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MICROPLASTIC CONTAMINATION ALONG THE TENA RIVER, NAPO, ECUADOR.

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DEDICATORIA

A mis papás y abuelitos con mucho amor y cariño,
por su confianza y apoyo en todo momento,
por sus oraciones y bendiciones.

A mis hermanos Meli y Kevin por ser inspiración,
para poder seguir adelante y tener un futuro mejor.

A todas las personas que fueron parte del proceso.

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TABLA DE CONTENIDO

ÍNDICE DE TABLAS

ÍNDICE DE FIGURAS

RESUMEN

La producción y el consumo de plástico se han intensificado en las últimas décadas. Los residuos plásticos han terminado en el ambiente, donde se acumulan, fragmentan y transportan, provocando impactos sociales y ambientales. Sin embargo, la investigación sobre la contaminación por microplástico (MP) en los ríos interiores de la cuenca del Amazonas aún es escasa, especialmente en áreas escasamente urbanizadas, como el río Tena, ubicado en la Amazonía ecuatoriana. Analizamos el río Tena desde zonas vírgenes, hasta su paso por toda una zona urbana y evaluamos los patrones de distribución de microplásticos en agua, sedimentos y materia en suspensión, también evaluamos la influencia de factores externos (origen antrópico) e internos (velocidad del río y tamaño del sedimento) en los patrones de distribución de MP. En el laboratorio, los microplásticos fueron cuantificados y descritos por microscopía y los tipos de polímeros fueron identificados por espectroscopía infrarroja. Se encontraron más microplásticos en el sedimento (promedio 753 partículas kg^{-1}) y la mayoría de ellos fueron microplásticos pequeños (63-250 µm representando 66.36%), que en materia suspendida (promedio 129 partículas L^{-1}) y en el agua superficial (media 94 partículas L^{-1}). Encontramos que la densidad de población humana influye en la distribución de microplásticos en los sedimentos (r^2=0,9962, valor p=9,987e-05) y en la materia suspendida (r^2= 0,7375, valor p= 0,06232). En las aguas superficiales, las cantidades de microplástico se ven afectadas en menor medida por la densidad de población (r^2=0,3806, p-value= 0,2677) y la velocidad del río (r^2= 0,2914, p-value= 0,3477). Se encontraron fibras (87,37%), colores azules y transparentes (54,59%) y los tipos de microplásticos fueron celofán, poliacrilamida, resina de poliéster insaturada y poliestireno. El tipo y los colores encontrados indican que los microplásticos proceden principalmente de actividades antropogénicas como la pesca, la lavandería y la agricultura. Llegamos a la conclusión de que, tras el paso por zonas urbanas, se ha multiplicado por 2 a 5 la cantidad de PM en todas las matrices evaluadas. Esto indica una mala gestión de los residuos sólidos, incluso en las pequeñas ciudades de las zonas menos urbanizadas, en las regiones amazónicas.

Palabras clave: Sistema de agua dulce; materia suspendida; Región Amazónica; río interior; espectroscopia infrarroja por transformada de Fourier; Polímero

ABSTRACT

Plastic production and consumption have intensified in recent decades. Plastic waste has ended up in the environment, where it accumulates, fragments and is transported, causing social and environmental impacts. However, research on microplastic (MP) pollution in the inland rivers of the Amazon basin is still scarce, especially in sparsely urbanized areas, like The Tena River, located in the Ecuadorian Amazon. We surveyed the Tena River from pristine areas, to pass through an entire urban area and assess the microplastic distribution patterns in water, sediment and suspended matter, and also assessed the influence of external factors (anthropogenic origin) and internal factors (velocity of the river and sediment size) on MP distribution patterns. In the laboratory, the microplastics were quantified and described by microscopy and the types of polymers were identified by infrared spectroscopy. More microplastics were found in the sediment (mean 753 particles kg^{-1}) and most of them were small microplastics (63-250 µm representing 66.36%), than in suspended matter (mean 129 particles L^{-1}) and surface water (mean 94 particles L^{-1}). We found that human population density influences the distribution of microplastic in sediment (r^2=0.9962, p-value=9.987e^{-05}) and suspended matter (r^2= 0.7375, p-value= 0.06232). In surface waters the amounts of microplastic are affected to a lesser extent by population density (r^2=0.3806, p-value= 0.2677) and river velocity (r^2= 0.2914, p-value= 0.3477). Fibers (87.37%), blue and transparent colors (54.59%) were found and the types of microplastics were cellophane, polyacrylamide, unsaturated polyester resin and polystyrene. The type and colors found indicate that microplastics come mainly from anthropogenic activities such as fishing, laundry and agriculture. We conclude that, after passage through urban areas, there has been a 2 to 5-fold increase in the amount of PM in all matrices evaluated. This indicates poor solid waste management, even in small towns in less urbanized areas, in the Amazon regions.

Keywords: Freshwater system; suspended matter; Amazon Region; Inland River; Fourier transform infrared spectroscopy; Polymer

ARTÍCULO ORIGINAL DESARROLLADO BAJO LAS DIRECTRICES DE LA REVISTA SCIENCE OF TOTAL ENVIRONMENT.

