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# CHARACTERIZATION OF MICROPLASTICS IN MARINE SEDIMENTS FROM THE GULF OF TEHUANTEPEC, MEXICAN PACIFIC

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**Abstract:** Microplastics (MPs), a universal pollutant is widely distributed in sediments, which attracted the environmental researchers worldwide. MPs are harmful may adsorb toxic compounds present in the environment, which can be ingested by benthic organisms and easily transfer to humans. We investigated the distribution of MPs and its types in beach sediments from the Tehuantepec River mouth, Gulf of Tehuantepec, Mexican Pacific coast. MPs are categorized by their size, shape, color, and polymer types. 73 % of MPs detected are < 5 mm in size. Fiber and colorless are mostly dominated in all samples. The fibers are weathered and degraded with adhered particles on their surfaces. The polymer types detected are polyacrylamide (PAM) and poly(methyl acrylate) (PMA), which are rarely reported in Mexico beach sediments. The prevalence of colorless MPs at the Gulf of Tehuantepec beach needs further attention.

**Keywords:** Mexico, Polymer, Microplastics, SEM, Microtexture, Fiber

## 1. INTRODUCTION

Recently, plastic pollution has become increasingly considered as a global problem among research community (Ruíz-Reyes et al., 2023; Páez-Osuna et al., 2023). Manufacturing of plastic products is increasing daily and are widely used by the people, because of their lightweight, corrosion resistant, waterproof, durability, and low price (Vegter et al., 2014). Improper management of plastic wastes results an enormous input of plastics into the sea, which simultaneously contaminate the coastal environment. In particular, floating plastic particles are transported by rivers to the sea through polluted industrial areas, later during its permanence in water, plastics can absorb both organic and inorganic substances (Zhang et al., 2015; Ma et al., 2020). Their exposure to ultraviolet (UV) radiation for a particular time makes them brittle and fragmentation, which leads a rapid disintegration (Darshan et al., 2023). In addition, the high temperature in coastal marine environments can increase the intensity of degradation of plastic particles (Zhang, 2017).

MPs are plastic particles smaller than 5 mm in size (Au et al., 2017; Auta et al., 2017). Primary MPs can originate from textile industries, packaging, and plastic products. Secondary MPs are the product originated by the destruction of plastic bags and bottles (Darabi et al., 2021; Uddin et al., 2021). Due to its rapid destruction, MPs are abundant in sediments and water of all environments and organisms (Fossi et al., 2018; Digka et al., 2020). Hence, sediment and water play a key role on the environmental dynamics of MPs, especially coastal environments are exposed to the large accumulation of plastic wastes (de Lucia et al., 2014; Stolte et al., 2015; Said et al., 2022). Rivers are the major source of MPs, which deliver large quantity of MPs to the ocean (Holmes et al., 2014). The coastal environments are more susceptible to plastic wastes, especially to those located near to the densely urbanized areas. Coastal sediments are reliable to investigate the environmental variations in the transitional area (Kirkwood et al., 2016). Tehuantepec River is the largest River in the Oaxaca state, has an area of 10.090 km² and drains cross 90% of surface area, and finally empties 30 m³/s into the Gulf of Tehuantepec (SNIEG, 2004).

Studies on the abundance of MPs in Mexican beach sediments are very scarce (Silva-Iñiguez & Fischer 2003; Ríos-Mendoza et al., 2021; Grillo et al., 2022). Recently, MPs in Mexican sea water and Gulf of Mexico coastal sediments were investigated by a few researchers (Ramírez-Álvarez et al., 2020; Castro-Zárate, 2022; Flores-Ocampo & Armstrong-Altrin, 2023; Ruíz-Reyes et al., 2023). These studies analyzed the abundance, type, composition, and seasonal variations in the distribution of plastic debris.

In this study, we selected beach sediment samples in the Tehuantepec River mouth, Gulf of Tehuantepec, Oaxaca State, Mexican Pacific. This study examines the distribution of MPs in the beach sediments, based on their shape, size, color, and polymer types. As mentioned previously, studies on the distribution of MPs in beach sediments of Mexico are little, this is the first preliminary study to report the polymer types in the beach sediments at the Gulf of Tehuantepec, Mexican Pacific.

## 2. STUDY AREA

The Tehuantepec River mouth is located at the Gulf of Tehuantepec, southeastern Mexico (16°10'59'' N - 95°09'28'' W to 16°11'04'' N - 95°09'54'' W; Figure 1). Twenty sediment samples were collected at the beach in October 2022. In 2020, the population in Oaxaca State was approximately calculated as 4,132,148 inhabitants, in ten years it increased about 9% (Ramos-Vázquez et al., 2023).

