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Microplastics in sediments deposited by rainwater runoff in a populated center in the Peruvian Andes

Microplásticos em sedimentos depositados pelo do escoamento da água da chuva em um centro povoado nos Andes peruanos

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ABSTRACT

Microplastics (MPs) are present in surface sediments deposited on city streets as a result of stormwater runoff. The objective of this study was to determine the abundance and characteristics of MPs in surface sediments deposited by stormwater runoff from the village of Madeán in the Peruvian Andes based on size, shape, and color. Surface sediment samples were collected in triplicate at each of the eight sample sites. The sediments were deposited in some parts of the streets of this village due to the effect of rainwater runoff. The separation of MPs from the sediment was carried out in the laboratory by the density separation method with NaCl solution. The eight sampling sites in Madeán presented 292.91 ± 149.32 (MP Items/Kg of sediment) of MPs, showing significant differences in the abundance of MPs among the different sampling sites. The predominant characteristics of the MPs were small size (SMP) (50.95%) and large size MPs (LMP) (49.05%), being fiber (60.66%) and fragmented (38.39%) in morphology, and blue (29.86%), black (25.59%), and red (23.22%) in color, respectively. The following investigation suggests that solid waste is not being adequately managed by finding the presence of MPs in the sediments that are in the street ditches.

Keywords: Characteristics of microplastics; Stormwater runoff; Surface sediments.

RESUMO

Microplásticos (MPs) estão presentes em sedimentos superficiais depositados nas ruas das cidades como resultado do escoamento de águas pluviais. O objetivo deste estudo foi determinar a abundância e as característica com base no tamanho, forma e cor dos MPs em sedimentos superficiais depositados pelo do escoamento de águas pluviais da cidade de Madeán nos Andes peruanos. Amostras de sedimentos superficiais foram coletadas em triplicata em cada um dos oito locais amostrados. Os sedimentos são depositados em alguns trechos das ruas do centro povoado devido ao efeito do escoamento das águas pluviais. Em seguida, em laboratório, foi realizada a separação dos MPs do sedimento pelo método de separação por densidade com solução de NaCl. Os oito pontos de amostragem apresentaram MPs no centro povoado com valor de 292,91 ± 149,32 (Itens de MPs/Kg de sedimento), mas houve diferenças significativas na abundância de MPs entre os pontos de coleta. As características de tamanho predominantes dos MPs foram SMP (pequenos microplásticos) (50,95%) e LMP (grandes microplásticos) (49,05%), da forma: fibra (60,66%) e fragmento (38,39%) e da cor: azul (29,86%), preto (25,59%) e vermelho (23,22%), respectivamente. A seguinte investigação quantifica sugere que os resíduos sólidos não estão sendo adequadamente gerenciados ao encontrar a presença de MPs nos sedimentos que estão nas valas das ruas.

Palavras-chave: Características dos microplásticos; Escoamento de água de tempestade; Sedimentos de superfície.

INTRODUCTION

Urban rainwater transports sediment in suspension and other contaminants such as microplastics (MPs), which enter from the land to the aquatic environment through the runoff of rainwater (McKee & Gilbreath, 2015; Auta et al., 2017). In Peru the abundance and characteristics of MPs in the aquatic environment have been evaluated only in fishes, mollusks, and crabs (Chota-Macuyama & Chong-Mendoza, 2020; Iannacone et al., 2021; De la Torre et al., 2022; Iannacone et al., 2022) and, on sandy beaches (Iannacone et al., 2019; Zárate & Iannacone, 2021). The deposition, retention, and transport of MPs will depend on many factors including hydrology, weather, environmental topography, particle characteristics, and, human behaviors. The aquatic environment is the main route of MPs transport and the main flows of MPs within and between the three environmental compartments: terrestrial, freshwater, and marine. Water flow mediate the spread of MPs between the aquatic and terrestrial environments. The properties of MPs will be significantly changed during the transport process because of the fragmentation and aging reaction, such as photodegradation, weathering, biodegradation, etc. (Li et al., 2022). The abundance of MPs is increasing in the aquatic environment (Thompson et al., 2009; De la Torre et al., 2022; Li et al., 2022), due to the fragmenting of larger plastics into smaller fractions (Browne et al., 2008). It is important to evaluate the characteristics of MPs, such as the size, color and shape, as they can be ingested by different aquatic species for appearing similar to their prey (Lima et al., 2015; Iannacone et al., 2021; Foo et al., 2022).

In urban areas, MPs have been found in the sediments of rainwater ponds (Liu et al., 2019) and in rainwater runoff (Piñon-Colin et al., 2020). The populated Peruvian Andean center of Madeán does not have a drainage system or rainwater tanks, and thus, a suitable system is required to eliminate runoff from this populated Andean center (Flores & Changanaqui, 2019). Macroplastics and MPs have previously been found in the sediments of the Yuncaypara irrigation channel and the Ishoj creek (Canchari, 2022; Canchari & Iannacone, 2022). Therefore, the hypothesis is that MPs are likely present in the irrigation channel and the creek due to rainwater runoff from the village of Madeán and MPs deposited in the streets of the village. The objective of the present study was to determine the abundance and characteristics (size, color and shape) of MPs in surface sediments deposited by the effect of rainwater runoff in the center of Madeán in the Peruvian Andes.

MATERIALS AND METHODS

Study area

The study was carried out in the town center of Madeán, which has a population of 223 inhabitants and is located in the district of Madeán, province of Yauyos, Lima region, Peru at 3275 meters above sea level. The populated center is located within the Huangáscar sub-basin with an average annual rainfall of 642.2 mm. The average monthly precipitation is greater than 50 mm from December to April, presenting higher rainfall in January, February and March with 123.1 mm, 131.4 mm and 135.7 mm respectively (Agência Nacional de Águas e Saneamento Básico, 2019). Madeán has no rainwater drainage system or rainwater collection pond (Flores & Changanaqui, 2019). All the rainwater and sediment flow through ditches generated by the power of the water, emptying at several exit points of irrigation the canal and on the outskirts of the village (Figure 1). Photographic records have shown the presence of mesoplastic and macroplastics in the streets determined by the study of the composition of municipal solid waste (Canchari & Iannacone, 2021).