1. INTRODUCTION

Plastic plays an increasingly important role in societies, and has been widely used because it is cheap, durable, versatile, lightweight and airtight (Horton et al., 2017; Horton and Dixon, 2018; Chatterje and Sharma, 2019). Plastic waste mostly (79%) ends up in landfills or, due to improper waste management, ends up in the environment (Geyer et al., 2017). Plastics tend to disintegrate due to environmental conditions (Horton and Dixon, 2018; Shen et al., 2019), when their sizes are smaller than 5 mm, they are defined as “secondary microplastics”, usually fibers, fragments or films (Chae and An., 2017; Chatterje and Sharma, 2019; Helm, 2017). In addition, there are microplastics that are manufactured in this size and added to cosmetics and personal care products, referred to as “primary microplastics” (Horton et al., 2017). All particles microplastics are prone to accumulate, transform and transport in the environment causing environmental and social impacts (Browne et al., 2015; Horton et al., 2017; Horton and Dixon., 2018; He et al., 2018; Cox et al., 2019; Kutralam et al., 2020; Zhang, 2020; Du and Wang, 2021; Villegas et al., 2021). So currently, environmental pollution by MP is one of the fastest growing emerging problems in the world and a concern in all ecosystems (Chae and An. 2017; Horton et al., 2017; Kutralam et al., 2020; Rillig and Lehmann, 2020).

However, most studies have been conducted in marine ecosystems (Chae and An., 2017; Kutralam et al., 2020; Ryan, 2014). Research in freshwater aquatic ecosystems is scarce, despite the fact that these environments provide an important conduit for microplastics between terrestrial ecosystems and marine environments (Horton and Dixon, 2018; Horton et al., 2017). There is very little research on the quantities, characteristics, and factors influencing their distribution in the environment that would allow us to better understand their fate, transport and accumulation (Kutralam et al., 2020). Studies in the Ecuadorian Amazon are urgent because in this region economic and extractive activities are mainly a source of waste (Capparelli et al., 2020; Galarza et al., 2021) and the waste collection and treatment system, ordinances and environmental education are deficient (Lucas et al., 2021). To date, they have been limited to describing microplastic pollution (Lucas et al., 2021), and there is substantial uncertainty about the effect of urbanization and hydrological properties on the distribution of MPs in rivers at the local level. Therefore, physicochemical characterization and determination of the factors (human population density, channel velocity, sediment size) that influence the abundance of MP is fundamental to understanding the patterns that microplastics follow in freshwater environments. For example, it has been shown that the presence of human settlement, finer sediments and lower velocities tend to contain higher amounts of microplastic (Klein et al., 2015; Horton and Dixon, 2018; Tibbets et al., 2018; Kutralam et al., 2020). It is clear that is clear that studies quantifying the abundance of microplastics and identifying the factors that influence their disposition are currently lacking in the Ecuadorian Amazon. The objective of this study is to establish the magnitude of the microplastic pollution in environmental samples (surface water, sediment and suspended matter) as a function of human population density, water velocity and particle size in the Tena River basin. Which would allow a better understanding of their fate, transport and accumulation in the environment.

2. MATERIALS AND METHODS

2.1. Study areas and sampling sites

The study site has an area of ~240.56 km^2, with about ~44135 inhabitants projected for the year 2020 (GADM TENA, 2019). The Tena River is located in the interior of the city and has a length of approximately 20 km, flows from the rural area, passing the urban area of the city, and eventually flows into Misahualli River reaching the upper basin of the Napo River, which is the main tributary of the northern Ecuadorian Amazon. Samples were collected from five sampling sites (P1- P5) along the Tena River, between points having a distance of ~ 3 km, with a sampling distance of ~15 km (Fig. 1). These points were selected to get an overview of microplastic contamination in the watershed and to identify how much the microplastic increase is from the higher, pristine zone (P1 y P2) to the lower zone that passes through multiple sources of contamination (P3- P5).

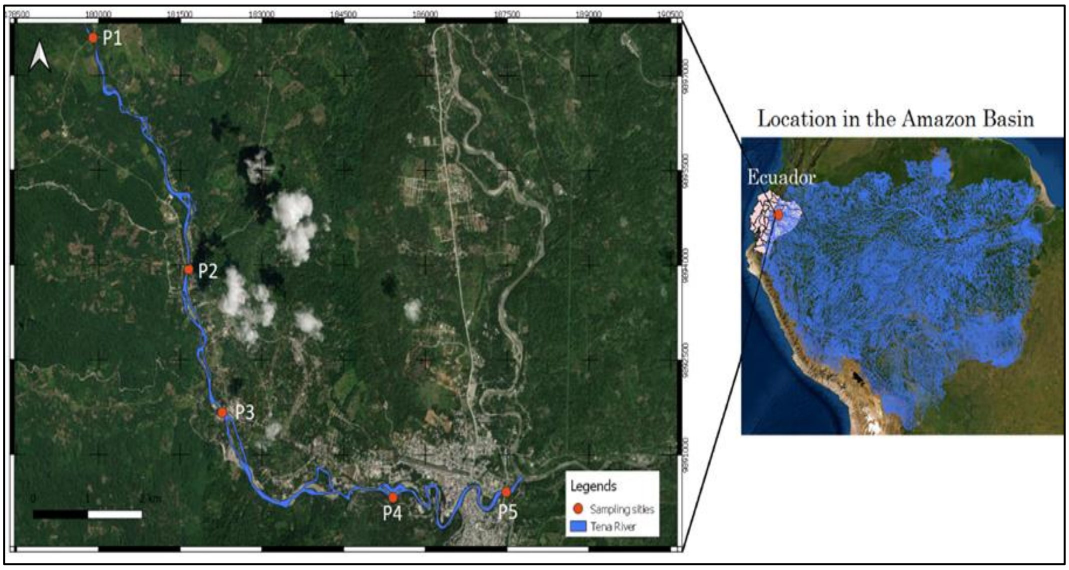

Fig. 1. Sampling sites in the Tena River from the rural zone (P1 and P2) to the urban zone (P3- P5**).**