The climate in the coastal region varies from warm to sub humid with an average temperature of 28°C (Amador et al., 2006). The intensity of the Costa Rica Coastal Current (CRCC) in the Gulf of Tehuantepec is highest in November and nil in June (Kessler, 2006).

## 3. METHODOLOGY

Twenty sediment samples (~2 kg each) were collected in the Tehuantepec beach, Mexican Pacific coast, Oaxaca state to investigate the abundance of MPs. The samples were collected at the high tide line, where the wave ends by maintaining 50 m distance between samples. The sediments were collected at a depth of 1-5 cm using a metal spoon. The collected samples were air-dried at room temperature. For grain size analysis, the samples were dried at 50°C in an oven for 24 hrs. Among 20 sediment samples, 13 (T1, T3, T5, T6, T7, T9, T10, T11, T13, T14, T15, T17, and T19) were selected to investigate the abundance of MPs and all 20 samples were selected for grain size analysis.

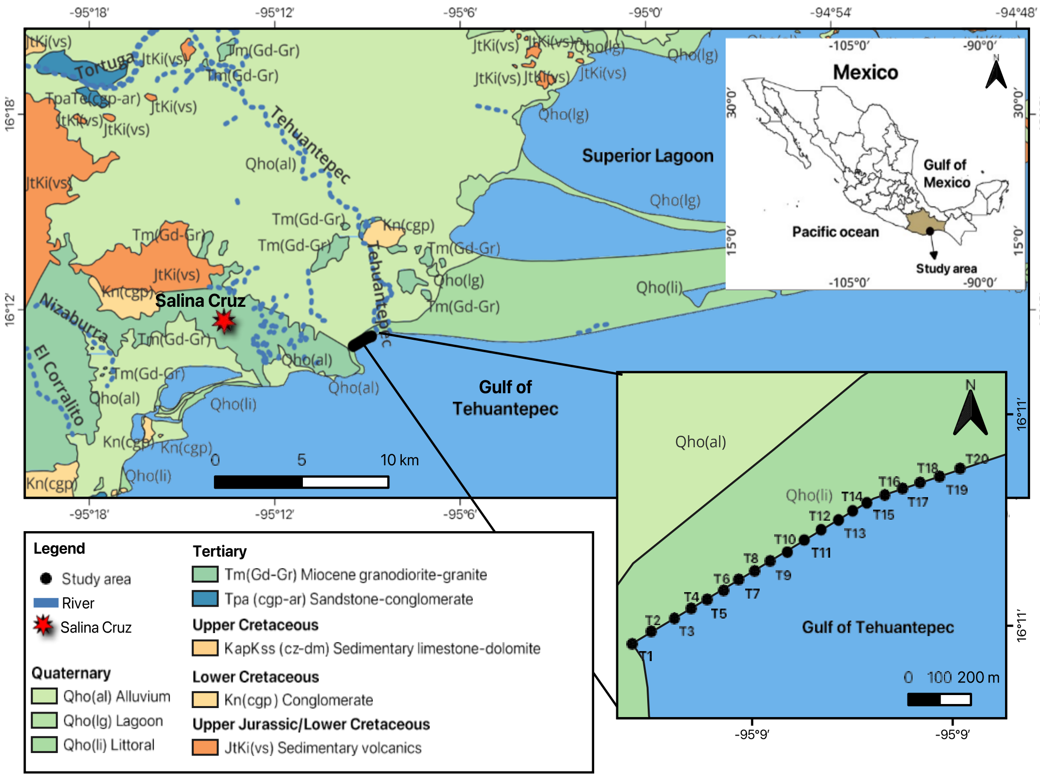


Figure 1. Geological Map showing the sample locations in the study area Gulf of Tehuantepec (source: Dirección General de Geografía del Territorio Nacional; scale 1:1,000,000). Numbers from T1 to T20 represent sample locations.

### 3.1. Grain-size analysis

The samples were analyzed by a Ro-Tap Sieve Shaker, at the Sedimentology Laboratory, Institute of Marine Sciences and Limnology (ICML), National Autonomous University of Mexico (UNAM), Mexico City. The textural parameters like mean, standard deviation, skewness, and kurtosis were calculated based on the methodology proposed by Wentworth (1922) and Folk & Ward (1957).