Together with rainwater runoff, surface sediments were transported by furrows and deposited in different areas of the village. The samples were taken in areas of sediment deposition located ditches in the center of the village (Figure 1) (Table 1). Due to the action of the water, a ditches has been generated, through which the runoff water goes to the ditches. Two ditches together refer to the fact that the water comes from two sources due to the fusion of the ditches, it does not refer to the fact that there are two ditches (Figure 1).

Sampling

The surface sediment samples were collected during the high precipitation season corresponding to the month of April (Agência Nacional de Águas e Saneamento Básico, 2019). Samples of the sediments at each site were obtained in triplicate using a stainless steel blade (Horton et al., 2017) and a 20 cm × 20 cm high metal frame (Wang et al., 2017). Then, the sediments were placed in an aluminum foil bag, in which they were transported to the laboratory for further analysis (Wang et al., 2017).

The ditches in the streets shown vertically on the map have a high slope (Figure 1). The sampling sites were selected in places with low slopes (Table 1). Absence of vegetation cover was observed in all sampling sites, except CP8. Also, all sampling sites were in urbanized area, except CP4 (Table 1).

Processing of samples

Thirty grams of dry sediment was obtained in triplicate at each site and were dried at 50 °C for 48 h (Wang et al., 2017). 30 g of dry sediment sample was added to a precipitate vessel. Then, 30 mL of 30% H_2O_2 was added to the precipitate vessel and discarded overnight to eliminate natural organic remains (Shruti et al., 2019).

The sample was then mixed with 200 mL of saturated NaCl solution in a glass precipitate vessel and stirred for 2 min with a glass rod. High density salts such as zinc chloride ($ZnCl_2$), sodium iodide (NaI) or others were not used. This is because according to Quinn et al. (2017) are very expensive and toxic to the environment. In addition, we only had financing to purchase NaCl salt, a low-cost salt. Previously, the solution was prepared by dissolving the salt in distilled water with the help of a magnetic stirring plate (Quinn et al., 2017). After 2 h of sitting (Wang et al., 2017), the supernatant containing the MPs was filtered through filter paper with a pore size of 6 µm with a vacuum pump (Shruti et al., 2019). Finally, filtered water was added several times to the walls of the filtration device and the washing solutions were filtered.

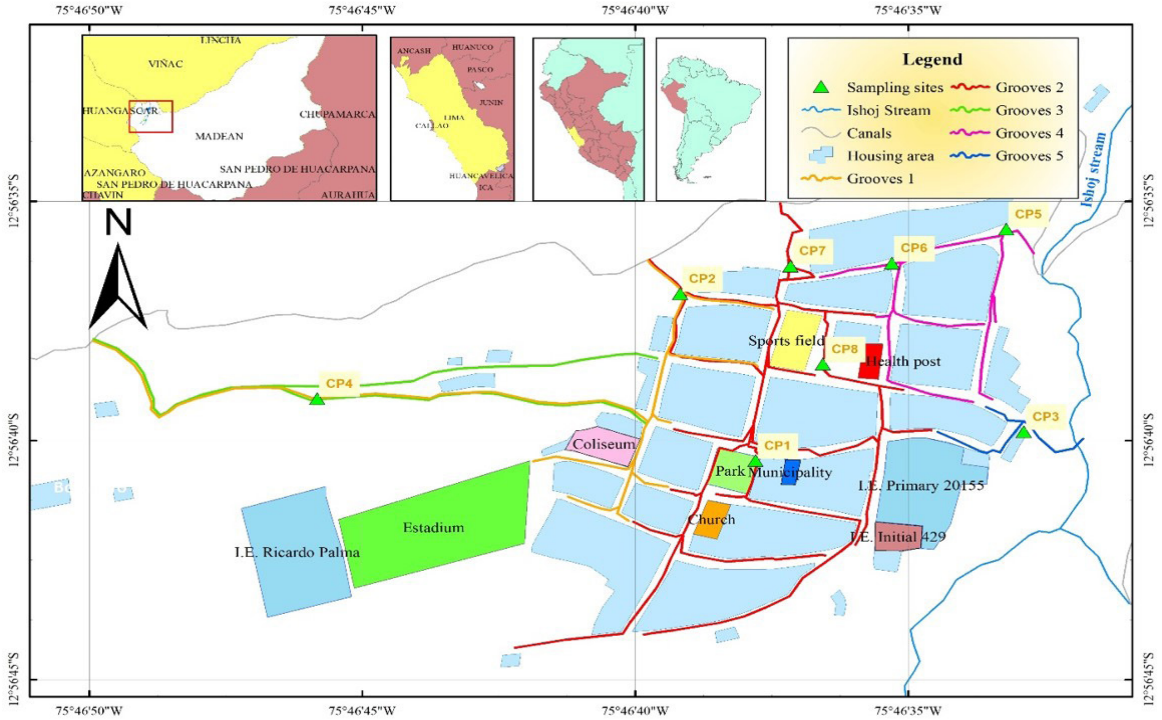

Figure 1. Ditches generated by rainwater flow in the center of Madeán, district of Madeán, province of Yauyos, Lima region, Peru. I.E. = Educational institution; CP = Sampling sites.

Table 1. Description of sampling sites in the village of Madeán.

