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MICROPLASTIC CONTAMINATION IN TROPICAL HIGH ANDEAN LAKES: PERSPECTIVES ON SOURCE AND DISTRIBUTION IN REMOTE AREAS

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INGENIERO EN CIENCIAS DEL AGUA

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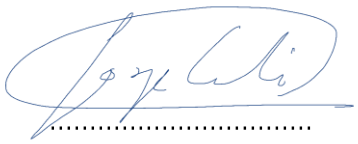
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Jorge Emilio Celi
Sangurima

DEDICATORIA

A mis padres, a mi hermana y mi hermano por el apoyo incondicional para culminar mis metas académicas.

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TABLA DE CONTENIDO

CARÁTULA

DECLARACIÓN DE DERECHO DE AUTOR..... ii

AUTORIZACIÓN DE PUBLICACIÓN EN EL REPOSITORIO INSTITUCIONAL..... iii

CERTIFICADO DE DIRECCIÓN DE TRABAJO DE INTEGRACIÓN CURRICULAR..... iv

DEDICATORIA..... v

AGRADECIMIENTOS..... vi

TABLA DE CONTENIDO..... vii

ÍNDICE DE TABLAS..... ix

ÍNDICE DE FIGURAS..... ix

RESÚMEN..... x

ABSTRAC..... xi

GRÁFICO RESUMEN..... 1

HIGHLIGHTS..... 1

INTRODUCCIÓN..... 2

MÉTODOS..... 3

Área de estudio y colecta de muestras..... 3

Extracción de microplástico..... 6

Análisis de microplástico..... 6

Muestra control..... 7

Rosa de los vientos..... 7

Análisis estadístico..... 7

RESULTADOS..... 8

Abundancia de microplástico en muestras de agua y sedimentos..... 8

Color, forma y tamaño en muestras de sedimento..... 9

Color, forma y tamaño en muestras de agua..... 9

Tipo de microplástico..... 11

Correlación entre la superficie de la cuencas y microplásticos..... 11

Rosa de los vientos..... 11

DISCUSIÓN..... 12

Abundancia de microplástico en agua y sedimento..... 12

Características de microplásticos: color, forma y tamaño..... 13

Polímeros……..... 15
Superficie de las micro cuencas con respecto a la abundancia…….. 15
Impactos de las actividades humanas……..…….. 16
Transporte atmosférico…… 16
CONCLUSIÓN…….. 17
AGRADECIMIENTOS……. 17
REFERENCIAS…… 18
MATERIA SUPLEMENTARIO…….. 23

ÍNDICE DE TABLAS

Tabla 1. Información sobre los sitios muestreados…….…….. 6

ÍNDICE DE FIGURAS

Figura 1. Localización geográfica de Ecuador (a), la reserva ecológica Cayambe-Coca (b) y los puntos muestreados en agua y sedimento por cada laguna (c), C13* es la estación meteorológica Salve Faccha……... 5
Figura 2. Abundancia de microplásticos en sedimento (a) y agua superficial (b)…..……. 8
Figura 3. Muestras de microplásticos en agua y sedimento del sistema de lagunas. Muestras de sedimentos: color (a), forma (c) y tamaño (e). Muestras de agua: color (b), forma (d) y tamaño (f)…….……..……..... 10
Figura 4. Correlación lineal entre microplástico y superficie de las micro cuencas de cada laguna en sedimento (a) y agua (b)…..……. 11
Figura 5. Gráfico de rosa de los vientos con datos dentro del periodo 2019 a 2020 tomados de la estación meteorológica Salve Faccha [C13]. Cada barra fue coloreada in proporción a la velocidad del viento registrado en la dirección representada……..... 12

RESUMEN

El fácil transporte de las partículas microplásticos (MPs) a través de las corrientes del agua y de aire han alcanzado todos los ecosistemas, incluso zonas remotas, como las montañas de gran altura. En el siguiente trabajo se estimó la abundancia y las características de MPs en el agua superficial y los sedimentos de cinco lagos de gran altitud desde los 3848 a 4245 m.s.n.m en los Andes ecuatorianos. Las concentraciones medias de MPs fueron de 10 ± 5 MP/m^3 en las muestras de agua y 2838 ± 1489 MP/kg en los sedimentos. No se encontró correlación entre la micro cuenca y la abundancia de MP de cada lago. Los MPs de color transparentes dominaron en todas las muestras de agua y las partículas de color blanco dominaron en las muestras de sedimentos. Los microplásticos que tenían un tamaño entre 150 y 1800 µm eran predominantes en los sedimentos, mientras que los de 1800 y 3400 µm en el agua. Las fibras y las películas fueron las formas más identificadas en el agua y sedimentos. Las composiciones poliméricas estaban compuestas por celofán, polietileno (PE) y polipropileno (PP). La pesca deportiva, zonas de campamento y turismo se identificaron como posibles fuentes locales de MPs. Como fuente externa podría ser mediante transporte atmosférico desde la región amazónica. Este trabajo tiene impacto en el sistema lacustre, su biodiversidad de especies y quienes hacen uso de este ecosistema.

***Palabras claves**:* Microplásticos, transporte atmosférico, lagunas de alta elevación, microcuenca, velocidad del viento.

ABSTRACT

Easy transportation of microplastic particles (MPs) through water and air currents has facilitated their spread over ecosystems, even in remote areas, such as high altitude mountains. I report the abundance and characteristics of MPs in surface water and sediments of five high elevation lakes ranging from 3848 to 4245 m.a.s.l in the Ecuadorian Andes. Average concentrations were 10 ± 5 MP/m^3 in water samples and 2838 ± 1489 MP/kg in sediments. I found that MPs abundance not is correlated with the micro watershed of the lake. Transparent MPs dominated in all water samples and white particles dominated in sediment samples. Microplastics between 150 and 1800 µm in size were predominant in sediments, whereas MPs between 1800 to 3400 µm were more common in water. Fibers and films were the predominant types in water and sediments. Predominant polymer compositions included cellophane, polyethylene (PE), and polypropylene (PP). Fishing, camping, and trekking might be the main local sources of MPs, while easterly winds from the Amazon region could be the main external source of MPs. This study has an impact on the lacustrine system, its biodiversity, and who made use of this environment.

