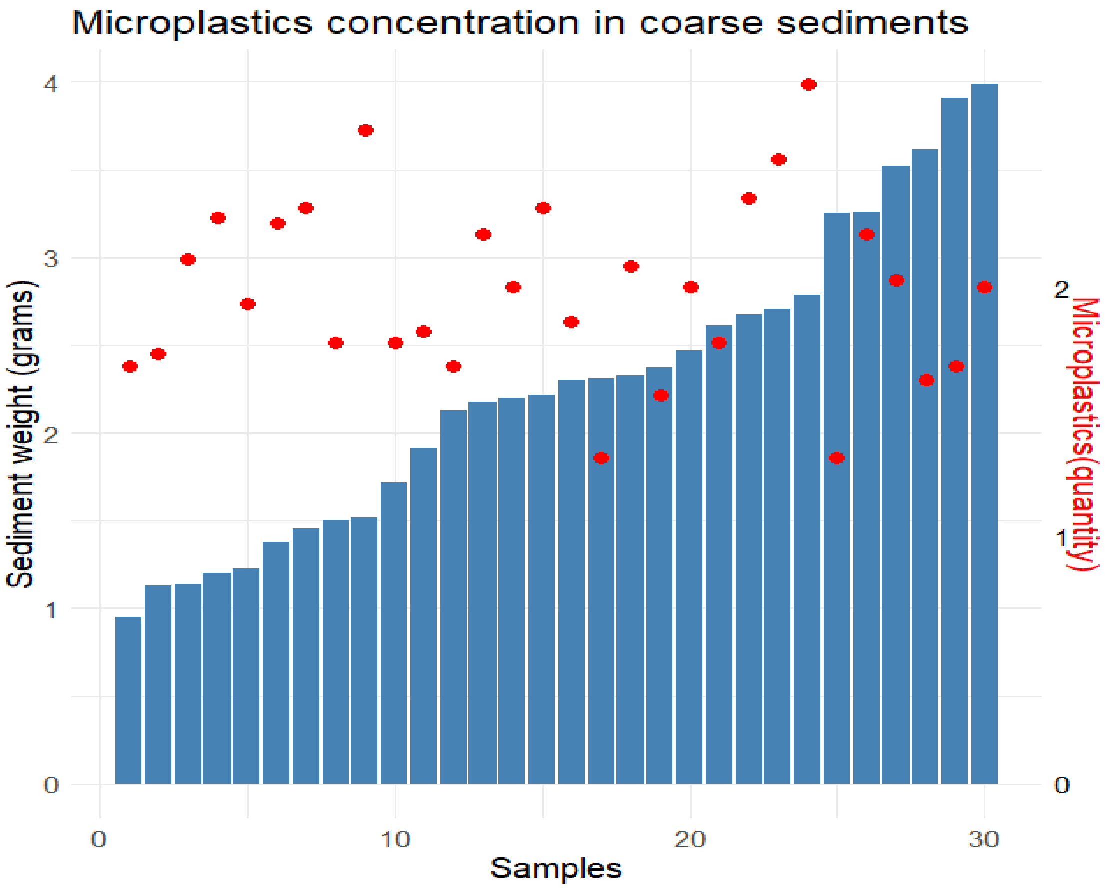


Figure 3. It shows the concentration of microplastics (amount) VS the amount of coarse sediments (grams) in the different samples ordered from the lowest to the highest amount of coarse sediments. The X axis shows the number of samples while the Y axis on the left shows the amount of coarse sediments (grams), on the other hand the Y axis on the right shows the amount of microplastics found in each sample.

Data analysis

The data were grouped into different grain size categories to facilitate the analysis. Sediments were classified into groups according to their size: coarse sediments (> 2 mm and >1 mm) and muds (>63 µm and <63 µm). This classification allowed a more detailed analysis of the differences between extreme size fractions and the distribution of extreme values. In addition, a transformation of the data was performed by applying the square root to the weights of the different sediment and microplastic fractions, in order to stabilize the variance and approximate the distribution of the data to normality (Fernandez, 1992). Subsequently, normality tests were carried out to verify whether the transformed data followed a normal distribution, providing a solid basis for interpreting the differences observed between the different grain size groups.