Sampling sites	Geographical Coordinates			slope (%)	Description
	Longitude (W)	Latitude (S)	meters above sea level		
CP1	75°46 ‘ 37.6856 “	12°56 ‘ 39.8797 “	3274	2.8	Located in the Park Zone (Figure 1) which presents accumulation of sediment that is removed from the park after the period of precipitation. Absence of vegetation cover. Sampling point in urbanized area.
CP2	75°46 ‘ 39.0686 “	12°56 ‘ 36.3926 “	3247	11.8	Accumulation of sediment in the site and the ditch that passes through the site where water runs off from the irrigation canal. Absence of vegetation cover. Sampling point in urbanized area.
CP3	75°46 ‘ 32.7721 “	12°56 ‘ 39.2728 “	3262	4.6	Site with minimal accumulation of sediment through the ditch that transports runoff water from the Ishoj creek. Absence of vegetation cover. Sampling point in urbanized area.
CP4	75°46 ‘ 45.7126 “	12°56 ‘ 38.5862 “	3235	8.0	This site presents sediment accumulation and there is a ditch through which the runoff water flows into the canal. Absence of vegetation cover. Sampling point not in urbanized area.
CP5	75°46 ‘ 33.0909 “	12°56 ‘ 35.0433 “	3245	1.1	At this site sediment accumulation is minimal and there is a ditch that derives from the runoff water in the canal. Absence of vegetation cover. Sampling point in urbanized area.
CP6	75°46 ‘ 35.1838 “	12°56 ‘ 35.7532 “	3242	9.2	Here the sediment accumulated from the runoff water passes through the ditch and flows in the direction of the CP5 site and continues to flow into the channel. Absence of vegetation cover. Sampling point in urbanized area.
CP7	75°46 ‘ 37.0424 “	12°56 ‘ 35.8127 “	3249	25.6	This site presents minimal accumulation of sediment which passes through the ditch that drains water from the channel. This site has a greater slope than the remaining sites. Absence of vegetation cover. Sampling point in urbanized area.
CP8	75°46 ‘ 36.4514 “	12°56 ‘ 37.8652 “	3249	9.5	This site is located close to a sports field, presenting vegetation, which has retained sediments on top. Sampling point in urbanized area.

The filter paper containing MPs was dried at 50 °C for 48 h in the laboratory and stored in Petri dishes (Wang et al., 2017). The separation procedure was repeated three times with each replica of sediment to ensure that a high proportion of floating remains was eliminated. The data MPs from the three filter papers were joined together (Thompson et al., 2004).

The MPs contained in the filter were observed under an optical microscope (Mark Euromex, Model Oxion) at 40X, 20X, 10X and 4X, respectively, and counted to determine the numerical concentrations, expressed as items·Kg^{-1} (abundance of MPs) of dry sediment (Lin et al., 2018). The size of the MPs was classified into small microplastics (SMP) ranging from 6 µm to 1 mm and large microplastics (LMP) ranging from 1 mm to 5 mm (van Cauwenberghe et al., 2015). In addition, the morphology was identified and classified as fiber, pellet, film, fragment and foam (Crawford & Quinn, 2016) ranging from 1 um to 5 mm, with the lower limit of our study being 6 µm. The characteristics of the MPs based on color were cataloged based on the color of the dominant surface, which could be green, transparent, blue, yellow, black, red or white (Rocha-Santos & Duarte, 2015; Su et al., 2016; Lin et al., 2018).

Image processing software (ImageJ, at http://imagej.nih.gov) with previous calibration was used to determine the characteristics of the MPs (Kataoka et al., 2019; Chen et al., 2021; Cowger et al., 2020).

Quality-control and quality-assurance (QA/QC) procedures

Analysis in the laboratory, a series of measurements were taken to avoid potential background contamination, followed quality assurance (QA) and quality control (QC) procedures to guarantee the results of the analysis of the sediment based on the Quality Management System designated by the USEPA and by the quality policy of the laboratory. QA/QC practices involve a broad range of activities including, but not limited to: a) manufacturer guidance and user manual, b) calibrations, c) acceptance, use, and maintenance of instruments and equipment, sediment sample chain of custody, d) pre- and postdeployment procedures, and record-keeping strategies (Rice et al., 2017; U.S. Environmental Protection Agency, 2002). Gloves and cotton lab coats were worn during the experimentation time. All of the solutions used in the study were filtered through a 0.45 µm filter before using for the assays. Tools, glassware, and containers were thoroughly rinsed with deionized water and covered with aluminum foil after each step. All synthetic clothes were refused while doing microscopic analysis to reduce the other contamination (Gela & Aragaw, 2022).

Statistical analysis

The statistical analyses were carried out using the SPSS Statistical Packet version 25.0, (Li et al., 2020). A correlation was made between the abundance of MPs and the slope of the sampling site using the Pearson correlation coefficient (r). A p-value less than 0.05 was considered significantly significant (Xu et al., 2020).

RESULTS AND DISCUSSION

The presence of MPs in the surface sediments from sites CP1 to CP8 showed a value of 292.91± 149.32 (minimum 144.44 – maximum 622.22) (MP items/ kg of dry sediment). The CP8 sample site close to the sports field had the highest concentration compared to the CP1, CP4 and CP6 sites (Figure 2a). The CP8 site showed the presence of vegetation retaining sediment and plastics of different sizes. The greater abundance of MPs in this sampling site can be explained by a previous study that suggested that vegetation likely captures MPs (Werbowski et al., 2021) (Figure 2a).