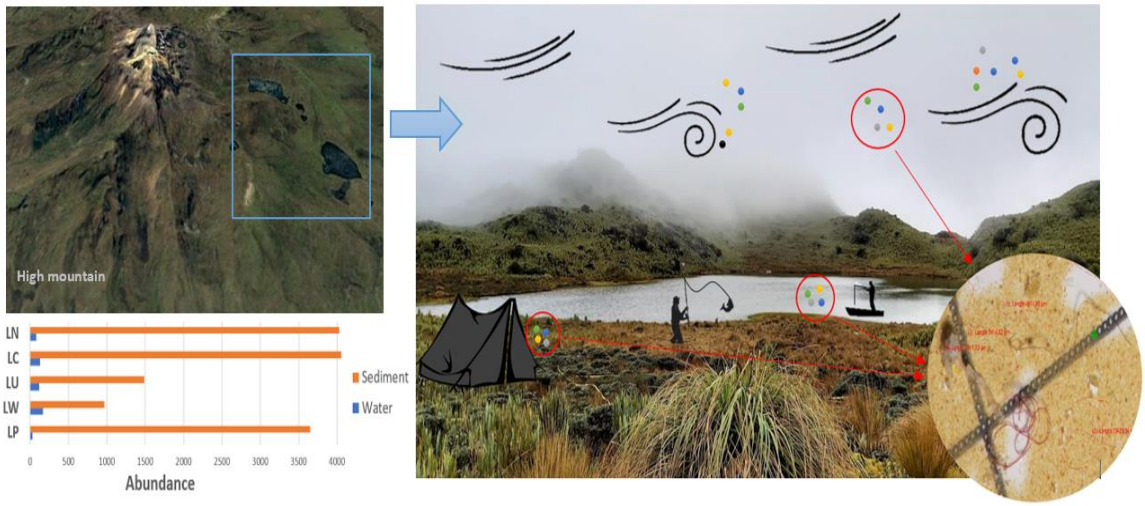
Keywords: Microplastic, atmospheric transport, high elevation lakes, micro-watershed, wind speed

SCIENCE OF THE TOTAL ENVIRONMENT

MICROPLASTIC CONTAMINATION IN TROPICAL HIGH ANDEAN LAKES: PERSPECTIVES ON SOURCE AND DISTRIBUTION IN REMOTE AREAS

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GRAPHICAL ABSTRACT



Made by: Ramos, Mariuxi, 2022

HIGHLIGHTS

- First evidence of microplastic in a tropical Andean lake system.
- Higher microplastic abundance in sediments than in water.
- Cellophane, PE, and PP were the dominant polymer types in water and sediment.
- Microplastic pollution sources are likely the atmosphere, fishing, camping, and trekking.

INTRODUCTION

Microplastic particles (MPs) are microscopic pieces of plastic between 5 mm to 1 µm (Thompson et al. 2004). MPs are present in the lithosphere, hydrosphere, and even the atmosphere (Petersen and Hubbart 2021). In recent years, atmospheric MPs have been explored, and findings show that they can reach high elevation mountains (Cabrera et al. 2020). In these areas, rain and snow are the main means of transportation (Allen et al. 2019) followed by, tourism and exploration activities like trekking (Cabrera et al. 2020; Napper et al. 2020). So far, few MP studies have been conducted in tropical mountains (Cabrera et al., 2022), high altitude rivers (Donoso and Rios 2020; Chauhan et al. 2021), or high mountain lakes (Çomaklı, Bingöl, and Bilgili 2020; Negrete et al. 2020). The MPs pollution studies help to register human activity in remote mountain ecosystems. Otherwise, high elevation catches the flux of chemicals coming from the lowland (Pastorino and Prearo 2020; Pastorino et al. 2022).

Research on MPs in the high-altitude lakes is new. Free et al. (2014) found 20.264 MP/m^2 in Lake Hovsgol, while Xiong et al. (2018) reported 180900 ± 229533 MP/km^2 in water and 50-1292 MP/m^2 in sediments, Qinghai lake. Negrete et al. (2020) measured 2.6 MP/L and 33 MP/kg in the water and sediments of lake Sassolo, respectively. In Dzhulukul lake and in Talmen lake, Malygina et al. (2021) found 5 MP/L and 8 MP/L, in surface water. Among the most likely transportation routes of MPs in terrestrial environments are wind currents (Yulan Zhang, Kang, Allen, Allen, and Gao 2020; Xia et al. 2020; Kang et al. 2019).

Many studies record the damage caused by MPs introduced in the food chain (Free et al. 2014; Xiong et al. 2018; Pastorino et al. 2021). Intestinal obstructions, hormonal changes and low reproductive performance are negative effects in some organisms (López 2021), due to MP has high resistance to degradation, easy propagation and chemical composition of varied polarity (Crawford and Quinn 2017).

Páramos, a type of ecosystem of grasslands and shrubs, are located in the high Andes. These have high levels of biodiversity and numerous lakes, wetlands, and ponds. The Andes of Ecuador páramos concentrate between 3500 to 5000 meters above sea level (m. a.s.l.) (Vuille et al. 2003; Giles et al. 2018). Páramos are relatively rich in mostly oligotrophic lakes (Maldonado et al. 2011; Van Colen et al. 2017). Plastic waste generated within a lake's watershed can be directed into the lake’s area, and transported by rainfall, rivers, and

groundwater (Xiong et al. 2018). However, research on remote lake systems is scarce. For instance, China's freshwater lake system described by Jian et al. (2020) detected MPs in water samples (1064 ± 90 MP/m^3) and sediment (1936 ± 121 MP/kg). Therefore, my research contributes to a complex freshwater system in the Cayambe - Coca Ecological Reserve (CCER) with the register of MPs in high-altitude ecosystems, possible sources of pollution and their distribution.

A recent study by Cabrera et al. (2022) reported the presence of MPs in Andean tropical mountain glaciers (Antisana), showing the first evidence of MPs pollution in Andean zones. Thus, I was interested in knowing the presence of MPs in high mountain lakes and why they differ from each other. So, in this study, I quantified the amount, shapes, colors, sizes and polymer type of MPs in surface water and sediments of five lakes at the CCER. Also, I associated the number of MPs with the surface of the micro-watershed for each lake. Finally, I discussed the origin and distribution patterns of MPs in the lakes in relation to wind data and human activities reported at the CCER. This study provided important dates about the origin and distribution of the high mountain lacustrine system and helps provided ecological risk assessment of MPs in the ecosystem.