2.2. Sample collection

Water and sediment samples were collected in April 2021. At each site, three sediment samples of approximately 500 milligrams weight were collected at depths of 5 to 10 cm. Sediment samples were collected in glass containers with a metal spoon (Tibbets et al 2018; Gimiliani et al., 2020; Lucas et al., 2021). Three samples of water and suspended matter were collected with a plankton net (200 microns). The net was introduced on the surface of the river against the current for 5 minutes to collect the microplastics carried by the river. Subsequently, the captured particles were introduced in glass containers with the help of water from the river, approximately 350 ml. The water and sediment samples were transported to the National Water Reference Laboratory of the Universidad Regional Amazónica Ikiam for processing. In addition, the stream velocity was recorded at the sampling point by implementing the float method and with a portable multiparameter HACH model HQ40D, water chemical parameters were recorded: electrical conductivity (EC, $\mu S.CM^{-1}$), temperature (T, °C), dissolved oxygen (DO, %), potential of hydrogen (pH), total dissolved solids (TDS, $mg. L^{-1}$) and floating matter of anthropogenic origin (absent- visible). The physical and chemical parameters of the water subsequently recorded were compared with the permissible parameters established in the water quality criteria for the preservation of aquatic and wildlife life in fresh waters and quality criteria for recreational waters (Acuerdo Ministerial 097-A, 2015) (Table 1.).

2.3. Sample preparation

Sediment samples were treated following established protocols for freshwater and Amazonian ecosystems (Tibbets et al 2018; Gimiliani et al., 2020; Lucas-Solis et al., 2021). First, they were dried at 60° C for 42 hours, homogenized, weighed 40 grams per sample and sieved in ranges of 2000- 4000 microns (µm), 250- 2000 µm and 63- 250 µm. The obtained subsamples were reweighed and stored in Petri dishes for further analysis.

Water samples were treated with an adaptation of the protocol established by the National Oceanic and Atmospheric Administration (NOAA) (Masura, 2015; Villegas et al., 2021). They were sieved in ranges of 2000- 4000 µm and 63- 250 µm. Microparticles from the 63 µm sieve were transferred to a 100 ml glass bottle with a minimum amount of deionized H_2O. Subsequently, the samples were dried at 60°C for 24 h, digested with 30% hydrogen peroxide solution (H_2O_2) in an oscillation incubator (60°C at 100 rpm for 2 h) and sieved over a membrane (pore size 0.45 µm) in a vacuum filtration system. The contents of the 2000 µm sieve were dried at 60 °C for about 42 h and stored in Petri dishes for further processing as independent environmental samples (suspended matter).

2.4. Observation and identification of microplastics.

For a robust analysis a combination of analytical tools was used to identify microplastics in the environmental samples (sediment, suspended matter and water), a microscopic analysis was implemented followed by a spectroscopic analysis (Shim et al., 2017). In the microscopic analysis an Olympus SZX7 stereomicroscope was implemented, with a magnification of 10X- 20X, in the sediment and suspended matter samples we evaluated a quadrant of the Petri dish. The particles were recorded considering the following characteristics: homogenous texture, unnatural shape such as spherical, unnatural homogenous color such as blue or yellow, have homogenous width and are not tapered at the end (Hidalgo et al., 2012; Helm, 2017). Microplastics were photographed, described by their relevant physical characteristics (dimensions, shapes, colors) (Helm, 2017; Tibbets et al., 2018; Wang et al., 2020; Lucas et al., 2021). On the other hand, in the surface water samples, the filter paper was fully evaluated, where the identified microparticles were characterized just like the other environmental samples. For spectroscopic analysis (Shim et al., 2017), environment samples were transported to the Laboratory of the Universidad de Cuenca (Ecuador) for processing. The The polymers of the plastic particles were identified using a Fourier transform spectrometer (FTIR) with a Thermo Scientific™ Nicolet™ iS™5, ATR iD7.

2.5. Quality assurance and quality control

A control was performed during the microscopy analysis of the environmental samples, a Petri dish with a filter paper was placed to identify the microplastics present in the workplace.

2.6. Characterization of sampling sites

The main waste generating sources in the Tena River were characterized using QGIS3 software. Land cover and land use data were obtained from Sistema de Información Geográfica del Ecuador and population data for Ecuador were obtained from the web portal https://data.humdata.org/. A buffer 3km upstream of each sampling point was delimited, land use and mean population density were bounded (Tibbets et al., 2018). To determine the population density, the points at each site were summed and to determine the proportion of land use, the area was found and subsequently the percentage of each activity was determined.

2.7. Data analysis

We applied a simple linear regression to determine the influence of each of the predictor variables (population density and river velocity) on the response variable (amount of microplastics). In the R program (Core R Team, 2019), statistics were performed using the *lm ()* function, obtaining the r^2 *value* and *p- value*.

3. RESULTS AND DISCUSSION

The main sources of microplastics identified in the Tena River basin are anthropogenic activities such as agriculture, fish farming and urbanization. In all the study sites, agriculture is predominant with >50% of the land use. Fish farming is evident in the sites with less anthropogenic activity (P1, P2). Anthropogenic activity is the only variable that has an increase in land use from the most pristine areas to the center of the city. Additionally, the parameters measured in surface water, potential of hydrogen, dissolved oxygen, total suspended solids, were within the permissible ranges within current regulations on water quality for aquatic and wildlife in freshwater (Acuerdo Ministerial 097-A, 2015). On the other hand, the parameter of floating matter of anthropic origin in the regulations is established as absent. However, the Tena River does not comply with the regulations on water quality criteria for aquatic and wild fauna in fresh water and water quality criteria for recreational purposes, because in the sites closest to the city (P3-P5) floating matter of anthropogenic origin could be observed (Table 1).

Table 1: Land use and characteristics of sampling sites: potential of hydrogen (pH) total dissolved solids (TDS, mg. L^{-1}), dissolved oxygen (DO, %), electrical conductivity (EC, $\mu S.CM^{-1}$), temperature (T, °C), floating matter of anthropogenic origin (absent- visible) and velocity river (m/s).