Differences were observed in the abundance of MPs among the sampling sites located in the center of Madeán (Figure 2a). CP8 showed a greater abundance of MPs compared to sites CP1, CP4 and CP6 (Figure 2a). No correlation was observed between the abundance of MPs and the slope of the sampling site ($r = 0.07$, $p = 0.85$). Some research has shown physical characteristics such as slope of sampling sites has a positive correlation with MPs concentrations. This way, sites with lower slope tend to deposit more material of MPs. However, there is no scientific published information that relates the slope sampling sites of ditches to the size, shape, and color of MPs (Grbić et al., 2020; Talbot & Chang, 2022). The results suggested that distribution patterns, abundance, contamination level, and pathway of MPs in ditch sediments are highly influenced by anthropogenic activities, prior significant contributors to plastic pollution, topography, geography, and weathering conditions (Gela & Aragaw, 2022).

The lines in Figure 1 show the ditches formed by the action of rainwater runoff, having different outlet points, mainly to the mouth of the irrigation channel of Yuncaypara and towards the Ishoj creek. These results suggest that the sediments and rainwater runoff from the village of Madeán described in the present study contribute MPs to the sediment of the irrigation canals (Canchari & Iannacone, 2022) and the Ishoj creek (Canchari, 2022), but atmospheric deposition is also a factor that influences the presence of such synthetic particles, and MPs are transported over long distances in the atmosphere (Beaurepaire et al., 2021; Li et al., 2022).

SMP and LMP were found in all the sites sampled (Figure 2b) with a total of 50.95% and 49.05%, respectively. It is important to note the lower limit in size of the present study was 6 µm. Several studies have described the lower limit of MP size in different environmental compartments such as river sediments with 20 µm (Adomat & Grischek, 2021), sediments in stormwater ponds (10 µm) (Liu et al., 2019), in rainwater runoff (25 µm) (Piñon-Colin et al., 2020), in beach sand on marine coasts (4 µm) (Zárate & Iannacone, 2021), and in fish and crustaceans of economic importance in Lima (2.5 µm) (Iannacone et al., 2021, 2022). SMPs have a larger surface area with the same volume ratio and, therefore, have a greater capacity to adsorb persistent organic compounds than LMPs, representing a greater ecotoxicological threat to aquatic species (Crawford & Quinn, 2016; Ghosh et al., 2021).

The morphology of the MPs identified was fibers (60.66%), fragments (38.39%) and film (0.95%), which were found in great abundance in all the sites sampled, with the exception of the CP2 site, in which film was also found (Figure 2c). Similarly, fibers were the most abundant in stormwater runoff in the urban area

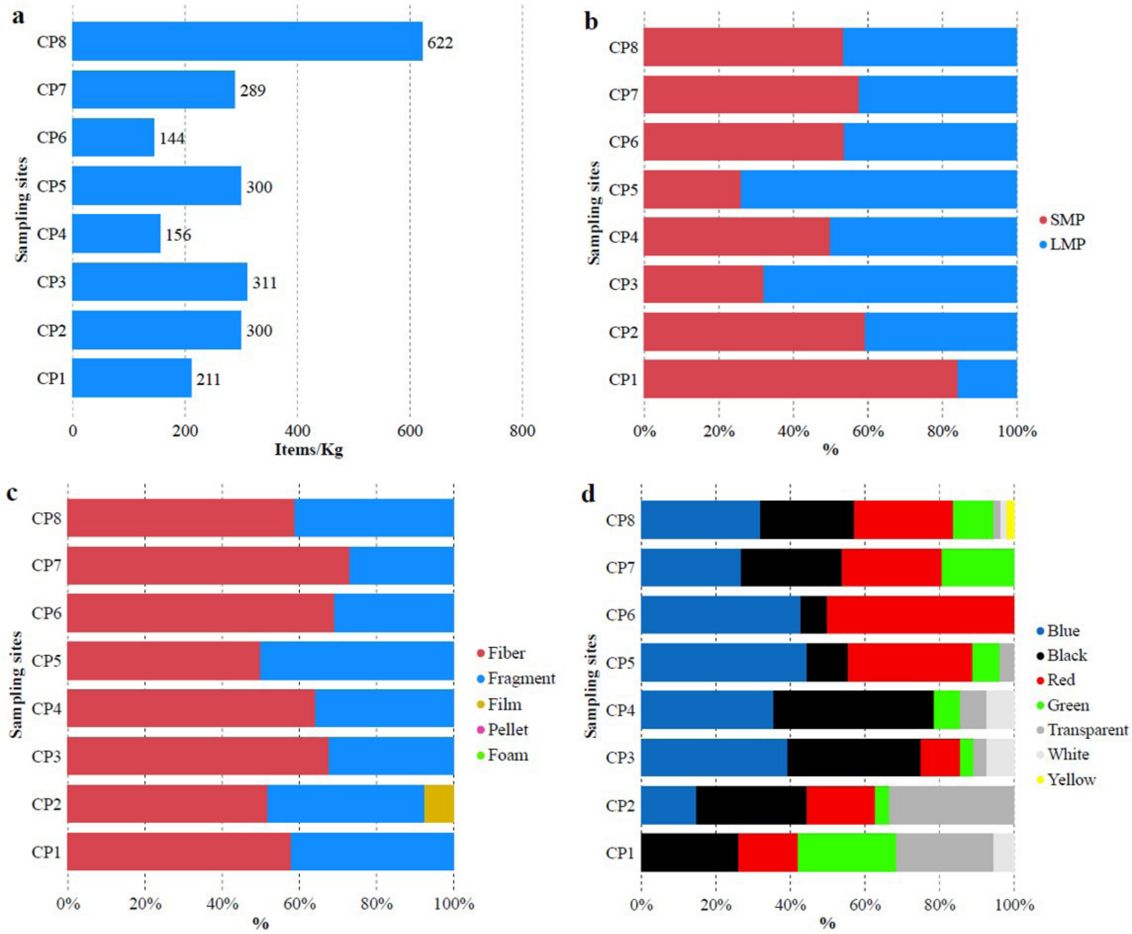

Figure 2. (a) Abundance of microplastics by sampling site in center of Madeán, district of Madeán, province of Yauyos, Lima region, Peru; (b) Size of micoplastics in surface sediments; (c) Morphology of microplastics in surface sediments; (d) Color of microplastics in surface sediments. SMP = small size microplastics. LMP = large size microplastics. CP = Sampling sites.