METHODS

Study area and sample collection

CCER is located between the Napo and Pichincha provinces, it's represented by a green circle (Fig 1.a). CCER is affected by agriculture, grazing, biomass burning, tourism, roads, and community expansion. It has an area of 403.103 ha with over 150 lakes in the Papallacta Oyacachi lacustrine system (POLS). The annual precipitation in the study area ranges from 111 to 216 mm, the mean temperature is 7° C. More than half of the lakes are remotes due to difficult access, while others supply drinking and irrigation water for Quito (Ecuador's capital). Sampled lakes included Ciega [LC], Patos [LP], William [LW], Peine [LN], and an unnamed lake [LU]; orange triangle indicates C13* Salve Faccha meteorological station (Fig 1.b and Table 1). Sampling was carried out in February of 2021. Altitude was measured with Garmin GPS (Table 1) and Qgis 3.6.2 was used to extract the micro-watershed of each lake (Fig 1.b).

Water sampling collection was performed following Xiong et al. (2018) methodology on a raft without a motor and with a phytoplankton net (diameter: 28.5 cm, length: 50 cm, mesh size 200 µm) that was dragged at a velocity of 2 m/s during two minutes on the surface water of lakes. The water samples were taken in the center and shore of each lake. Approximately 50 mL of water was collected in glass bottles for further analyses. At the lakeshore, 2 kg of sediment was collected with a plastic shovel, obtaining one sample by lake. In total, five sediment samples and nine water samples were collected. Sediment samples were stored in plastic bags using a stainless-steel spoon. Finally, samples were transported in a cooler with ice (to ensure the stability of the samples because they contained organic matter, keeping 4°C) to the laboratory.

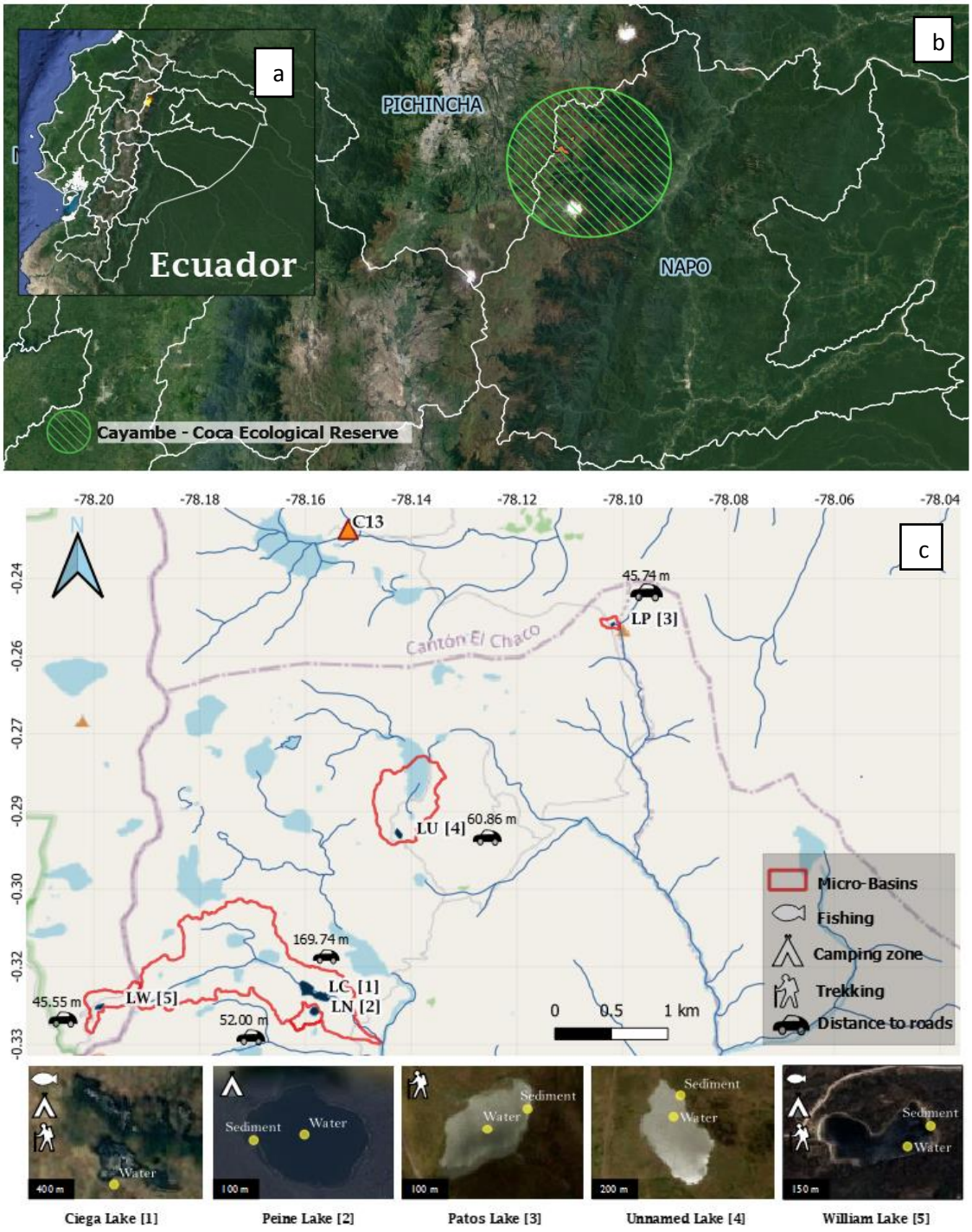


Fig.1. Geographic location in Ecuador (a), Cayambe – Coca Ecological Reserve (b) yellow points show sampling sites (water and sediment) for each lake (c). **Made by:** Ramos, Mariuxi, 2022

Table 1: Location information about sampling sites. **Made by:** Ramos, Mariuxi, 2022

ID	Lakes names	Lake type	Altitude (m)	Surface (ha)	Samples type	Latitude	Longitude
LC	Ciega Lake	Depth	3825	10.21	Littoral	816149	9964485
LN	Peine Lake	Shallow	3850	1.40	Center	816302	9964165
					Littoral	816241	9964158
LP	Patos Lake	Shallow	3881	0.47	Center	816406	9974146
					Littoral	822658	9972471
LU	Unknown Lake	Shallow	4100	1.72	Center	818096	9968011
					Littoral	818110	9968055
LW	William Lake	Shallow	4223	1.78	Center	811998	9969330
					Littoral	812051	9969911

Microplastic extraction

Sample processing was adapted from Cabrera et al. (2022). To decompose the organic matter contained in the 50 mL of water samples was dried at 60 °C for 48 h. Added 15 mL of 30 % hydrogen peroxide (H_2O_2) in an oscillation incubator (60°C at 100 rpm for 72 hours). After the chemical digestion, 15 mL of sodium chloride (NaCl) saturated solution with a density of 1.2 g mL^{-1} was added. The resulting mixture was transferred to a 250 mL glass separator funnel and rested for 24 hours. Last, the supernatant was filtered with a 0.45 µm cellulose nitrate membrane for vacuum filtration to obtain a MP membrane by sample.