### 3.2. Extraction method

To detect the abundance of MPs in sediments 13 samples (25 g each) were mixed with ultrapure 1:3 (18.2 MΩ) water, then oil was added (5 mL). For separation of MPs, we used olive oil stored in a glass bottle to avoid possible contamination during the process. Other studies also recommended that density separation using olive oil was an efficient method to extract MPs in sediments, especially is reliable for high density polymers (Lekse et al., 2024; Scopetani et al., 2020). After settling (approximately 2 h), the beakers were covered with aluminum foil and the samples were frozen at 0°C. The ice columns together with the oil layers were pushed out and transferred to a Buchner funnel to a suction flask. The samples were filtered through glass microfiber filters (GF/A, 90 mm diameter, Whatman), the oil layer was filtered before filtering the water layer. The filters were carefully washed out with water and then with hexane to remove oil traces. The recovered plastic particles were transferred to Petri dishes covered with filter papers (Scopetani et al., 2020). The plastic particles were then sorted manually under a Stereo Microscope, which was attached with a digital camera. During the separation process, plastic materials, which can release MPs were carefully eliminated. The MPs separation was done at Sedimentology Laboratory, ICML, UNAM.

### 3.3. Morphology and polymer types

The shape and surface features of MPs were studied by a Scanning Electron Microscopy (SEM). The samples were coated with Au and the microphotographs obtained were analyzed using JEOL JSM6360LV. The polymer types were detected by a Fourier transform infrared (FTIR) spectroscopy using a Thermo Nicolet 6700 Spectrophotometer in a range from 500 to 3600 $cm^{-1}$ with 124 scans.

## 4. RESULTS

### 4.1. Textural characteristics

The grain-size characteristics are highly reliable to investigate the provenance and transport processes (Jian-Wu et al., 2013; Szcześniak et al., 2023; Tanabe et al., 2023). The grain size varies from medium (55%) to fine-grained (45%, Table 1; number of samples n = 20) and are classified as well-sorted (n = 6), moderately well-sorted (n = 6), and moderately sorted (n = 8). The kurtosis varies from very leptokurtic to very platykurtic distributions (Table 1).

### 4.2. Abundance of MPs

Among 20 samples, 13 were selected to investigate the abundance of MPs. Totally, 85 plastic particles are identified (~ 0.5 - 4 mm length). About 73% of MPs are < 5 mm and are mostly represented by 0.5-1.4 mm size (40% of MPs). Fiber type is dominant (100%) (Figure 2). MPs are colorless (35%), black (18.7%), and blue (20%), while other colors are accounted for 26.3% (Figure 3).

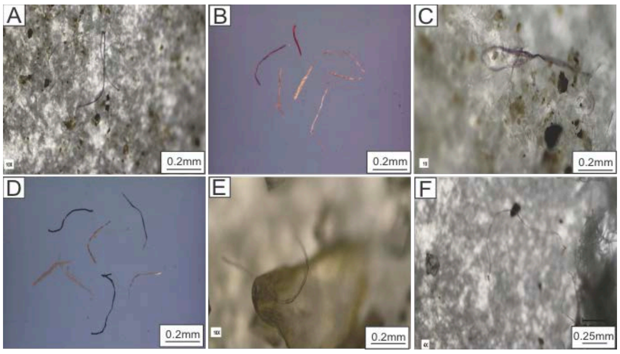



Figure 2. Fibers observed under a stereomicroscope in the beach sediments (magnification 10X). A) blue; B) colorless, blue, and red; C) colorless; D) red, colorless, and blue; E) colorless; and F) colorless.

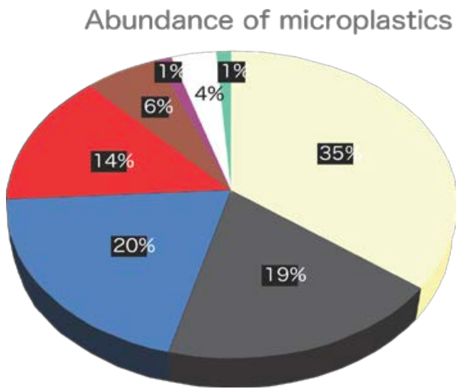



Figure 3. Distribution of MPs in the Tehuantepec beach sediments, classification based on their color.