of Tijuana, Mexico (Piñon-Colin et al., 2020) and in Paris, France (Dris et al., 2018). In the sediment of rainwater retention ponds, MPs were more abundant in the form of fragments, followed by film and fiber (Liu et al., 2019). Other studies show that fragments in sediments (Gela & Aragaw, 2022). Fiber particles are generated from wastewaters of laundering, and, fragment MPs come from the widest range of plastic waste in the urban area that can be degraded and fragmented from plastic bags, plastic bottles, packaging materials, containers, and toys used in a daily manner (Gela & Aragaw, 2022). Our results show that fibers and fragments predominated in the sediments accumulated in the streets of the Andean village center studied.

Figure 1 shows that rainwater flows to the Yuncaypara irrigation canal. Fibers, fragments and film were found in sediments in this irrigation channel (Canchari & Iannacone, 2022). Similarly, the same MP morphologies were described in the sediment of the Ishoj creek, possibly because rainwater flows into this stream (Canchari, 2022).

The source of fibers in the sediments has been described as originating from people throwing their laundry wastewater into the street (Piñon-Colin et al., 2020). This agrees with the results of the present study because it was observed that some residents throw their clothes washing water into the streets. In the case of fragments, these come from the largest plastic waste (Jiang et al., 2019), and the films originate from the breakage of plastic bags and packaging materials (Zhang et al., 2015). All these forms of MPs (fibers, fragments and films) are a concern, because they can enter the aquatic environment from the terrestrial environment through stormwater runoff (Auta et al., 2017), and affect the aquatic biota (Curren et al., 2020; Iannacone et al., 2021; Foo et al., 2022).

Figure 3 shows the various fiber, film and fragment type morphologies of the MPs in the surface sediments of the Andean village of Madeán. In addition, Figure 3c and 3d shows breaks in the MPs, which can give rise to smaller MPs (Canchari, 2022).

The colors of the MPs found in sediments of pluvial waters in the center of Madeán, Blue (29.86%), black (25.59%), red (23.22%), green (9.95%), transparent (8.53%), white (2.37%) and yellow (0.47%) MPs were found, with the first three colors being found in almost all the sampling sites. Only the yellow color was found at the CP8 site (Figure 2d).

The color of the MPs is important since MPs entering the aquatic environment from the land through stormwater runoff (Auta et al., 2017) may be misidentified as prey and consumed by aquatic organisms (Lima et al., 2015; Crawford & Quinn, 2016).

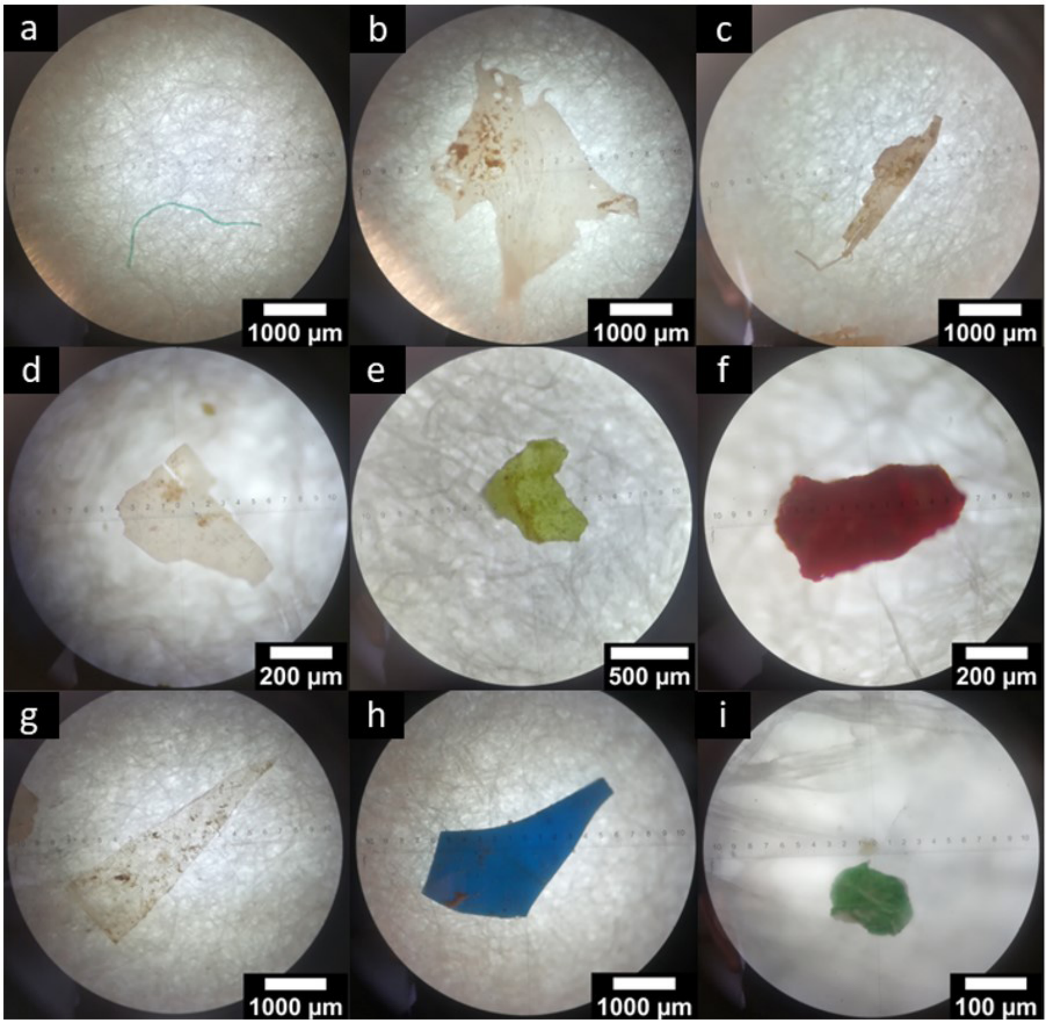

Figure 3. Morphology of microplastics: fiber (a), film (b and c), fragment (d, e, f, g, h and i) in surface sediments, Madeán village center, Madeán district, Yauyos province, Lima region, Peru.