Each sediment sample (2 kg per lake) was homogenized in the laboratory, and dried on aluminum foil in an oven at 50°C from 12h to 28h. Following, 30 g was weighed of each dry sediment sample and sieved through a series of sieve meshes of 4000 µm, 2000 µm, 250 µm, and 63 µm. The sieved fraction was divided into three pseudoreplicates that were put on Petri dishes.

Microplastic Analysis

In each membrane with water samples and Petri dish with sediment samples, the MPs were visually quantified and classified by color, shape, and size using an Olympus stereomicroscope of magnification 10X-H/22. The size of MPs was measured by Stream basic program to imagen analysis.

MPs identification were made at Cuenca University. A standard percentage (3%) of MP was analyzed with Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) (Thermo Nicolet iS5). The characterization was performed in reflection mode in a wavenumber range of 4000–650 cm^{-1} and scans were performed using a spectral resolution of 4 cm^{-1} and were executed in 32 scans. The spectral search was carried out using OMNIC® software (Thermo Fisher Scientific 2015) with a large spectral database of polymers (13,000 spectra of polymers). A polymer was considered as such when the matching with the respective polymer in the library was >70%.

Contamination Control

To reduce plastic contamination of the samples, all materials were cleaned with Milli-Q water and ethanol before usage. For the quantification process in sediment and water, one control sample was prepared for each sample. Next to the stereomicroscope we placed a membrane filter (0.45 µm) to identify air contamination present in the laboratory that could generate false positives.

Wind Rose

The wind rose was created in the Excel program. Wind speed and direction data were extracted from the [C13] Salve Faccha meteorological station for the years 2019 and 2020 obtained by *Empresa Pública Metropolitana de Agua Potable y Saneamiento de Quito* (EPMAPS).

Statistical Analysis

The MP amount of each lake was presented with their abundance. MP total at sediment and water was presented with the means of all lakes. The MP amounts and MP sizes were analyzed with a Kruskal-Wallis test, and significant differences among multiple samples were considered at ($p < 0.05$). Following, the Tukey test was used only to show what lakes differed from others. Finally, MPs abundance and the surface of the micro-watershed lake were analyzed with a linear correlation. All analyses were conducted using the statistical software R version 4.0.5 and GUI R-Studio.

RESULTS

Abundance of MPs in water and sediment

MPs were found in water and sediment samples collected in all lakes. The mean abundance for all lakes in sediments was 2838 ± 1489 MP/kg and water was 10 ± 5 MP/m^3. As observed in Fig. 2a, the total sediment concentration in lakes ranged from 969 MP/kg to 4056 MP/kg. In Fig. 2b, total water concentration ranged from 3 MP/m^3 to 17 MP/m^3. I found that MP concentration in sediment significantly differed among lakes (X^2 = 10.67, df = 4, p = 0.03). A similar pattern was found in water (X^2 = 12.86, df = 4, p = 0.01). For more details, differences between lakes are observed in Fig S1.

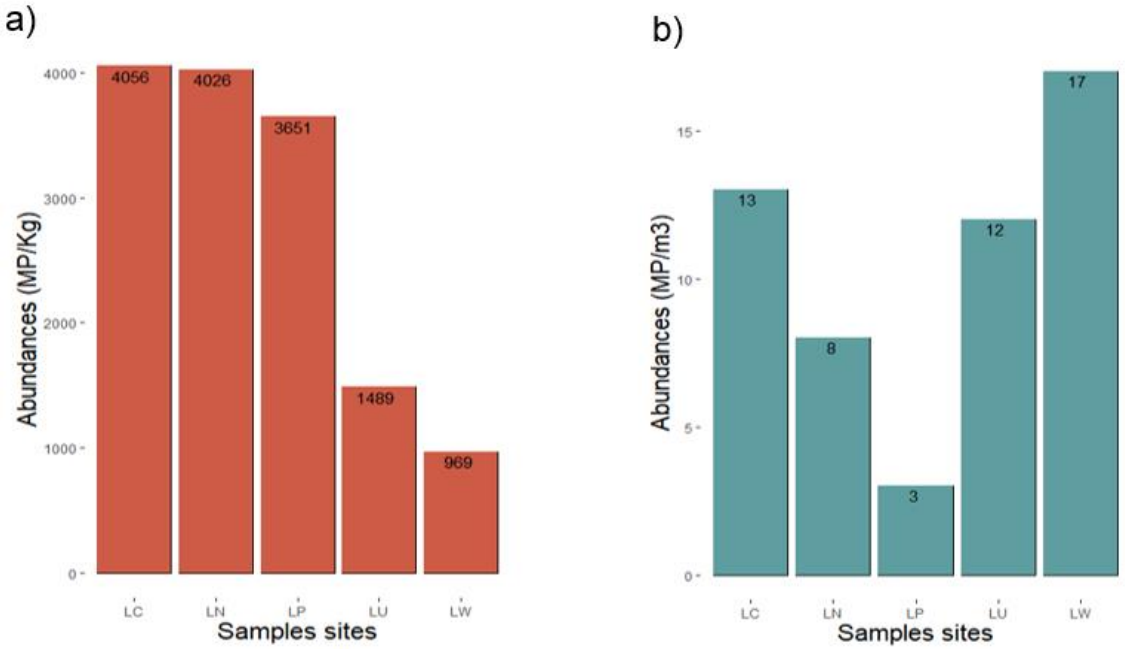


Fig.2. Abundance of microplastics in sediment (a) and surface water (b). **Made by:** Ramos, Mariuxi, 2022

Color, shape and size in sediment samples

Nine colors were observed in sediment samples, such as yellow, white, transparent, red, purple, green, brown, blue, and black (Fig. 3a). White represented 55 % of total samples, being the dominant color, transparent contribute 27 %, yellow, red, and blue with 4 % respectively, and 6 % is contributed by other colors (black, brown, green, and purple). Shapes of MPs were fibers, films, and fragments and are shown in Fig. 3c. Fibers represent the highest percentage (85 %), followed by films (11 %) and fragments (4 %). Finally, MPs were divided into three size categories, 3400 – 5000 µm, 1800 – 3400 µm, and 150 – 1800 µm (Fig. 3e). In sediment samples, the percentage of 3400 – 5000 µm categories was 52%, for 1800 – 3400 µm categories were 39 % and 150 – 1800 µm categories were 9 %. In addition, at least one sample comes from the same distribution in size between lakes, significantly similar ($\chi 2=19.66$, df= 4, p=0.0005).