Shapiro Wilk test

In the result of the Shapiro-Wilk test to verify the normality of the data, the following results were obtained: in the data of coarse sediments the associated p-value was 0.1937. While the data group of muds had an associated p-value of 0.4585. Where it shows normality in both cases, given that the p-values are greater than the conventional significance level of 0.05, there was not enough evidence to reject the null hypothesis of normality, as can be seen in Figure. 4

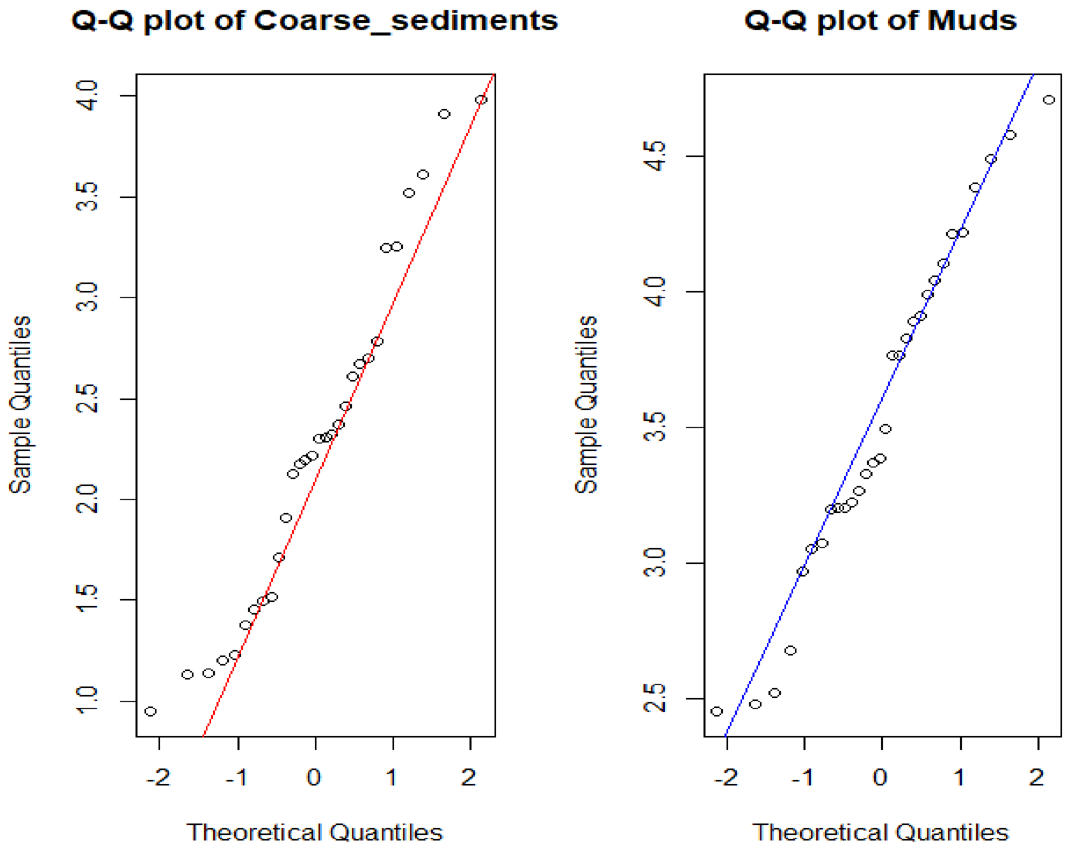


Figure 4. Results of the Shapiro-Wilk test to verify the normality of the data in coarse sediments and muds.

Analysis of Variance (ANOVA)

The results revealed a statistically significant difference between the muds and coarse sediments groups in terms of the measured variable ($p < 0.05$). The p value obtained was ($p = 1.09e\text{-}08$) being an extremely low value.

Boxplot

The results of the analysis revealed that no outliers were found in either group. This analysis shows that the distribution of values in both groups is relatively symmetrical and that the medians are well centered in the boxes, showing consistency in the data for each group. See in Figure 5.