## 5. DISSCUSION

### 5.1. Microplastics

The differences in MPs color are primarily determined by the type of parent plastic wastes. Studies estimated that 700,000 fibers were released from

Table 1. Textural parameters of sediments in the Tehuantepec beach, Gulf of Tehuantepec.

| Sample | Mz (θ) | | Sorting (θ) | | Skewness ($Sk_1$) | | Kurtosis ($K_G$) | |
|---|---|---|---|---|---|---|---|---|
| T1 | 2.12 | Fine sand | 0.58 | Moderately well sorted | -0.24 | Coarse skewed | 0.97 | Mesokurtic |
| T2 | 2.38 | | 0.40 | Well sorted | -0.10 | Symmetrical | 1.28 | Leptokurtic |
| T3 | 2.40 | | 0.42 | | -0.09 | | 1.08 | Mesokurtic |
| T4 | 2.28 | | 0.41 | | -0.13 | Coarse skewed | 1.23 | Leptokurtic |
| T5 | 2.12 | | 0.65 | Moderately well sorted | -0.44 | Strongly coarse skewed | 1.34 | |
| T6 | 2.17 | | 0.74 | Moderately sorted | -0.46 | | 1.98 | Very leptokurtic |
| T7 | 2.40 | | 0.43 | Well sorted | -0.26 | Coarse skewed | 1.31 | Leptokurtic |
| T8 | 2.43 | | 0.43 | | -0.29 | | 1.23 | |
| T9 | 1.88 | Medium sand | 0.81 | Moderately sorted | -0.43 | Strongly coarse skewed | 0.93 | Mesokurtic |
| T10 | 1.60 | | 0.75 | | -0.24 | Coarse skewed | 0.98 | |
| T11 | 1.45 | | 0.94 | | -0.32 | Strongly coarse skewed | 0.75 | Very platykurtic |
| T12 | 1.52 | | 0.79 | | -0.20 | Coarse skewed | 0.99 | Mesokurtic |
| T13 | 1.48 | | 0.97 | | -0.38 | Strongly coarse skewed | 0.82 | Platykurtic |
| T14 | 1.62 | | 0.65 | Moderately well sorted | -0.03 | Symmetrical | 1.00 | Mesokurtic |
| T15 | 1.53 | | 0.63 | | 0.04 | | 0.96 | |
| T16 | 1.03 | | 0.86 | Moderately sorted | -0.09 | | 0.63 | Very platykurtic |
| T17 | 1.68 | | 0.72 | | -0.17 | Coarse skewed | 0.97 | Mesokurtic |
| T18 | 1.83 | | 0.62 | Moderately well sorted | -0.20 | | 0.96 | |
| T19 | 2.10 | Fine sand | 0.46 | Well sorted | -0.18 | | 0.95 | |
| T20 | 1.92 | Medium sand | 0.65 | Moderately well sorted | -0.28 | | 1.06 | |
| Mean | 1.90 | | 0.64 | | -0.22 | | 1.07 | |
| Std, Dev | 0.40 | | 0.18 | | 0.14 | | 0.28 | |

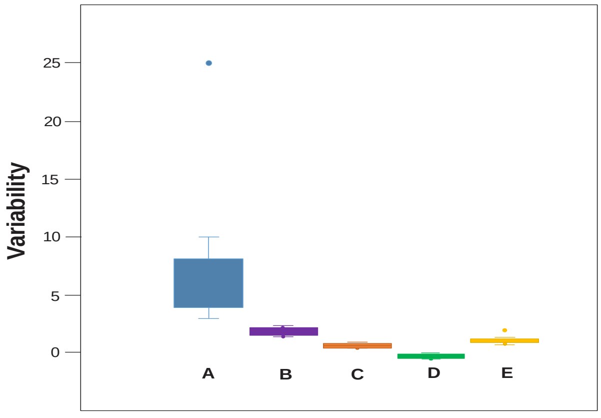



Figure 4. Box plot to visualize the distribution of MPs and textural parameters. A) MPs, B) grain size, C) sorting, D) skewness, and E) kurtosis

laundering synthetic textiles, among them 35% were transported to the estuarine coastal environment by rivers (Napper & Thompson, 2016; David et al., 2023). The abundance of colorless MPs in marine sediments suggesting its long-time duration and weathering. Fishing activity is the source for the release of colorless MPs into the beach, it is also due to the rapid fragmentation of fishing nets. The blue and black color MPs are sourced by the cessation of synthetic textiles and packaging materials. The predominance of light-colored MPs indicates its resistant to long-term degradation. In the Tehuantepec beach there is a high probability for MPs to transfer from sediments to the marine organisms, because MPs identified are mostly colorless, which increase the possibility of being consumed by an aquatic community (35%; Figure 3; Pan et al., 2022; Kalcíková, 2023). The relationship between the abundance of MPs in sediments (MPs/kg) and textural parameters are shown in Figure 4. It reveals that the abundance of MPs in beach sediments is not related with grain size variations and textural parameters.