Color, shape and size in water samples

Ten colors were observed in water samples yellow, white, transparent, red, purple, green, brown, blue, black, and gray (Fig. 3b.). The dominant colors were transparent (40 %), black (13 %), yellow, white and blue (11 %), and brown (6 %). The sum of gray, green, purple, and red contributes to 10 %. In terms of shape, fibers, films, and fragments were found in all water samples (Fig. 3d). The percentage of fibers (51 %) was highest, followed by films (25 %) and fragments (24 %). Percentage sizes for the 3400 – 5000 µm category and 1800 – 3400 µm category were 42 % in both cases and for the 150 – 1800 µm category was 16 % (Fig. 3f). The distribution is significantly different in MPs size among the five lakes ($\chi 2=$ 5.84, df= 4, p= 0.21).

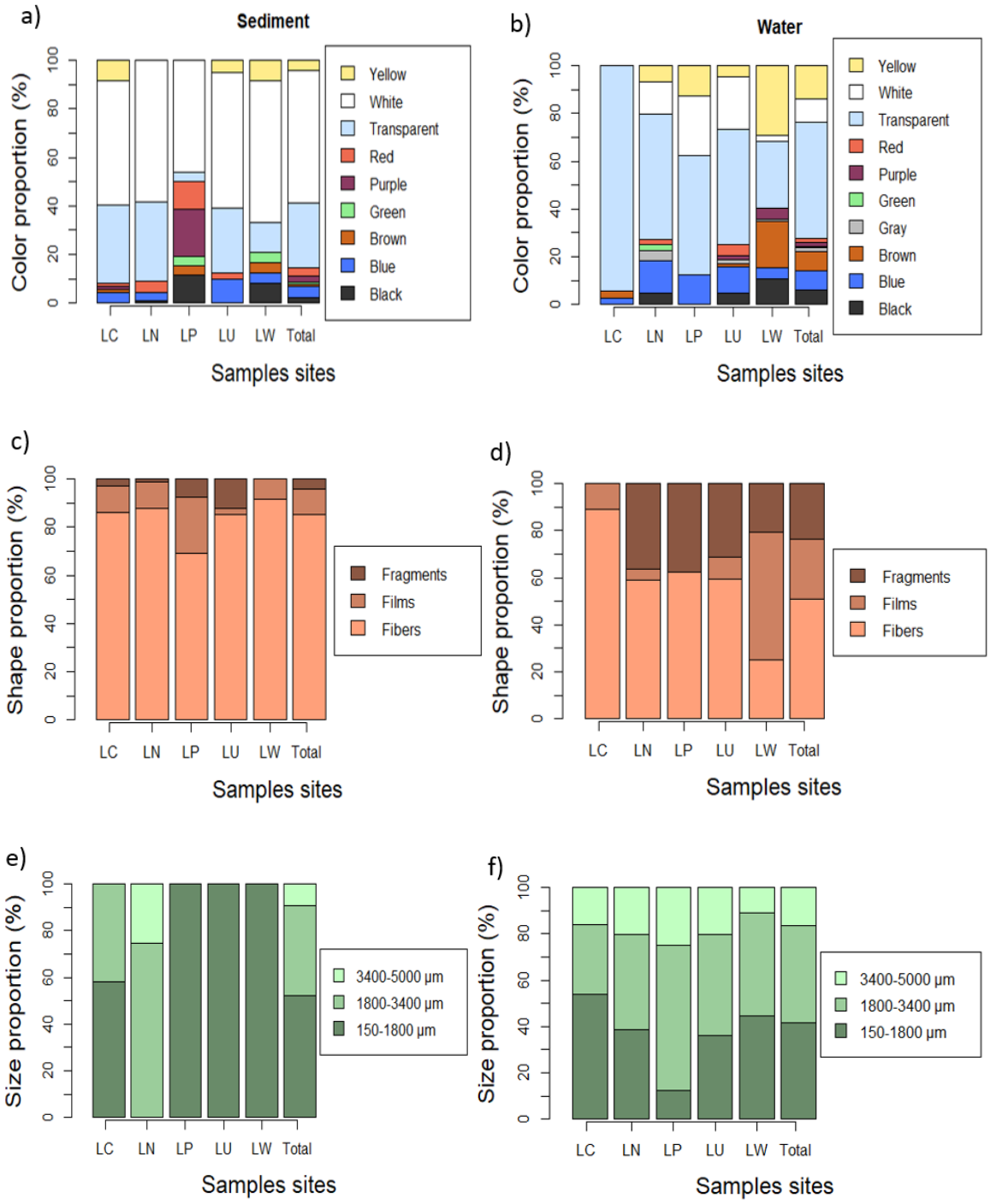


Fig.3. Microplastics in sediment and water samples of the lakes system. Sediments samples: colors (a), shapes (c) and sizes (e). Water samples: colors (b), shapes (d) and sizes (f). **Made by:** Mariuxi Ramos

Type of Microplastic

Between water and sediment samples, the most common type of plastic was cellophane, polyethylene (PE), and polypropylene (PP).

Correlation between Basin Surface and Microplastic in Water and Sediment

The aim of the correlation analysis was to observe if MP amount changed with respect to the area of the micro-watershed of each lake. The size of micro - watershed surfaces followed order LP < LN < LW < LU < LC. The smallest micro basin was 7.14 ha and the biggest was 686.78 ha (see table S2). Regarding Fig. 4b, the linear correlation between micro watershed surface and microplastic abundance in water was positive (corr= 0.35, r^2 = 0.12, *p*= 0.57). Likewise, Fig. 4a shows the correlation in sediment was positive (corr = 0.31, r^2 = 0.09, *p*= 0.068). But the model is not significant.