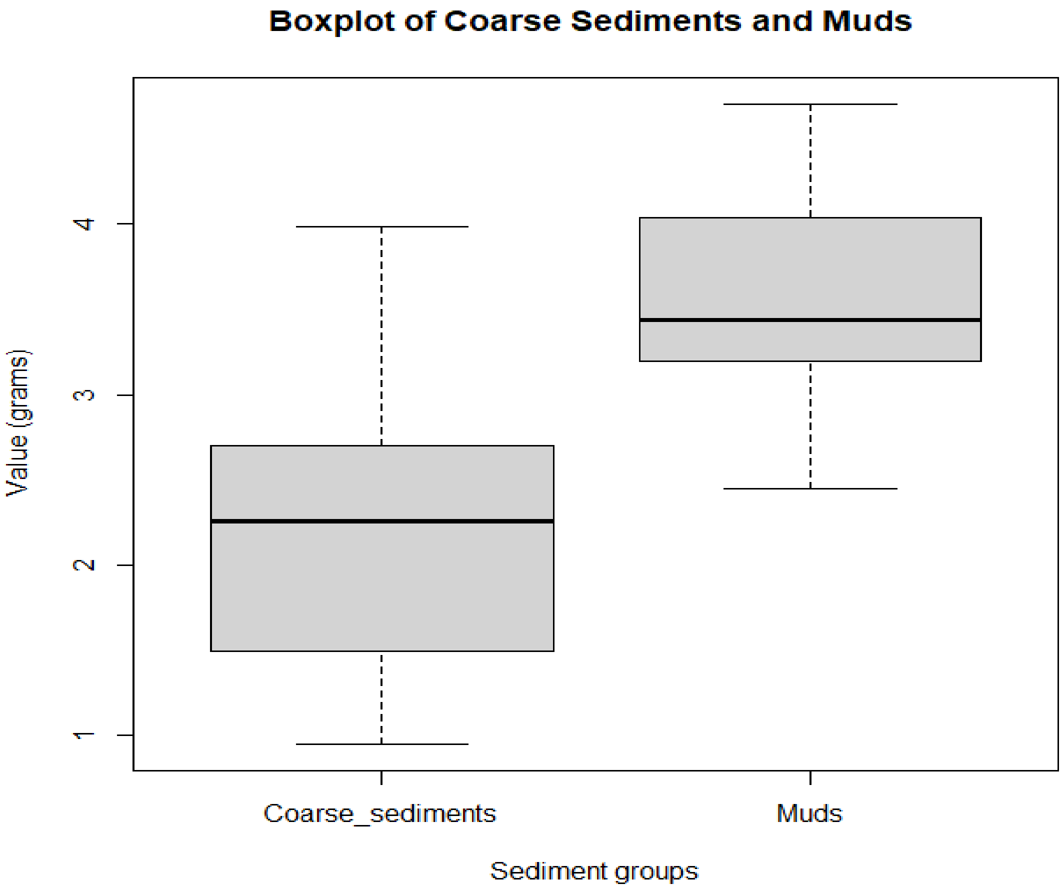


Figure 5. It illustrates the distribution of coarse sediment and muds values. The X-axis represents the different sediment groups (coarse sediments and muds), while the Y-axis shows the sediment value in grams. Each box on the graph represents the interquartile range (IQR) of the data of the corresponding group, showing the values between the first and third quartile. The

line within each box indicates the median of the group, providing an idea of the central tendency of the data.

Correlation between MP abundance and grain size

To determine if microplastic abundance is correlated with particle size, a Pearson correlation was performed on the seven particle size fractions as shown in Figure 6, which shows variations in the relationship between these variables. For the fraction (G1) 2mm, the correlation is very weak (-0.045) and the p-value is high (0.813), indicating that there is insufficient evidence for a significant correlation. Fraction (G2) 1 mm shows a weak negative correlation (-0.195) with a p-value of 0.302, suggesting that the relationship is not significant. Fraction (G3) 500 µm also shows a weak negative correlation (-0.228) with a p-value of 0.226, with no evidence of significance. The correlation for fraction (G4) 250 µm is negative and somewhat stronger (-0.286), but the p-value (0.125) is still above the significance threshold. The fraction (G5) 125 µm shows almost no correlation (-0.029) and a very high p-value (0.877), indicating the absence of a significant correlation. In contrast, the fraction (G6) 63 µm shows a moderate positive correlation (0.393) with a p-value of 0.032, suggesting a significant correlation. Finally, the fraction (G7) <63 µm has a strong positive correlation (0.515) and a p-value of 0.004, indicating a statistically significant correlation.