### 5.2. Morphology

MPs are categorized according to their morphotype and surface features. Well preserved fibers of small (Figure 5A and B) and large sizes (Figure 5C and D) are prevalent. Few fibers are tensed and stretched due to agitation and stress (Figure 5E and F). MPs are degraded and fragmented due to weathering (Figure 5 G, H, I, J, and K). The physical and biological degradations of MPs are due to its long-term exposure to ultraviolet light (Cole et al., 2011; Flores-Ocampo & Armstrong-Altrin, 2023). The degraded MPs can weather quickly when exposed to sunlight for a long span of time (Bosker et al., 2018; Puthcharoen & Leungprasert 2019).

Numerous authors demonstrated that effect of damage to the aquatic organisms are severe if MPs withstand for a longer time in a specific place (Piperagkas et al., 2019; Yang et al., 2021; Yu et al., 2021). The consumption of MPs may cause various effects like DNA damage and higher level of absorbed contaminants by tissues (Ashrafy et al., 2023). Degradation of MPs increase the adsorption of metals on their surfaces and can induce chemical reaction, because of its exposure to sun light. However, intensity of biodegradation of MPs is depends on the factors like exposure characteristics, moisture, temperature, polymer types such as molecular weight, size, shape, additives, and bio surfactants (Ahmed et al., 2018).

MPs with smooth textures and pellet types are less prone to contaminant adsorption (Xia et al. 2021). In fact, secondary MPs enter into the oceans are also the product of plastic wastes (Van Cauwenberghe et al., 2015; Rezende-Gerolin et al., 2020).

The municipal and industrial effluents are the major sources for these MPs in the coastal region. In addition, the surface of most fibers is covered by adhered particles, probably due to the precipitation of salt as well as the accumulation of pollutants in water (Figure 5L, M, and N). It seems that the cellulose detected in sediments belongs to viscose fiber group, probably non-plastic (Figure 5O). They are semi-synthetic type, generally used in dresses and jackets. Silica globules on fibers surface are also observed, indicating a silica saturated environment (Figure 5P).

### 5.3. Polymer types

The polymer types detected by FTIR are shown in Figure 6 and listed in Table 2. FTIR revealed two prevalent polymers including polyacrylamide (PAM) and poly(methyl acrylate) (PMA) (Figure 6). Polymers PAM and PMA are part of a group that polluting the marine ecosystem, which are not reported frequently in other coastal regions of the world (Perumal & Muthuramalingam, 2022).

In Mexico, PAM is reported at the Todos Santos Bay (Ramírez-Álvarez et al., 2020). Other polymer