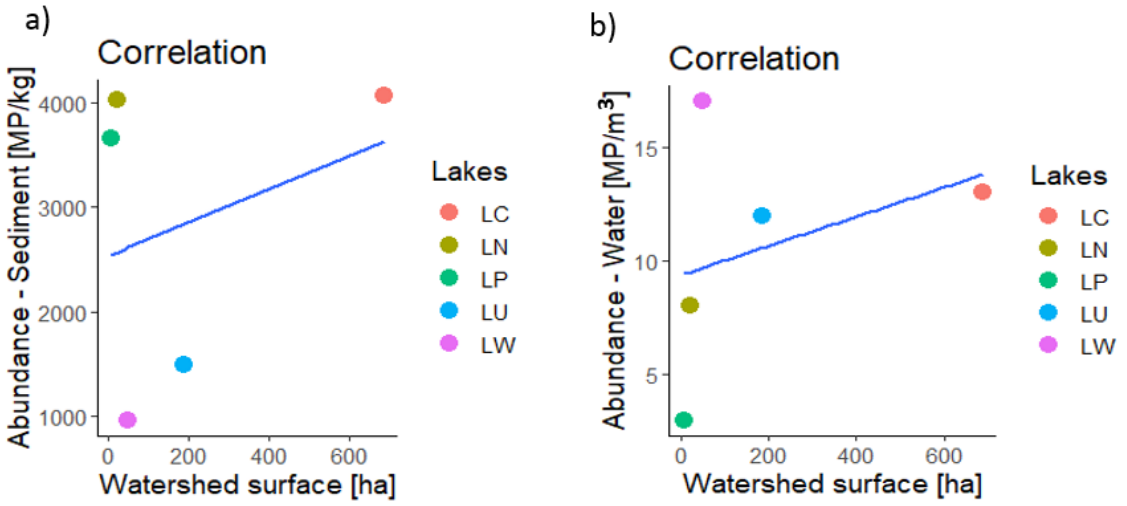


Fig.4. Plot showing the lineal correlation between microplastics and surface micro-basins of each lake in sediment (a) and water (b). **Made by:** Ramos, Mariuxi, 2022

Wind Rose

Fig. 5 shows the wind comes from the east and northeast. It means that contamination sources from the Amazon region. The highest values range of wind speed were 0 m/s to 5 m/s and 30 m/s to approximate 50 m/s.

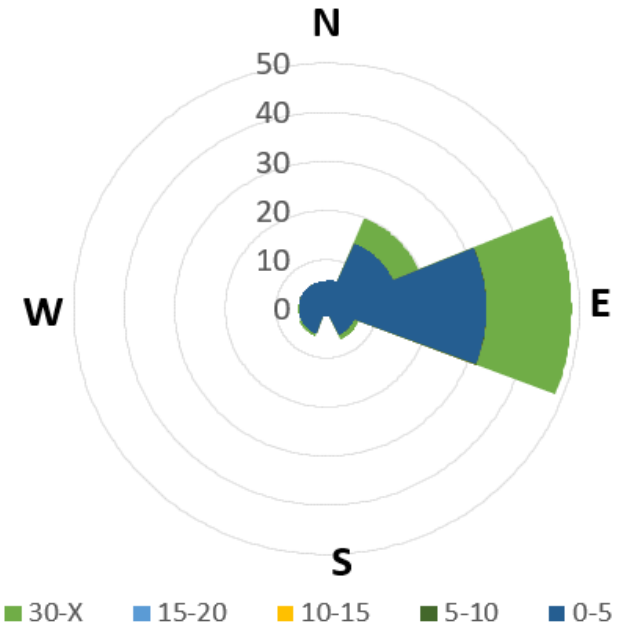


Fig.5. Plot for wind speed and wind direction for years 2019 and 2020 taken from [C13] Salve Faccha meteorological station. Each bar was colored in proportion to the wind speeds. **Made by:** Ramos, Mariuxi, 2022

DISCUSSION

Abundance of microplastic in water and sediment

To my knowledge, it is the first study focused on microplastic pollution in high altitude lakes in South America. The mean of sediments was 2838 ± 1489.03 MP/kg and the mean in water was 10 ± 5.32 MP/m^3. No significant relations were observed regarding MPs abundances between lakes in water and sediment samples, similar to the findings of Yuan et al. (2019). The differences in MPs abundance at lakes occur because characteristics of the micro watershed and human activities develop in each one (explained in the last two sections). Another factor could be the sampling methodology because the sampling technique with the net was different at the center and littoral in water sampling and the shore was covered with shrubs in sediment sampling.

In this study, the abundance in sediments samples was higher than in water samples. Li et al. (2019) explained high MP abundance in sediment was affected by long–term

accumulation and polymer type, but the low abundance of microplastics in the surface water could indicate a low discharge of microplastics by dry station. The sinking of MPs in sediments is related to suspended matter concentration, biofouling, sediments – resuspension, and mineralization (C. Zhang et al. 2018; Yafei Zhang et al. 2020). Biofouling refers to the deposition and growth of biofilms in the water that through mobilization and entrainment of sediment by sediments – resuspension, risen decomposition of suspended particulate matter is increasing to promote mineralization (Flemming 2002; Yafei Zhang et al. 2020). While, the moving of MPs in water can be due to heavy winds (Fischer et al. 2016) and water currents.

MPs abundance in shallow lakes is higher than in deep lakes, explained by MP re-suspends with organic aggregates or sediments, making it difficult to separate but promoting the mineralization process (Yafei Zhang et al. 2020). The high concentration of particulate matter floating favors resuspension through adsorption to MP's walls (Kaiser, Kowalski, and Waniek 2017; Yafei Zhang et al. 2020).

Relatively high MP abundance was found in other lake systems, for instance, Jian et al. (2020) reported MPs in water (> 1064 ± 90 MP/m^3) and sediment (> 1936 ± 121 MP/kg) in the Poyang Lake freshwater system. Li et al. (2019) found MPs in water (780 ± 429 MP/m^3) and sediment (219 ± 124 MP/kg) on lakes in the Yangtze River Basin. These lake systems researches focus on urban areas affected by increasing population, irrigation, wastewater, and WWTP discharge. For this reason, MP concentrations are high compared with my study. A recent study focusing on remote freshwater lake sediment found 606 ± 360 MP/kg, considering the airborne as a major route of MP to remote regions (Neelavannan et al. 2022).

Characteristics of microplastic: color, shape, and size

The variability of MPs colors was higher in surface water samples than in sediments. Because MPs in sediments lost their physical properties, especially their color (Hu, Zhang, and Shen 2020). During the sinking process, any MP particles are decayed by the current movement (Li et al. 2019), affecting their physical characteristics. Most particles are transparent colors, especially in water samples. MPs of transparent color were mainly found in remote aquatic systems (Xia et al. 2020). They originated from plastic bags, bottles, and cups, even from products of fishery and sport-fishery activities (K. Zhang et al. 2018; Xia et

al. 2020). Lakes studied in this research are riches in fishing activities similar to Dong Lake, where the identified transparent MPs were promoted by fishing equipment (Wang et al. 2017). Cabrera et al. (2022) reported MP of transparent and white colors in high elevations. Colored microplastics corresponded to the wide application of coloration in the production of plastic consumers. But in the sediment case, yellow, brown, and green colors could be confused with fibrous plants or roots due to high organic matter in the ecosystems of lakes.