CONCLUSIONS

In conclusion, MPs were present in sediment deposited by rainwater runoff in all the sampling sites in the streets of the Peruvian Andean village of Madeán. In addition, the populations of villages likely contributed MPs to rainwater runoff which flowed into the irrigation canal and the creek. The number of MPs is sediment was 292.91 ± 149.32 (144.44 - 622.22) (Items of MPs/Kg of dry sediment). The abundance of SMPs (with a lower limit of 6 μm) and LMPs was similar. Both SMPs (50.95%) and LMPs (49.05%) predominated, while fibers (60.66%) and fragments (38.39%) of the colors blue (29.86%), black (25.59%), and red (23.22%) were most frequently found. The following investigation quantifies MPs in surface sediments of rainwater in a small Andean populated center, which suggests that solid waste is not being adequately managed by finding the presence of MPs in the sediments that are in the street ditches. In addition, it provides information that populated centers are contaminated by MPs and that they are a source of contamination to aquatic environments through the migration of MPs.

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REFERENCES

Adomat, Y., & Grischek, T. (2021). Sampling and processing methods of microplastics in river sediments - A review. *The Science of the Total Environment*, *758*, 143691. PMid:33298323. http://dx.doi.org/10.1016/j.scitotenv.2020.143691.

Agência Nacional de Águas e Saneamento Básico – ANA. (2019). *Estudio hidrológico de la unidad hidrográfica Cañete*. Retrieved in 2022, September 12, from https://repositorio.ana.gob.pe/handle/20.500.12543/4713

Auta, H. S., Emenike, C., & Fauziah, S. (2017). Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. *Environment International*, *102*, 165-176. PMid:28284818. http://dx.doi.org/10.1016/j.envint.2017.02.013.

Beaurepaire, M., Dris, R., Gasperi, J., & Tassin, B. (2021). Microplastics in the atmospheric compartment: a comprehensive review on methods, results on their occurrence and determining factors. *Current Opinion in Food Science*, *41*, 159-168. http://dx.doi.org/10.1016/j.cofs.2021.04.010.

Browne, M. A., Dissanayake, A., Galloway, T. S., Lowe, D. M., & Thompson, R. C. (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). *Environmental Science & Technology*, *42*(13), 5026-5031. PMid:18678044. http://dx.doi.org/10.1021/es800249a.

Canchari, F. (2022). *Microplásticos en sedimentos fluviales en dos quebradas aledañas al centro poblado de Madeán, distrito de Madeán, Provincia de Yauyos, Región Lima, Perú* (Tesis). Universidad Científica del Sur, Lima. Retrieved in 2022, September 2, from https://hdl.handle.net/20.500.12805/2495

Canchari, F., & Iannacone, J. (2021). Residuos sólidos municipales en el centro poblado de Madeán, distrito de Madeán, provincia de Yauyos, región Lima, Perú en época de pandemia del COVID-19. *Paideia XXI*, *11*(2), 11-25. https://doi.org/https://doi.org/10.31381/paideia%20xxi.v11i2.4038.

Canchari, F., & Iannacone, J. A. (2022). Microplásticos en sedimentoa de canales de riego en el centro poblado de Madeán, distrito de Madeán, provincia de Yauyos, región Lima, Perú. *The Biologist (Lima)*, *20*(1), 85-92. http://dx.doi.org/10.24039/rtb20222011318.

Chen, S., Li, Y., Mawhorter, C., & Legoski, S. (2021). Quantification of microplastics by count, size and morphology in beverage containers using nile red and ImageJ. *Journal of Water and Health*, *19*(1), 79-88. http://dx.doi.org/10.2166/wh.2020.171.

Chota-Macuyama, W., & Chong-Mendoza, J. (2020). Primer registro de ingestión de microplásticos por un pez de importancia comercial en la ciudad de Iquitos, Amazonía Peruana. *Folia Amazonica*, *29*(2), 179-188. https://doi.org/10.24841/fa.v29i2.521.

Cowger, W., Gray, A., Christiansen, S. H., DeFrond, H., Deshpande, A. D., Hemabessiere, L., Lee, E., Mill, L., Munno, K., Ossmann, B. E., Pittroff, M., Rochman, C., Sarau, G., Tarby, S., & Primpke, S. (2020). Critical review of processing and classification techniques for images and spectra in microplastic research. *Applied Spectroscopy*, *74*(9), 989-1010. PMid:32500727. http://dx.doi.org/10.1177/0003702820929064.

Crawford, C. B., & Quinn, B. (2016). *Microplastic pollutants* (1st ed.). Amsterdam: Elsevier Science. https://doi.org/https://doi.org/10.1016/C2015-0-04315-5.

Curren, E., Leaw, C. P., Lim, P. T., & Leong, S. C. Y. (2020). Evidence of marine microplastics in commercially harvested seafood. *Frontiers in Bioengineering and Biotechnology*, *8*, 562760. http://dx.doi.org/10.3389/fbioe.2020.562760.