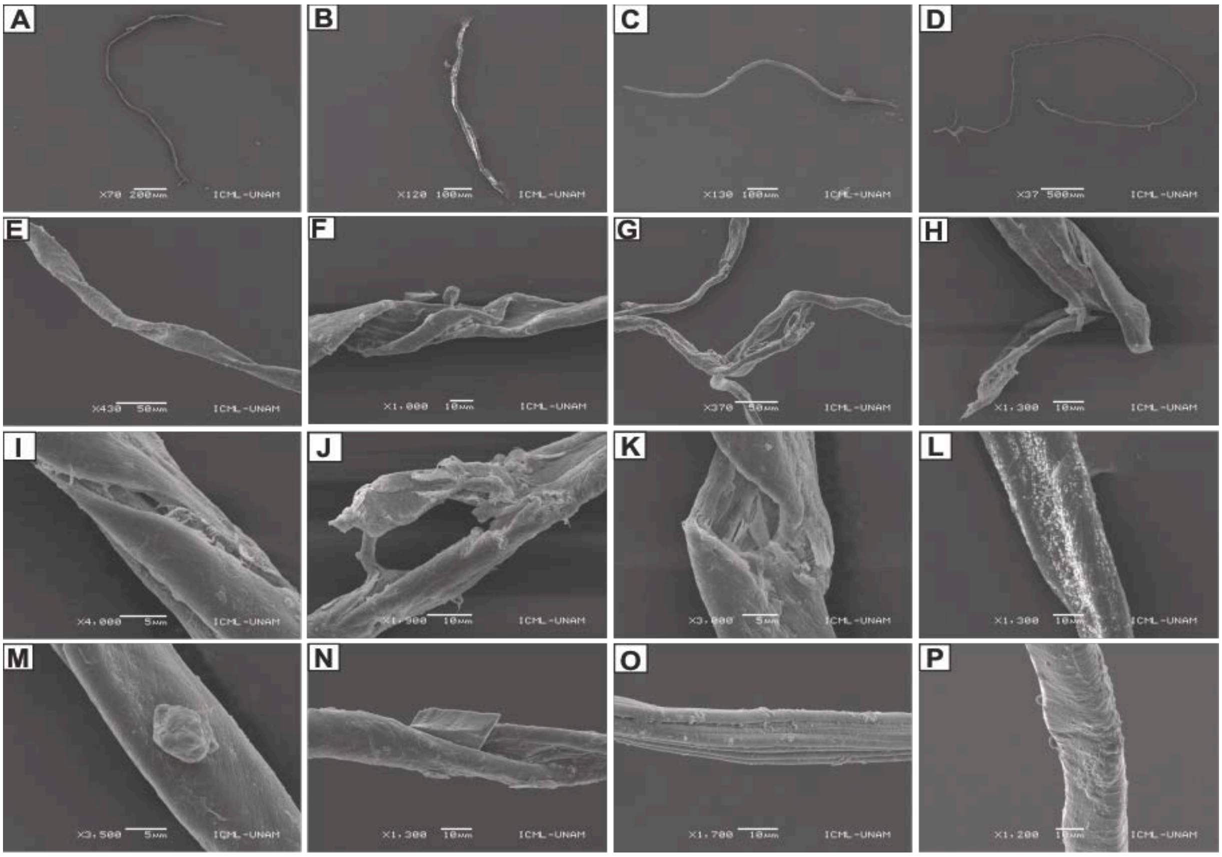



Figure 5. SEM images of MPs showing morphology and surface textures of beach sediments, Gulf of Tehuantepec, Oaxaca State, Mexican Pacific: A and B) well preserved small fibers; C and D) well preserved large fibers; E) Tensed fiber due to agitation; F) stressed fiber due to tension; G) degraded fiber; H) fragmented degraded fiber; I) degraded fiber; J) highly degraded fiber showing abrasion due to agitation, probably fragmented from textile; K) Exfoliation and abrasion due to weathering; L) Fiber with adhering particles; M) adhering particle on well preserved MPs surface; N) Abraded fiber with adhering particles; O) parallelly arranged fiber with adhering particles and striations, probably a cellulose; and P) fiber with silica globules.

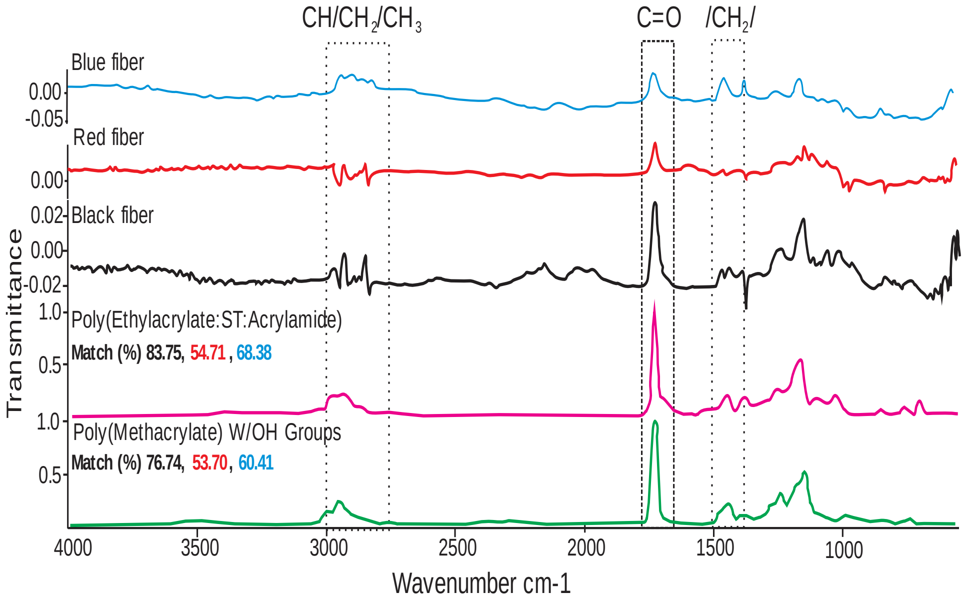



Figure 6. FTIR spectra of polyacrylamide (PAM) and poly(methyl acrylate) (PMA), which are compared with fibers of different colors (black, blue, and red)