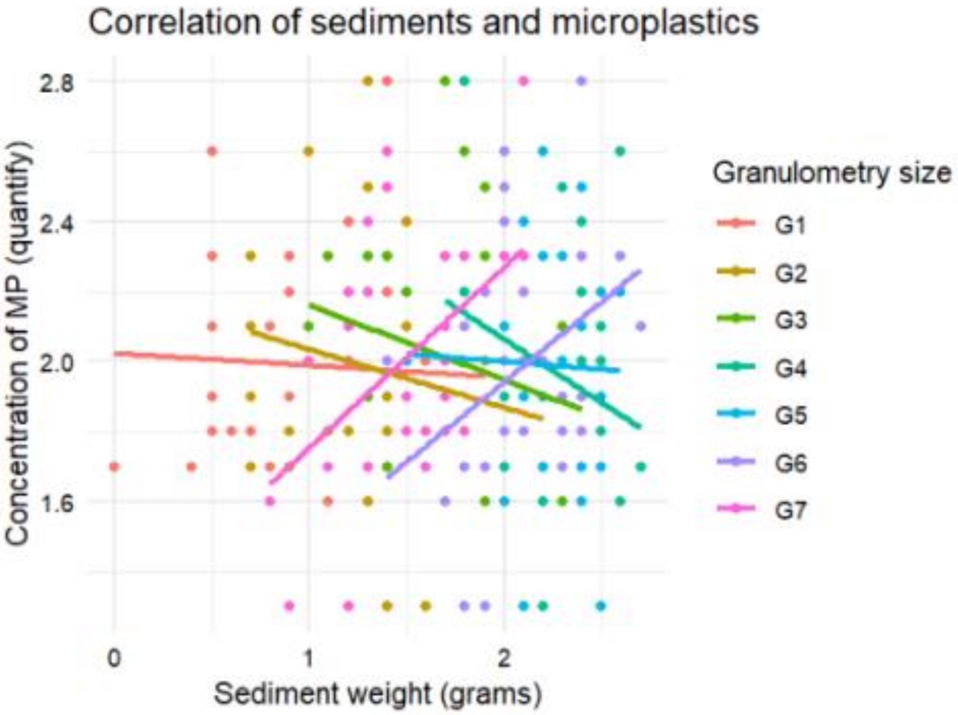


Figure 6. Correlation of the seven different sediment fractions between the amount of MP found in each sample.

From this analysis, fractions were grouped into two extreme categories: coarse sediments (2 mm and 1 mm) and muds (> 63 µm and < 63 µm). The abundance of coarse sediments and microplastics presented a non-significant negative correlation (r = -0.11, p-value = 0.54). In contrast, the abundance of muds and microplastics showed a significant positive correlation (r = 0.46, p-value = 0.009), see Figure 7.