De la Torre, G. E., Laura, R. P., & Mendoza-Castilla, L. M. (2022). Abundance and characteristics of microplastics in market bivalve *Aulacomya atra* (Mytilidae: bivalvia). *Acta Biologica Colombiana*, *27*(2), 232-239. http://dx.doi.org/10.15446/abc.v27n2.88832.

Dris, R., Gasperi, J., & Tassin, B. (2018). Sources and fate of microplastics in urban areas: a focus on paris megacity. In: Wagner M, Lambert S, editors. *Freshwater microplastics* (pp. 69-83). Cham: Springer. http://dx.doi.org/10.1007/978-3-319-61615-5_4.

Flores, R., & Changanaqui, M. (2019). *Estudios y diseños del sistema de agua potable y alcantarillado para el centro poblado Madean, distrito de Madean, provincia de yauyos, región Lima* (Tesis). Universidad José Faustino Sánchez Carrión, Huacho. Retrieved in 2022, September 6, from renati.sunedu.gob.pe/handle/sunedu/1573839

Foo, Y. H., Ratnam, S., Lim, E. V., Abdullah, M., Molenaar, V. J., Shau Hwai, A. T., Zhang, S., Li, H., & Mohd-Zanuri, N. B. (2022). Microplastic ingestion by commercial marine fish from the seawater of Northwest Peninsular Malaysia. *PeerJ*, *10*, e13181. PMid:35462757. http://dx.doi.org/10.7717/peerj.13181.

Gela, S. M., & Aragaw, T. A. (2022). Abundance and characterization of microplastics in main urban ditches across the Bahir Dar City, Ethiopia. *Frontiers in Environmental Science*, *10*, 831417. http://dx.doi.org/10.3389/fenvs.2022.831417.

Ghosh, G. C., Akter, S. M., Islam, R. M., Habib, A., Chakraborty, T. K., Zaman, S., Kabir, A. H. M. E., Shipin, O., & Wahid, M. A. (2021). Microplastics contamination in commercial marine fish from the Bay of Bengal. *Regional Studies in Marine Science*, *44*, 101728. http://dx.doi.org/10.1016/j.rsma.2021.101728.

Grbić, J., Helm, P., Athey, S., & Rochman, C. (2020). Microplastics entering northwestern Lake Ontario are diverse and linked to urban sources. *Water Research*, *174*, 115623. PMid:32088386. http://dx.doi.org/10.1016/j.watres.2020.115623.

Horton, A., Svendsen, C., Williams, R., Spurgeon, D., & Lahive, E. (2017). Large microplastic particles in sediments of tributaries of the River Thames, UK: abundance, sources and methods for effective quantification. *Marine Pollution Bulletin*, *114*(1), 218-226. PMid:27692488. http://dx.doi.org/10.1016/j.marpolbul.2016.09.004.

Iannacone, J., Huyhua, A., Alvariño, L., Valencia, F., Principe, F., Minaya, D., Ortega, J., Argota, G., & Castañeda, L. (2019). Microplásticos en la zona de marea alta y supralitoral de una playa arenosa del litoral costero del Perú. *The Biologist (Lima)*, *17*(2), 335-346. http://dx.doi.org/10.24039/rtb2019172369.

Iannacone, J., Príncipe, F., Alvariño, L., Minaya, D., Panduro, G., & Ayala, Y. (2022). Microplásticos en el «cangrejo peludo» *Romaleon setosum* (Molina, 1782) (Cancridae) del Perú. *Revista de Investigaciones Veterinarias del Perú*, *33*(1), e22161. http://dx.doi.org/10.15381/rivep.v33i1.22161.

Iannacone, J., Príncipe, F., Minaya, D., Panduro, G., Carhuapoma, M., & Alvariño, L. (2021). Microplásticos en peces marinos de importancia económica en Lima, Perú. *Revista de Investigaciones Veterinarias del Perú*, *32*(2), e20038. http://dx.doi.org/10.15381/rivep.v32i2.20038.

Jiang, C., Yin, L., Li, Z., Wen, X., Luo, X., Hu, S., Yang, H., Long, Y., Deng, B., Huang, L., & Liu, Y. (2019). Microplastic pollution in the rivers of the Tibet Plateau. *Environmental Pollution*, *249*, 91-98. PMid:30884397. http://dx.doi.org/10.1016/j.envpol.2019.03.022.

Kataoka, T., Nihei, Y., Kudou, K., & Hinata, H. (2019). Assessment of the sources and inflow processes of microplastics in the river environments of Japan. *Environmental Pollution*, *244*, 958-965. PMid:30469290. http://dx.doi.org/10.1016/j.envpol.2018.10.111.

Li, C., Jiang, B., Guo, J., Sun, C., Shi, C., Huang, S., Liu, W., Wu, C., & Zhang, Y. (2022). Aging process of microplastics in the aquatic environments: aging pathway, characteristic change, compound effect, and environmentally persistent free radicals formation. *Water*, *14*, 3515. http://doi.org/10.3390/w14213515.

Li, Y., Lu, Z., Zheng, H., Wang, J., & Chen, C. (2020). Microplastics in surface water and sediments of Chongming Island in the Yangtze Estuary, China. *Environmental Sciences Europe*, *32*(15), 1-12. http://dx.doi.org/10.1186/s12302-020-0297-7.

Lima, A. R. A., Barletta, M., & Costa, M. F. (2015). Seasonal distribution and interactions between plankton and microplastics in a tropical estuary. *Estuarine, Coastal and Shelf Science*, *165*, 213-225. http://dx.doi.org/10.1016/j.ecss.2015.05.018.

Lin, L., Zuo, L.-Z., Peng, J.-P., Cai, L.-Q., Fok, L., Yan, Y., Li, H. X., & Xu, X. R. (2018). Occurrence and distribution of microplastics in an urban river: a case study in the Pearl River along Guangzhou City, China. *The Science of the Total Environment*, *644*, 375-381. PMid:29981986. http://dx.doi.org/10.1016/j.scitotenv.2018.06.327.