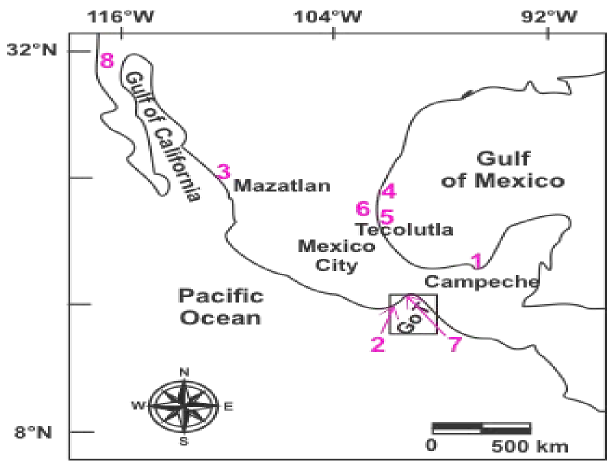



Figure 7. Map showing study area and locations of other similar studies in the Mexican coastal areas. 1) Campeche (Borges-Ramírez et al., 2019), 2) Huatulco (Retama et al., 2016), 3) Mazatlán (Ríos-Mendoza et al., 2021), 4) Tampico (Flores-Ocampo & Armstrong-Altrin, 2023), 5) Tecolutla (Sánchez-Hernández et al., 2021), 6) Tecolutla beach (Flores-Cortés & Armstrong-Altrin, 2022), 7) Tehuantepec River mouth (This study), and 8) Todos Santos Bay (Ramírez-Álvarez et al., 2020). B) Map showing the location of the Tehuantepec River mouth, Gulf of Tehuantepec (GoT) (Source: Carta Geológica; scale 1:1,000,000). Map modified after Ramos-Vázquez et al. (2023).

types reported in Mexico are Aliphatic Polyamide (APA), Cellulose (CL), Polyacrylonitrile (PAN), Polyamide (PA), Polyester (PES), Polyethylacrylate (PEA), Polyethylene (PE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS), Polyvinyl chloride (PVC), and Styrene-acrylonitrile Copolymer (SAN) (Retama et al., 2016; Wessel et al., 2016; Borges-Ramírez et al., 2019; Ríos-Mendoza et al., 2021; Sánchez-Hernández et al., 2021; Flores-Ocampo & Armstrong-Altrin, 2023) (Table 3; Figure 7). The possible explanation for the predominance of PAM and PMA is due to the result of fragmentation of fishing nets. Synthetic alkyl resins are produced from the polymerization of methyl methacrylate. These are generally used as a substitute for glass products (Britannica, 2023). MPs of different colors with similar spectra and broad absorption band at 1500 cm$^{-1}$ are corresponds to bending.

Similarly, the absorption bands at 2750 cm$^{-1}$ - 3000 cm$^{-1}$, and 1750 cm$^{-1}$ are associated with stretching, which may be due to carboxyl group (Figure 6). Polyacrylamide identified by the FTIR technique by Raza et al., (2023) showed bands at 3378 cm$^{-1}$, 3257 cm$^{-1}$, 1663 cm$^{-1}$, 1619 cm$^{-1}$, and 1026 cm$^{-1}$. The polyacrylamide spectra showed peaks at 3050 cm$^{-1}$ (Nair & Sawant 2006). As reported in other studies, fibers in the estuarine sediments are probably supplied by the wastewater effluents (De Falco et al., 2018).

### 5.4. Comparison of MPs abundance and polymer types

MPs abundance and polymer types recovered in coastal sediments of Mexican beaches and the study are listed in Table 3. The MPs in the Tehuantepec sediments range from 120 to 1000 MPs/kg, which is lower than reported in the Campeche and Tampico beaches of Gulf of Mexico (Borges-Ramírez et al., 2019; Flores-Ocampo & Armstrong-Altrin, 2023), Huatulco, and Todos Santos beaches of Mexican Pacific (Retama et al., 2016; Ramírez-Álvarez et al., (2020). The highest concentration of MPs was found in Tampico beach, with 13,392 MPs/kg (Flores- Ocampo & Armstrong-

Table 2. Abundance of microplastics and their polymer types in the beach sediments, Gulf of Tehuantepec.