ID.	Agricultural (%)	Pisciculture (%)	Anthropic (%)	Water (%)	Conservation (%)	Human population density (inhabitant/km^2)	pH	TDS (mg.L-1)	DO (%)	EC (µS.CM-1)	T (°C)	Floating matter of anthropogenic origin	Velocity River
P1	98.11	0.12	0.1	1.67	-	5.44	7.38	17.5	80	24.4	20	Absent	1
P2	96.11	0.52	0.48	2.89	-	13.89	7.51	18.2	85.6	26.2	22.4	Absent	0.4
P3	82.22	-	6.11	3.33	8.33	42.67	7.41	17.55	80	26.6	23.7	Visible	0.64
P4	83.78	-	7.22	2.89	6.11	72.44	6.97	18.85	87	29	25.5	Visible	0.75
P5	63.33	-	28.89	7.78	-	208.67	6.88	22.1	82.5	34.3	26	Visible	0.36
Threshold Acuerdo Ministerial 097- A (2015)							6.5-9	max increment 10% of the condiction natural	>80%	-	-	Absence	-

3.1. Abundance and spatial distribution of microplastics

In the sediment, microplastics were present in all samples analyzed with a total of 3767 elements, the range of microplastic abundance was 400 to 1567 elements per kilogram of dry sediment (particles kg^{-1}). The mean abundance (753 particles kg^{-1}) is lower than that found in the Misahualli River (874 particles kg^{-1}), Ecuador (Lucas et al., 2021), due to the fact that this river receives some tributaries including the one in the study. However, it is in the range of plastic particles (17 to 8178 particles kg^{-1}), found in Amazonian rivers (Gerolin et al., 2020). We found that population density influences the amount of microplastic with an r^2= 0.9962 and p-value= $9.987e^{-05}$ (Fig. 2a). On the other hand, we found that river velocity has minimal influence on the amount of microplastic (r^2= 0.2606, p- value= 0.3795) (Fig. 2b). Thus, the number of plastic particles found was 56% higher in the more urban section (P3-P5) of the Tena River (average 978 particles kg^{-1}) compared to the more rural sites (P1, P2) of the Tena River (average 426 particles kg^{-1}). P5 had the highest abundance of microplastics (1567 particles kg^{-1}), within the urban reach, due to the effect of human population density, as this site is located at the end of the watershed, where residues from anthropogenic activities, traffic and other sources of pollution predominate compared to the other sampling sites. P2 had the lowest abundance of microplastics (400 particles kg^{-1}), maybe because this site is located in the rural area where the population density is relatively lower compared to the other sampling sites and it is also located far from the city. However, P1 had a higher abundance of microplastics than P2, which may be due to the action of the wind, the influence of the river velocity or the high tourist demand combined with a deficient solid waste collection system, where garbage tends to accumulate and spread in the environment, reaching the water bodies (Lucas et al., 2021). In general, a trend of increasing abundance with distance from the rural area is identified, this result is similar to that of River Tame, United Kingdom (Tibbetts et al., 2018), in the area of the Rhine-Main River, Germany (Klein et al., 2015) and Amazonian rivers (Gerolin et al., 2020).

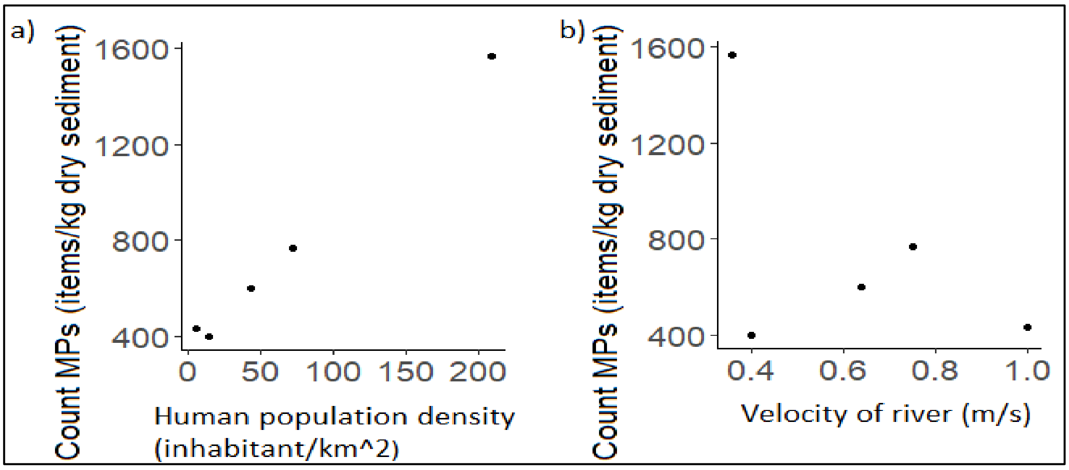

Fig. 2. Total abundance of microplastics in sediment (particles/kg dry sediment) of the Tena River according to human population density (inhabitant/ km^2) (a), and river velocity (m/s) (b).

In suspended matter, plastic particles were present in all samples analyzed in this study with a total of 649 items L^{-1}. The abundance of microplastics varied between P2 (74 particles L^{-1}) and P5 (197 particles L^{-1}) along the Tena River. We found that human population density influenced microplastic abundance with an r^2= 0.7375 and p-value= 0.06232 (Fig. 3a). On the other hand, the amount of microplastic has no dependence on river velocity (r^2= 0.0204, p-value= 0.8188) (Fig. 3b). Thus, the abundance of plastic particles was 43% higher in the more urban section of the Tena River (average 154.66 particles L^{-1}) compared to the more rural sites along the Tena River (average 92.5 particles L^{-1}). These findings indicate that the variation in the abundance of microplastics found follows a similar pattern to the distribution in the sediment samples.

However, in suspended matter, the evaluation of microplastics has not been evaluated in situ, it has been performed in the laboratory to test extraction methods (Goedecke et al., 2020).