A worldwide lakes review revealed that fibers and fragments are commonly found in water and sediment samples (Dusaucy et al. 2021). Results of this study show that fibers (51 % to 85 %) were the principal source of MP pollution in water and sediment samples. Similar outcomes reported by Alfonso, Arias, and Piccolo (2020) in nine lakes found a high percentage range of fibers (66.70 % to 96.40 %). In addition, Antisana Glacier located 20 km SE of this site study was also dominated by fibers (Cabrera et al. 2022). Nonetheless, many studies explain that fibers were airborne because of their low density (Horton and Dixon 2018; Xia et al. 2020; Yulan Zhang et al. 2020). Finally, Yulan Zhang, Kang, Allen, Allen, and Gao (2020) concluded that fibers were the dominant shape (> 60%) in atmospheric microplastics.

High altitude diverse environmental conditions (low temperature (<10 °C), UV irradiation intensity, wind's intensity) in remote areas, play important roles in breaking down the plastic (Mao et al. 2020; Duan et al. 2021). Fragments originate from the degradation of plastic bags and bottles (B. Zhang et al. 2019). In this study the majority of the lakes are near the principal access road to CCER (Fig 1.c.), possibly tourists and local people pollute with plastic waste that was transported by runoff into the lakes (see evidence of MPs shapes in Fig. S2).

A worldwide study of lakes reported that most MP particle sizes were < 2000 µm. But, ranges 300 – 4700 µm only in rural lakes (Dusaucy et al. 2021). In this study, the size of MPs in sediment samples was smaller than that in water samples. These differences could be explained MP sources and watershed characteristics (Dusaucy et al. 2021). Almost all lakes in the 100 – 1800 µm category were predominant in sediment. Similarly, Xiong et al. (2021) reported in the ponds and nearby lakes to the aquaculture area, sizes were predominantly in the “> 1000 µm” and “100–500 µm” range. The smaller MP particles were 150 µm, no observation < 150 µm because the capacity of the stereomicroscope was limited.

Polymer

The polymer composition of MP was mostly composed of cellophane, polyethylene (PE), and polypropylene (PP). These polymers come from the packaging industry (Y. C. Yang et al. 2019). Similar to this study, cellophane was the principal polymer identified in Taihu Lake, the third-largest Chinese lake (Su et al. 2016). Cellophane has been a semi-synthetic material used in wrappers (cigarettes and food) and additionally acts as a release agent (D. Yang et al. 2015; UNEP 2016). In this study, cellophane was considered a microplastic, likewise that Su et al., 2016; Yang et al., 2015; Yang et al., 2019.

PE and PP could rapidly breakdown (Weinstein, Crocker, and Gray 2016) which explains their register in high-mountain lakes (Pastorino et al. 2022). Negrete et al. (2020) reported PE and PP microplastics in a remote mountain lake called Sassolo in Switzerland. Çomaklı, Bingöl, and Bilgili (2020) also identified only PE and PP microplastics in a crater lake above 2380 m altitude in Turkey. In addition, PE is widely used in different plastic bag types or plastic containers, while PP is used in plastic bottles, household products, and battery cases. See evidence of the possible origin of types of MPs in Fig. S3.

Surface micro-watershed respect to MPs abundance

The spatial distribution of MPs could be affected by physical watershed characteristics (Talbot and Chang 2022). This study only focuses surface of micro watersheds. Consequently, there is no relation between the number of MPs and the micro watershed area of each lake. Because there were few samplings points by lake that no given enough information in representation to micro-watershed. In fig 4a, b., LC was the biggest micro-watershed, then capture more MPs. With respect to lakes of micro–watershed (< 200 ha) had dispersed values in water and sediment. May be due to the internal variables of the lake as lake type (oligotrophic and eutrophic), water column (depth) and sedimentation process (resuspension and mineralization). New research reported that no data is available about studies linking MPs and watershed spatial factors (altitude, slope, and water body width) on static water bodies (Talbot and Chang 2022).

Werbowski et al. (2021) explained different watersheds are affected to land use characteristics and distances between theirs, which can have a significant effect on the number of microplastics present. To future research could incorporate a focus on

relationships between the altitude of micro-watershed and MPs abundance, although this study has the elevation data by each lake, it´s not representative for the entire watershed.

Human activity impacts

High levels of microplastics in these regions may be due to heavy tourist activities, resulting in increased littering (Feng et al. 2020) tourism activities like fishing, trekking and camping (Fig. 1.c). Certain activities like trekking entail synthetic clothes and trekking gears were made from MPs fibers (Ambrosini et al. 2019). Even camping equipment could be made of synthetic fibers. Pastorino et al. (2022) indicated these activities were principal sources of MPs to high mountain ecosystems.

In this study, the distance to roads was considered close to lakes, around 45 to 60 m (Fig. 1.c). Roads allow people to enter remote areas, impacting negative way to the ecosystem; as evidence see Fig. S2. For more detail, future studies could show the number of people entering the reserve. Additionally, Grbić et al. (2020) found a positive relationship between microplastics and total road length at the catchment scale.

Trout fish are located in all lakes of the POLS lacustrine system and has been an invasive species since the early 19th century in South America (MacCrimmon 1971). Therefore, fishing is the principal activity for community people and tourists in LC and LW (Fig 1.c). Recommended to develop further studies about microplastic occurrence in body and digestion of trout.

Atmospheric transport

A previous study in Antisana Glacier of Ecuador reported that MP particles come from the Amazon basin (Cabrera et al. 2022). Similar in this research, the prevalence of airflow is east and northeast (Fig. 5). Both directions indicated Amazon Basin are the primary sources of MP particles, Quito city is discarded as the plastic possible source, located to 40 km from system lakes. My data suggested MP particles arrived at the lake system by atmospheric transport, even though, should be deepened in the MPs distance that can achieve to páramo sites and confirm the depositional processes for MPs in tropical lakes. Microfibers deposition in remote areas is proportional to the proximity of the source pollution region (Roblin et al. 2020). Atmospheric transport of MP depends on wind velocity, wind direction,

precipitation, and air mass (Enyoh et al. 2019). Roblin et al. (2020) showed that the distance of microfibers deposition ranged from 40 to 50 km, however, Allen et al. (2019) reported 95 km. Dusaucy et al. (2021) estimated 287 X 106 particles/(km^2·d) were mean flux MPs in atmospheric fallout.