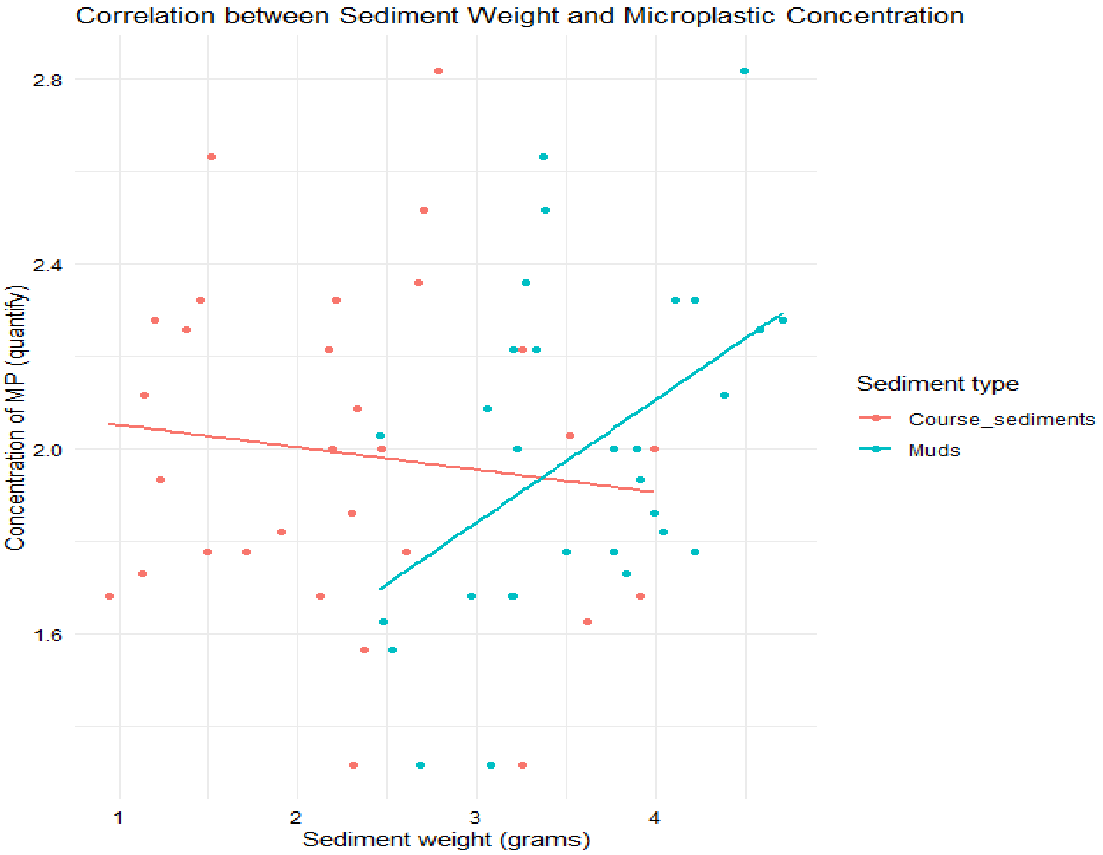


Figure 7. Correlation of muds and coarse sediments between the amount of MP found in each sample.

DISCUSSION

The accumulation of microplastics depends on grain size. The amount of microplastics is positively correlated with increasing muds (63 um and <63 um) (r=0.46, p-value= 0.009). Although the abundance of MP decreases with increasing concentration (weight) of coarse sediments (r= -0.11, p-value= 0.54), this correlation is not significant, indicating a large variability in the abundance of MP in coarse sediments and suggesting that the presence of these sediment sizes (>2 mm and >1 mm) is not a determining factor in MP accumulation. Given the variability of MP concentration in coarse sediments, their sampling should be avoided when estimating MP abundance. This positive correlation between the presence of muds and microplastic abundance highlights the importance of understanding MP transport and deposition processes in river systems (Wagner et al., 2019). Furthermore, analysis of variance (ANOVA) revealed a statistically significant difference between the fine sediment group versus the coarse sediment group in terms of MP abundance, with an extremely low p-value (p = 1.09e-08). These results highlight the importance of taking sediment size ans texture into account when assessing the presence of microplastics in riverine environments (Thompson et al., 2009).

The abundance of MP in samples taken from the same river at the same time will produce a higher number of MP if the samples are collected from locations where there is a greater amount of muds. Conversely, if samples from the same river are rich in coarse sediments, the abundance of MP will be low and highly variable. Within the identified relationship, it is perceived that the abundant presence of microplastics (MP) is linked to the sediment granulometry; as the presence of muds increases, a higher amount of microplastics is recorded.

To accurately compare the abundance of microplastics (MP) between muds and coarse sediments, surface samples were collected in accumulation zones, such as the river banks. Prior to sampling, field visualization was carried out to observe sediment accumulation and the presence of organic matter. It was found that at that initial stage there was a notable accumulation of organic matter. However, during sampling, it was observed that the accumulation of organic matter had decreased considerably. This approach allowed the collection of sediments with more representative granulometric characteristics and less influenced by organic matter. The collection was carried out after a precipitation event that caused an increase in the river level, resulting in the deposition of a new layer of sediment.

In this study, a significant amount of fiber-type microplastic particles were found in freshwater sediments. The results revealed the presence of a total of 564 MP particles in 30 sediment samples collected along the river. The fibers imply that the presence of MP is due to atmospheric transport not derived from the fragmentation of greater than five plastics. Sampling took place after a precipitation peak that increased the river flow removing previously deposited materials. Therefore, the Van Zuidam slope classification from a DEM model was used for sampling. This slope classification only helped to determine possible sampling zones a priori (before sampling). This does not guarantee that the zones chosen in the DEM have to be sampled. If there is no sediment in the area, the nearest area was searched. This is why it was assumed that the proposed method is 100% effective, but it is only used to identify possible sampling zones. This means that if sediment is found in the area in the field, it is collected, while if it is not found because the model has failed, then something nearby is searched for.