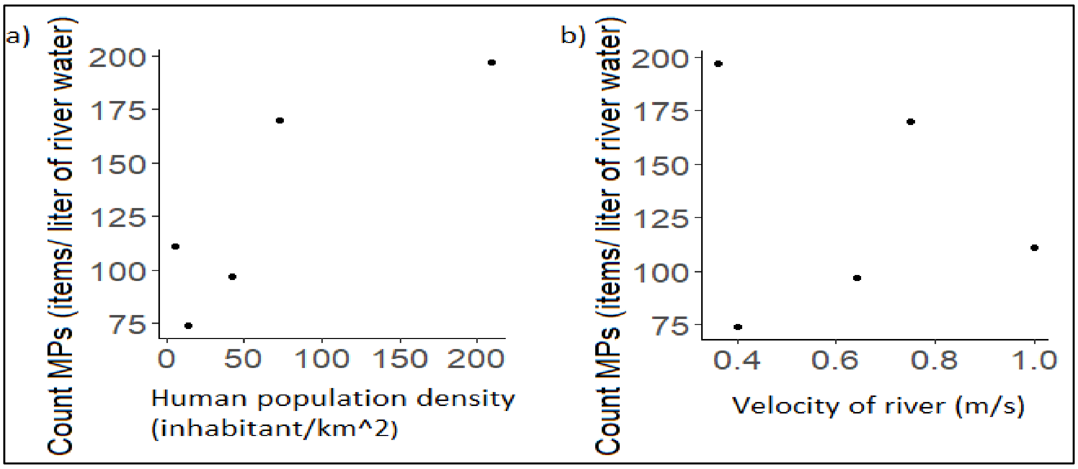

Fig. 3. Total microplastic abundance in the suspended matter (item/ liter of surface water) of the Tena River according to human population density (inhabitant/ km^2) (a), and river velocity (m/s) (b)

In surface waters, microplastics were detected at each sampling site in this study with a total of 470 plastic particles, the range of plastic items was 54- 153 particles per liter of surface water. The abundance of plastic particles was 56.80% in the urban section of the Tena River (mean 89 particles L^{-1}) and in the rural sites of the Tena River it was 43.20% (mean 101.5 particles L^{-1}). P5 had the highest abundance of microplastics (153 elements/L surface water) and P4 had the lowest abundance of microplastics (54 elements L^{-1}). In addition, we found that human population density has a relatively low influence on the amount of microplastics (r^2=0.3806, p-value= 0.2677). The influence that river velocity has is similar to that of population density (r^2= 0.2914 and p-value= 0.3477). These results indicate that population density and river velocity have a relatively low influence on the disposition of plastic particles in surface waters (Horton and Dixon, 2018). However, sites with low velocity environments (P2= 0.4 m/s, P5= 0.36 m/s) are observed to favor microplastic abundance at P2 (106 particles kg^{-1}) and P5 (153 particles kg^{-1}) which have the highest amounts of microplastics. This result is similar to that of the River Shore, Germany (Klein et al., 2015), which found a weak correlation between population density, river velocity and microplastic abundance.

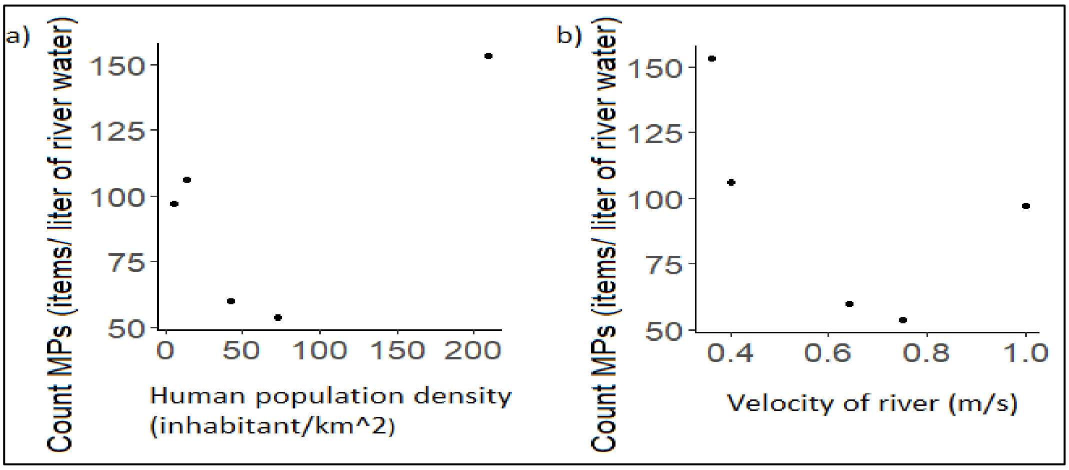

Fig. 4. Total abundance of microplastics in surface water (items/liter of surface water) of the Tena River according to human population density (inhabitant/ km^2) (a), and river velocity (m/s) (b).

3.2. Morphological characteristics of microplastics

The shapes of the microplastics detected in environment samples of the Tena River were secondary microplastic in the form of fibres, fragments or films. Fibres were the dominant, accounted for 87.37% of the total probed microplastic samples. The contents of fragments and films are lower, with proportions of ~9.50% and 3.13% respectively. In sediment, we found two types of microplastic, fibres and fragments (Fig. 5a). Fibres were the most abundant particle shape in all sites of study (~89.35%). In P2 and P3 all microplastics found were fibres. Because fibres are trapped between the settling sediment grains (Gimiliani et al., 2020) and larger densities tend to be retained in sediment (Alam et al., 2019). In suspended matter was mainly fibres, accounting for 88.30%, fragments representing 6% and films around 5.70% (Fig. 5b). Only P1 has the three types of microplastics found. In surface water, we found fibres were the most abundant particle type and contributed ~70.21%, films accounting for 24.69% and 5.10% corresponded to fragments of the total plastic count (Fig. 5c).