CONCLUSION

In this study, the results of sediments showed a high abundance of MPs in deep lakes than in shallow lakes. Otherwise, water samples showed a high abundance of MPs in shallow lakes than in deep lakes. MPs abundance in water and sediment had similar spatial distributions and shape particles. I identified Cellophane, PE, and PP polymers in fragments, fibers, and film types. Generally, sediment contained more films than water. While water contains more size distribution than sediments. MPs abundance in sediments and water is not correlated with the surface micro watershed of each lake. The presence of MPs in high Andean lakes most likely is associated with touristic activities, accessibility to the lakes and MPs arrival by atmospheric transportation from the Amazon region. This study about the high Andean lakes system needs more similar research to monitor the origin and transport of MP. Also, to understand the spatial distribution, watershed characteristics, and ecological effects of MPs in the freshwater systems and prepare for future problems of climate change.

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SUPPLEMENTARY MATERIAL

Table S1: Statistical summary

Variable	Test	Water	Sediment
MPs abundance	Kruskal-Wallis (p)	0.01197	0.03052
Size of MPs	Kruskal-Wallis (p)	0.2111	0. 00058
Micro-watershed surface	Lineal correlation	0.347	0.307

Table S2: The surface of the micro- watershed of each lake

Lakes	Micro-watershed (ha)
LC	686.78
LN	21.35
LP	7.14
LU	187.21
LW	48.96

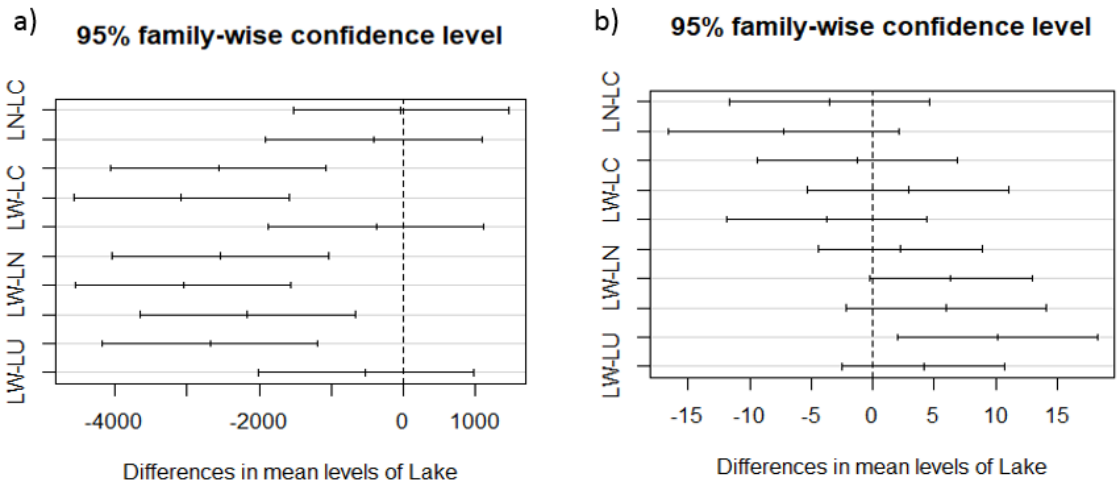


Fig S1. Tukey test plot of MP abundance in sediment (a) and water (b).

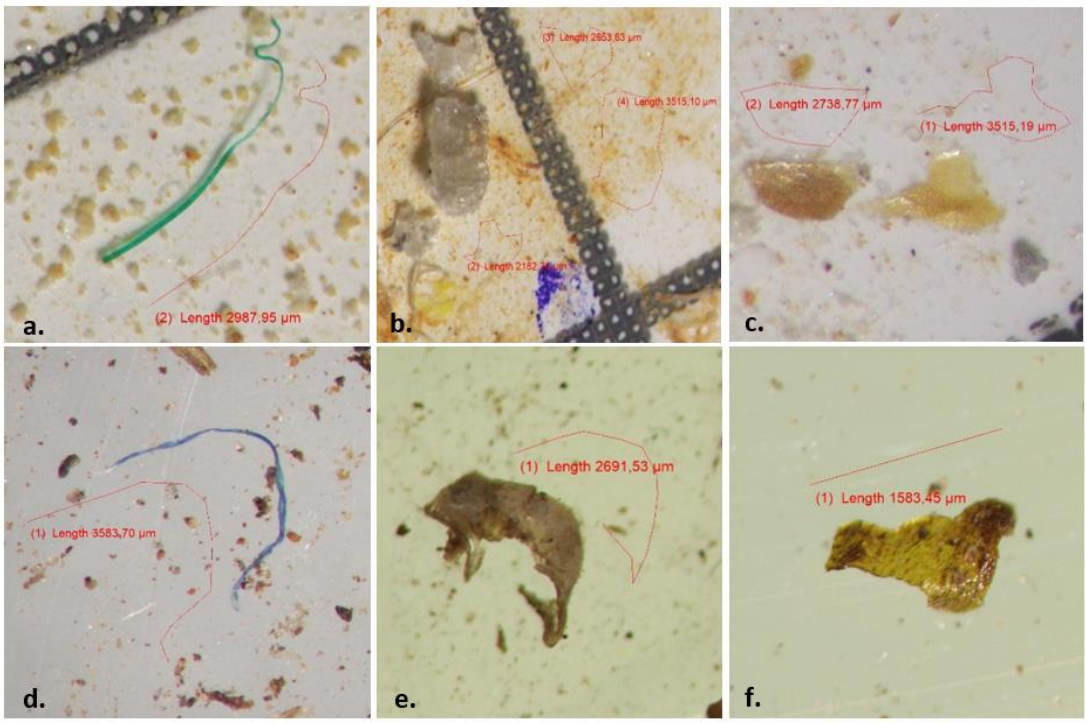


Fig S2. Microscope photos of MP shapes with size respect. Water: a. Fiber, b. fragment and c. films. Sediment: d. Fiber, e. fragment and f. films



Fig S3. Evidence of water plastic (a.,b.,c.,d.) textile clothes (e.), and fishing net (f.) in the surface water and shore of the lakes