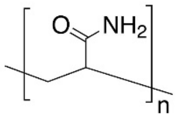
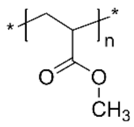
| Sample No. (number of samples = 13) | MPs in 25 g of sediments | Abundance (MPs/kg) | MPs polymer types (Formula) | |
|---|---|---|---|---|
| T1 | 25 | 1000 |  | |
| T3 | 4 | 160 | | |
| T5 | 8 | 320 | | Polyacrylamide |
| T6 | 7 | 280 | | ρ=1.20 g/cm$^3$ |
| T7 | 4 | 160 | | |
| T9 | 3 | 120 | | |
| T10 | - | - |  | |
| T11 | 10 | 400 | | |
| T13 | 3 | 120 | | Poly (methyl acrylate) |
| T14 | 4 | 160 | | ρ=1.20 g/cm$^3$ |
| T15 | 5 | 200 | | |
| T17 | 8 | 320 | | |
| T19 | 4 | 160 | | |

Table 3. Comparison of microplastics abundance of this study with other studies of Mexico (Refer Figure 7 for locations).

| **Location** | **n** | **Concentration** | **Polymer type** | **Inferred source** | **References** |
|---|---|---|---|---|---|
| 1. Campeche (GoM) | 27<br>36 | 1392/m$^2$<br>49315 µg/g | MPs/Phthalate esters (PAEs) | Packers (fishery products), tourism, and urban waste | Borges-Ramírez et al., (2019) |
| 2. Huatulco, Oaxaca (MP) | 35<br>35 | 0-48/10g DW<br>2-69/10g DW | - | Tourism, restaurants, boutiques and craft stores | Retama et al., (2016) |
| 3. Mazatlán, Sinaloa (MP) | 14 | 0.31-6.87MPs/kg | PA (polyamide), PC (polycarbonate), PE (polyethylene), PET (polyethylene terephthalate), PP (polypropylene), PS (polystyrene), PU (polyurethane), PVC (polyvinyl chloride), and cotton fibers | Waste water discharge | Ríos-Mendoza et al., (2021) |
| 4. Tampico, Tamaulipas (GoM) | 20 | 12800-14150 MPs/kg | PET, polyethylacrylate (PEA), cellophane, polyacrylonitrile, PS, acrylonitrile, and polyvinyl acetate ethylene. | Domestic and industrial waste sewages, tourism fishing activities | Flores-Ocampo & Armstrong-Altrin (2023) |
| 5. Tecolutla estuary, Veracruz (GoM) | 15 | 121 ± 115 MPs/kg | LDPE, PP, PC, rayon, PVC, polyacrylonitrile, PA, nylon, and PET | Fishing gear, laundry, cosmetics, sanitation, plastic bags and bottles | Sánchez-Hernández et al., (2021) |
| 6. Tecolutla beach, Veracruz (GoM) | 10 | 27-720 MPs/kg | - | Fluvial detritus supplied by the Tecolutla River | Flores-Cortés & Armstrong-Altrin (2022) |
| 7. Tehuantepec beach, Oaxaca (MP) | 13 | 120-1000 MPs/kg | polyacrylamide (PAM) and poly(methyl acrylate) (PMA) | Waste water effluents | ***This study*** |
| 8. Todos Santos Bay (GoC) | 12 | 85-2494 MPs/0.1m$^2$ | PE, PP for fragments and nylon, PET, PAM, and cellophane for fibers. | Effluent waters from wastewater treatment plants | Ramírez-Álvarez et al., (2020) |

n = number of sediment samples; GoM = Gulf of Mexico; MP = Mexican Pacific; GoC = Gulf of California; DW = Dry Weight.

Altrin, 2023) and the lowest was reported in the Mazatlán beach, Mexican Pacific.

These studies illustrated that the abundance of MPs in coastal sediments were depends on the fluvial system, population, industrialization, fishing, tourism, and intensity of degradation. Although MPs in Tehuantepec are lower than in the Tecolutla and Mazatlan beaches, the results of this study are helpful to the researchers to identify the plastic pollutants and their sources, particularly in the Mexican Pacific.

## 6. CONCLUSIONS

The data reported in this work signifies a baseline study for plastic contamination in the beach sediments, Gulf of Tehuantepec, Oaxaca State. MPs were detected in all samples, with a prevalence of fiber type (< 5 mm length; n = 85).

The common MPs colors are colorless (35%), black (19%) and blue (18%), and remaining accounted for 28%. The MPs analyzed by SEM reveals fragmentation and biodegradation with adhering particles on their surfaces. In addition, adhered particles on their surfaces suggest intense weathering and their persistent in the estuarine environment for a long time.

PAM and PMA polymers are predominant in sediments. PAM is the most common polymer in sediments derived from wastewater effluent. PMA is a synthetic acrylate polymer, soft and tough rubbery material. A large number of fibers in the beach sediments reveals the biological risk, which requires further attention from the scientific community.

This study helps the scientific community to understand the MPs contamination problems and their ecological risk of the coastal estuarine system in the Mexican Pacific. Further studies on MPs adsorption capacity of trace metals and their relationship with sediment textural parameters are also necessary to understand the ecological risk.

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