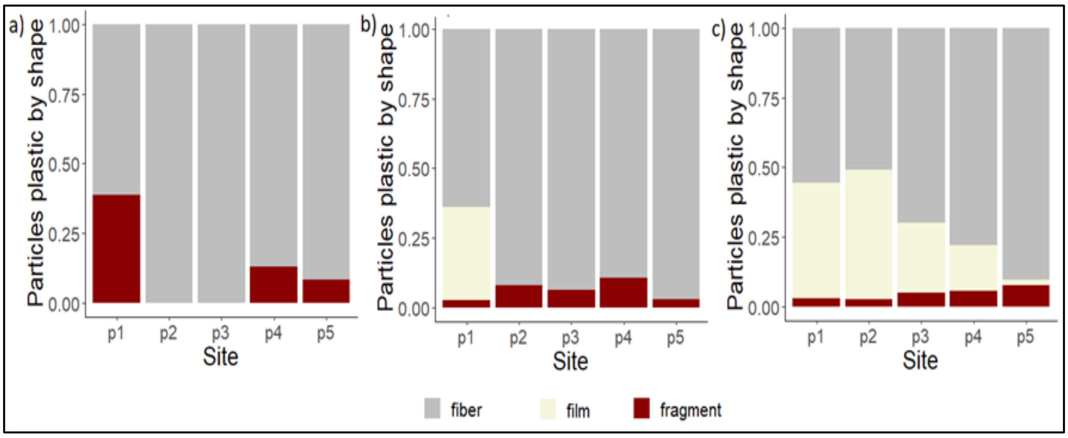

Fig. 5. Shape distribution of microplastics in sediment (a), suspended matter (b) and surface water (c)

The composition of microplastics shows little variation along the urban–rural transition of the Tena River. Overall, there is thus evidence for a predominance of secondary microplastics (i.e., fibres) within the environmental samples analyzed (Fig. 6 a, d). This result was similar with those of previous studies on freshwater systems (Vermaire et al., 2017; Alam et al., 2019; Wang et al., 2020; Li et al., 2020; Lucas et al., 2021). In Tena, the main sources of pollution are urban pollution, fish farming, mining and landfills (Capparelli et al., 2020; Galarza et al.,2021; Lucas et al., 2021). This type of microplastic found most likely originated from sources such as, household sewage, fishing, washing of synthetic textiles or transported from land via wind or surface runoff, due to inadequate waste disposal (Wang et al., 2020; Horton and Dixon, 2018; Horton et al., 2017; Gimiliani et al., 2020; Lucas et al., 2021). However, this is not universal because other studies show that fragments were the most predominant form of microplastic (Klein et al., 2015; Tibbets et al., 2018). The fragments and films (Fig. 6) found may have been derived from plastic products such as plastic bags after their use or improper treatment and materials used in agricultural cultivation such as films and water pipes (Horton & Dixon, 2017; Tibbets et al., 2018; Wang et al., 2020).

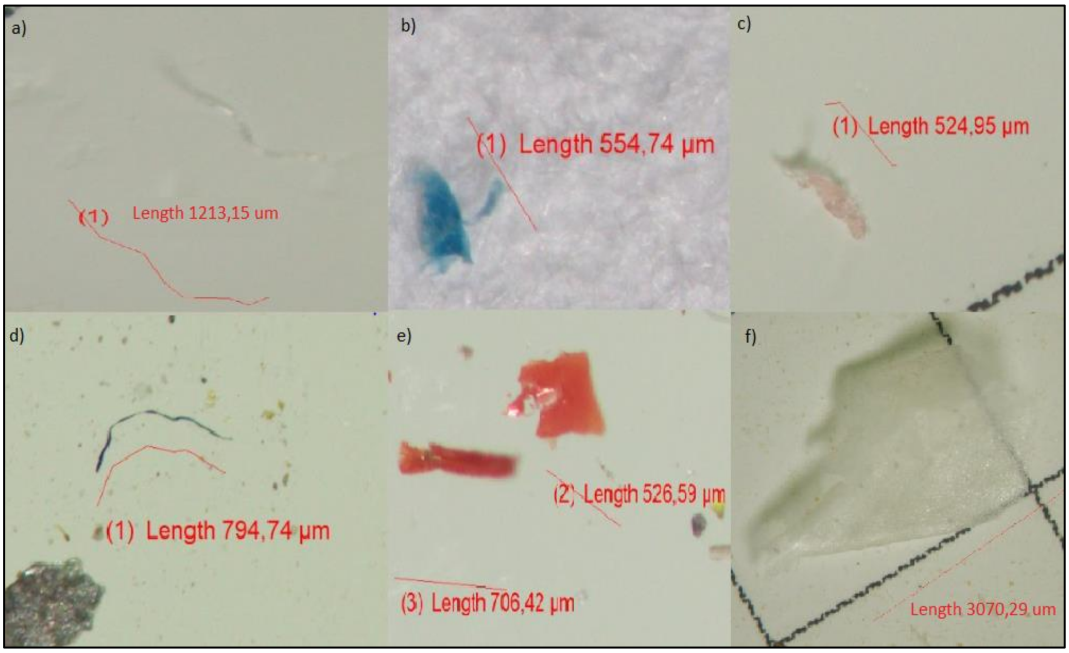

Fig. 6. Photographs of microplastics under the microscopy, namely fibres (a, d), fragments (b, e), films (c, f)

A variety of colors of microplastic in samples were detected in Tena River, and mainly included transparent (34.46%), blue (20.13%), red (11.62), black (11.35%), brown (9.18%), and other colours (13.26%), of which transparent and blue were the dominant colours. In sediment, we found transparent microplastics were the dominant accounted for 34.53% of the total probed microplastic samples, blue particles with proportion of 17.67%, brown items around 11.60%, the contents of red particles with a proportion of 11.46% and other colours with a proportion of 24.74% (Fig. 7a). In suspended matter, colours predominant are blue (27.75%), transparent (24.19%), red (14.79%), black (14.32%) and other colours accounting for 20.93% (Fig. 7b). In surface water, colours dominant are transparent (45.95%), blue (32.34.%), red (8.51%), black (6.38%) and 6.82% of others colours (Fig. 7c).