Then the MP that were collected are mainly influenced by the deposition processes after the rainfall event. Having fragments or films would represent local contamination, therefore the sampling design worked properly. An indication that the analysis of microplastics (MP) in this study has little prior contamination is the observation that only fibers of MP were found in the samples. If there had been direct contamination by human activity, such as the presence of people on nearby beaches, it is likely that other types of MP fragments, such as spheres, shards, etc., would have been found. The exclusivity of the fibers suggests that they were transported by the wind and deposited in the interior of the Tena River basin, a protected area. This phenomenon supports the hypothesis that the precipitation event cleaned the previous sediments and deposited a new layer of sediments, providing a more suitable environment for the study of the natural distribution of MP in this river system.

When examining the physical characteristics of microplastics, we found that the most common form was fiber, representing 100% of the particles identified. The predominant color was transparent, followed by blue and red. These data are consistent with previous studies that have shown a similar prevalence of MP shapes and colors in aquatic environments (Harris (2020). In addition, size analysis revealed an average length of 612.603 µm, with a median of 614.529 µm. These dimensions suggest the possible source of the microplastics and provide valuable information for future research on the degradation and transport of plastics in the aquatic environment (Jambeck et al., 2015). Contamination during the sampling and analyses process was evaluated using an open petri dish (control). The number of fibers counted in the control represent 0.1% of the MP found in the samples. Therefore, manipulation during the analysis was not a significant source for MP contamination. The high abundance of fibers relative to other types of MP shapes is consistent with results obtained for environments dependent on atmospheric transport such as glaciers. Ice and snow samples from glaciers contain mainly fibers as MP accumulation depends on atmospheric transport (Cabrera, 2020). The prevalence of microplastic MP fibers suggests that rainfall in the Amazon region is contaminated with MP (Cabrera, 2022), highlighting the need for sustainable and effective environmental management (Das & Dash, 2020).

CONCLUSIONS

The study reveals a significant relationship between the amount of microplastics and the presence of muds, indicating a greater accumulation of microplastics in muds.

Although the presence of coarse sediments showed a tendency to decrease the abundance of microplastics, this correlation was not significant, highlighting the variability in the accumulation of microplastics in coarse sediments.

The sampling strategy, based on natural events such as precipitation, allowed minimizing previous contamination and providing more representative data. The exclusive observation of microplastic fibers suggests minimal prior contamination in the analysis, supporting the possible hypothesis that the sediments were flushed by the precipitation event, emphasizing the importance of considering natural events in future studies of microplastic distribution in rivers.

In this study, a significant amount of fiber-type microplastic (MP) particles was identified in freshwater sediments of the Tena River, with a total of 564 MP particles in 30 samples collected. This finding highlights the widespread presence of microplastic contamination in river ecosystems, underscoring the urgency of implementing more effective environmental management strategies.

The prevalence of clear, blue and red fibers among the microplastics found is consistent with previous studies, indicating possible common sources of contamination. The average length of 612,603 µm suggests that these particles may originate from degraded textiles and plastic products, providing a basis for future research on the sources and pathways of microplastics in the aquatic environment.

The correlation between the presence of muds and microplastic abundance highlights the importance of transport and deposition processes in the distribution of these contaminants. Statistical tests confirmed significant differences between the coarse sediment and muds groups in terms of MP abundance, emphasizing the need to consider sediment grain size in river pollution studies.

Future research should expand the geographic coverage and explore the temporal dynamics of microplastic contamination. The high abundance of fibers relative to other types of MP shapes is consistent with results obtained for environments dependent on atmospheric transport such as glaciers. Ice and snow samples from glaciers contain mainly fibers as MP accumulation depends on atmospheric transport (Cabrera, 2020). The prevalence of microplastic (MP) fibers suggests that rainfall in the Amazon region is contaminated with MP (Cabrera, 2022), highlighting the need for sustainable and effective environmental management (Das & Dash, 2020).

Limitations of this study include sample size and geographic concentration, which may influence the generalizability of the results.

Although microplastics are not as obvious to the naked eye as larger plastic debris, they could pose a greater environmental threat than macroplastics. This is due to their ability to be ingested and absorbed into the food chain (Cole et al., 2011). This finding highlights the need for further research to better understand the factors that influence the distribution and behavior of microplastics in freshwater environments, as well as their potential impacts on environmental and human healt

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