Liu, F., Vianello, A., & Vollertsen, J. (2019). Retention of microplastics in sediments of urban and highway stormwater retention ponds. *Environmental Pollution*, *255*(Pt 2), 113335. http://dx.doi.org/10.1016/j.envpol.2019.113335.

McKee, L. J., & Gilbreath, A. N. (2015). Concentrations and loads of suspended sediment and trace element pollutants in a small semi-arid urban tributary, San Francisco Bay, California. *Environmental Monitoring and Assessment*, *187*(8), 499. PMid:26160738. http://dx.doi.org/10.1007/s10661-015-4710-4.

Piñon-Colin, T. J., Rodriguez-Jimenez, R., Rogel-Hernandez, E., Alvarez-Andrade, A., & Wakida, F. T. (2020). Microplastics in stormwater runoff in a semiarid region, Tijuana, Mexico. *The Science of the Total Environment*, *704*, 135411. PMid:31810711. http://dx.doi.org/10.1016/j.scitotenv.2019.135411.

Quinn, B., Murphy, F., & Ewins, C. (2017). Validation of density separation for the rapid recovery of microplastics from sediment. *Analytical Methods*, *9*(9), 1491-1498. http://dx.doi.org/10.1039/C6AY02542K.

Rice, E. W., Baird, R. B., & Eaton, A. D. (2017). *Standard methods for the examination of water and wastewater* (23th ed.). Washington: American Public Health Association, American Water Works Association, Water Environment Federation. Retrieved in 2022, September 6, from https://www.wef.org/resources/publications/books/StandardMethods/

Rocha-Santos, T., & Duarte, A. C. (2015). A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. *Trends in Analytical Chemistry*, *65*, 47-53. http://dx.doi.org/10.1016/j.trac.2014.10.011.

Shruti, V. C., Jonathan, M. P., Rodriguez-Espinosa, P. F., & Rodríguez-González, F. (2019). Microplastics in freshwater sediments of Atoyac River basin, Puebla City, Mexico. *The Science of the Total Environment*, *654*, 154-163. PMid:30445318. http://dx.doi.org/10.1016/j.scitotenv.2018.11.054.

Su, L., Xue, Y., Li, L., Yang, D., Kolandhasamy, P., Li, D., & Shi, H. (2016). Microplastics in Taihu Lake, China. *Environmental Pollution*, *216*, 711-719. PMid:27381875. http://dx.doi.org/10.1016/j.envpol.2016.06.036.

Talbot, R., & Chang, H. (2022). Microplastics in freshwater: A global review of factors affecting spatial and temporal variations. *Environmental Pollution*, *292*(Pt B), 118393. PMid:34678395. http://dx.doi.org/10.1016/j.envpol.2021.118393.

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at sea: where is all the plastic? *Science*, *304*(5672), 838. PMid:15131299. http://dx.doi.org/10.1126/science.1094559.

Thompson, R., Moore, C., vom Saal, F., & Swan, S. (2009). Plastics, the environment and human health: current consensus and future trends. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1526), 2153-2166. PMid:19528062. http://dx.doi.org/10.1098/rstb.2009.0053.

U.S. Environmental Protection Agency – US EPA. (2002). *Guidance for quality assurance project plans. EPA QA/G-5. EPA/240/R-02/009. EPA QA/G-5.* Retrieved in 2022, September 6, from https://www.epa.gov/sites/default/files/2015-06/documents/g5-final.pdf

van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., & Janssen, C. (2015). Microplastics in sediments: a review of techniques, occurrence and effects. *Marine Environmental Research*, *111*, 5-17. PMid:26095706. http://dx.doi.org/10.1016/j.marenvres.2015.06.007.

Wang, J., Peng, J., Tan, Z., Gao, Y., Zhan, Z., Chen, Q., & Cai, L. (2017). Microplastics in the surface sediments from the Beijiang River littoral zone: Composition, abundance, surface textures and interaction with heavy metals. *Chemosphere*, *171*, 248-258. PMid:28024210. http://dx.doi.org/10.1016/j.chemosphere.2016.12.074.

Werbowski, L. M., Gilbreath, A. N., Munno, K., Zhu, X., Grbic, J., Wu, T., Sutton, R., Sedlak, M. D., Deshpande, A. D., & Rochman, C. M. (2021). Urban Stormwater runoff: a major pathway for anthropogenic particles, black rubbery fragments, and other types of microplastics to urban receiving waters. *American Chemical Society Environmental Science and Technology Water*, *1*(6), 1420-1428. http://dx.doi.org/10.1021/acsestwater.1c00017.

Xu, Q., Xing, R., Sun, M., Gao, Y., & An, L. (2020). Microplastics in sediments from an interconnected river-estuary region. *The Science of the Total Environment*, *729*, 139025. PMid:32380331. http://dx.doi.org/10.1016/j.scitotenv.2020.139025.

Zárate, M., & Iannacone, J. (2021). Microplásticos en tres playas arenosas de la costa central del Perú. *Revista de Salud Ambiental*, *21*(2), 123-131. Retrieved in 2022, July 21, from https://ojs.diffundit.com/index.php/rsa/article/view/1079/999

Zhang, K., Gong, W., Lv, J., Xiong, X., & Wu, C. (2015). Accumulation of floating microplastics behind the Three Gorges Dam. *Environmental Pollution*, *204*, 117-123. http://dx.doi.org/10.1016/j.envpol.2015.04.023.

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Franklin Canchari: Study design, field sample collection, laboratory analysis, data processing, statistical analysis, graphs, maps; writing and revision of the article.

José Iannacone: Study design, laboratory use permit management, laboratory material acquisition management, statistical analysis, writing and review, translation into English, supervision, review of the article.

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