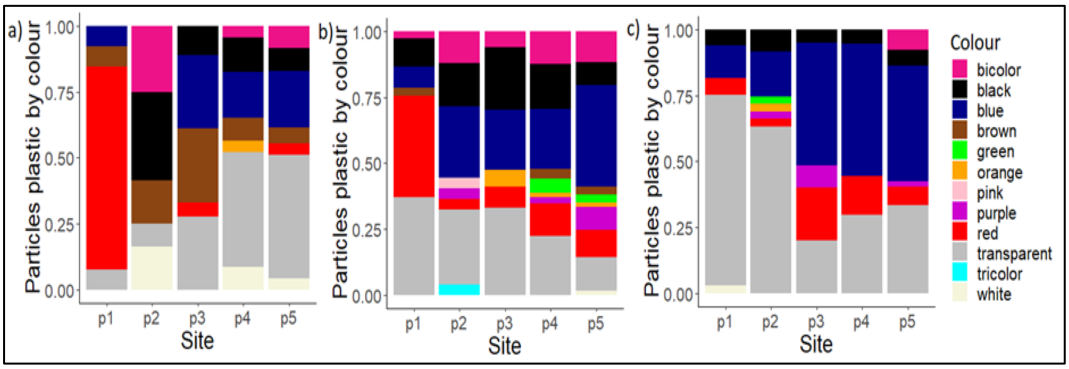

Fig. 7. Colour distribution of microplastics in sediment (a), suspended matter (b) and

surface water (c)

The variety of colours of microplastics illustrated the diversity of their sources of pollution. There is thus evidence for predominance of transparent microplastics and were mainly fibres and films. Also, because fibres were the principal shape of the microplastics, this result may have been related to the shape distribution. This result was similar with those of other studies on freshwater systems (Wang et al., 2020; Kutralam et al., 2020; Lucas et al., 2021).

The size distribution of microplastics was mainly divided into three ranges (2000- 4000 µm, 250-2000 µm, and < 250 µm); the greatest distribution was in 63- 250 µm (52.80%) followed by 250- 2000 µm (40.60%) and the lowest was 2000- 4000 µm (6.60%). In the sediment, the highest proportion of particles was found in the range 63- 250 µm representing 66.36%. In the range 250- 2000 µm a proportion of 32.75% was found and in the range 2000- 4000 µm it represents 0.87% of the total microparticles (Fig. 8a). In the environmental sample corresponding to suspended matter, the highest proportion was found in the range of 250- 2000 µm representing 66.25%, the microplastics in the size range of 2000 to 4000 µm had a proportion of 31.43% and the smallest proportion was found in the size range of 63- 250 µm with 2.31% (Fig. 8b). In the surface water particles, the greatest distribution was in 250- 2000 µm (68.08%) followed by 2000 -4000 µm (18.09%), and the lowest was 63 -250 µm (13.83%) (Fig. 8c).

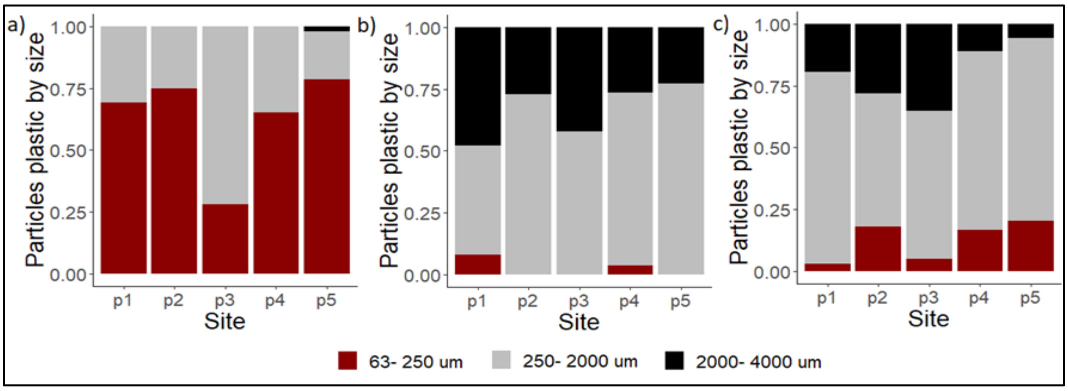

Fig. 8. Size distribution of microplastics in sediment (a), suspended matter (b) and surface water (c).

In sediments, these results provide information on the distribution of microplastics in different mesh sizes and show that the smaller the mesh size, the greater the number of plastic particles. The amount of small-sized microplastics (< 1 mm) accounted for the largest proportion, which was similar to the results of previous studies in the Amazon region (Lucas et al., 2021; Gimiliani et al 2020; Gerolin et al., 2020). These are abundant in small sizes because sand retains particles and accelerates plastic decomposition by intense weathering and abrasion (Enders et al., 2019; Ding et al., 2019; Wang et al., 2020). In suspended matter and surface water, the particle size found is in the range of 250- 2000 µm, so they are medium-sized particles. In this case, due to high river velocities at most sampling points, the particles are being entrained for deposition in areas where the river velocity is lower (Ballent et al., 2016; Horton and Dixon, 2018; Enders et al., 2019). In addition, microplastics when in the environment can degrade to nanoplastics, which have a particle size between 1 nanometer (nm) and 100 nm (Shen et al., 2019). Microplastics and nanoplastics when in the environment biota consume causing effects mainly on growth, development, reproduction and metabolism, in addition they can be transferred along food chains (Shen et al., 2019; Wang et al., 2020).

3.3. Polymer identification of microplastics

In the environmental samples, the types of polymers found were cellophane, polystyrene (PS), polyacrylamide (PAM) and unsaturated polyester resin (UPR). Polymers are potential indicators of the origin of microplastic in the environment (Yan et al., 2019). Cellophane and PS are widely used in the production of packaging products (Yan et al., 2019; Wang et al., 2020). Cellophane is an organic cellulose-based polymer, it is commonly used in cigarette and food wrappers and it was been reported to be prevalent in water systems worldwide (Yang et al., 2015). PS is often used in fast food boxes, jewellery wrappers and is used in abundance in the manufacturing of clothing fabrics (Wang et al., 2020). PAM comes from its use as to prepare agricultural soil, in detergents and as water-absorbing polymers in many consumer products (Arp and Knutsen, 2019). UPR is used in a broad range of technological fields such as building construction, marine and land transportation industries, naval construction and waterlines. Due to their low cost, ease of fabrication, and high-performance properties (Thomas et al., 2019).

4. CONCLUSION

The characterization of land use, chemical and physical parameters in the study area allows understanding the factors that influence (anthropogenic activity, hydrodynamic properties) the disposition of microplastics in the environment. Therefore, depending on the matrix to be studied, the study of microplastics should consider the main factors influencing their distribution. In the Tena River basin, it was found that the amount of microplastics in the sediment and suspended matter depends on the population density. That is, more pristine locations have lower amounts of microplastic compared to locations where population density is higher, passing through the city at the outlet of the watershed. In the sediment, sediment size was also evaluated, indicating that the highest amounts of microplastics are found in the finest sediments, putting the surrounding biota at risk, as smaller microplastics can be more easily ingested. On the other hand, the abundance of microplastics found in surface waters depend on both population density and river velocity. Predominant characteristics, such as the most abundant microplastic type (fibers), predominant colors (blue, transparent) and chemical compositions, point to anthropogenic activities such as agriculture, waste generation, laundry and fishing as the main sources of microplastics in the Tena River basin. Therefore, if waste management remains inefficient, tourism, health and biota will be directly affected.

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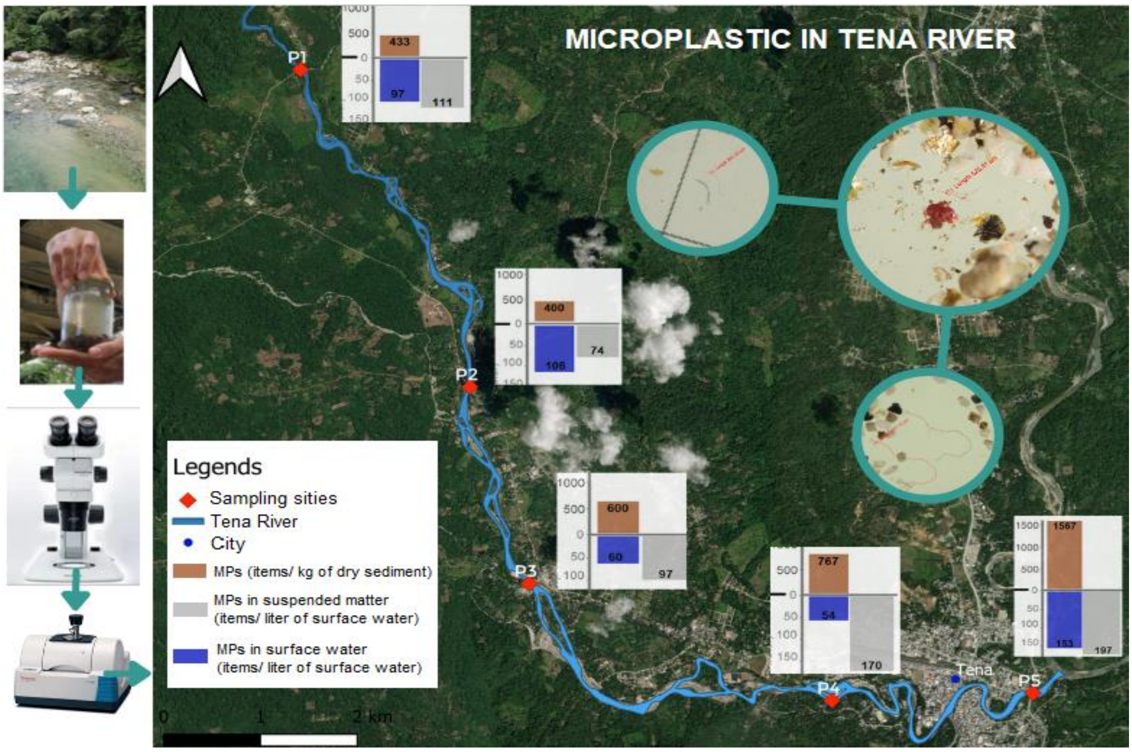
GRAPHICAL ABSTRACT



HIGHLIGHT

- Microplastics were investigated in environmental samples in Tena River.
- The amount of microplastics in the water and suspended matter samples of the Tena River are lower than the microplastics in the sediments.
- Human population density influences the amounts of microplastic in sediment and suspended matter, river velocity and population density influence the amount of microplastic in the water
- Fibres were the most abundant microplastic in the environmental samples.
- Particles with colored (transparent and blue) and small sized (63-250 mm) dominated the microplastic samples in sediment, and medium sized (250- 2000) dominated the microplastic samples in suspended matter and surface water.
- Cellophane, PS, PAM and UPR were the types of polymers found in the environmental samples.