

Risk assessment of microplastics accumulation in estuarine sediments at Cuddalore coast, Tamil Nadu, Southeast coast of India

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Abstract

In this study, the abundance of microplastics (MPs) in Uppanar and Gadilam estuaries in Cuddalore, southeast coast of India are reported. In the estuarine sediments, MPs abundance ranged from 36.3 ± 3.39 to 51.6 ± 2.05 particles/Kg dw. Various MPs shapes such as fibers (41.7-47.9%), films (21.2-27.2%), and fragments (18.3-25.5%) were observed which were in the size range of 100-1000 μm . Diverse colours of MPs were observed among which red (30.1-34.5%) was predominant. Six polymers were identified by μ -FTIR among which LDPE (39%) and PP (35%), were dominant. MPs pollution in these estuaries is contributed by domestic, industrial, and fishing wastes. Risk assessment shows that the area falls under hazard category IV to V indicating high to extreme danger. This study improves knowledge on MPs pollution in Uppanar and Gadilam estuaries and provides impulsion to identify actual sources and effects of MPs on water bodies along the east coast of India.

Keywords: Abundance and morphological characteristics, polymer identification, μ -FTIR, Polymer Hazard Index (PHI).

Introduction

Plastic products bring great benefits and convenience to people's lives, but its inappropriate disposal and mismanagement cause serious environmental problems (Xiong et al. 2019). The main environmental problem due to plastics is its accumulation in the aquatic environments where they may exist for centuries (Xu et al. 2020). Plastics in all sizes and shapes exist in the marine environments which originate from the inland sources Wagner et al. 2014).

Microplastics (MPs) are small fragments (< 5 mm) of plastic litter (Sathish et al. 2019) that are witnessed in all marine environs (Ghayebzadeh et al. 2021). The low molecular weight and insolubility of MPs enable higher mobility and ubiquity in the hydrological environments (Holland et al. 2016). Many studies on the distribution and occurrence of MPs arises from research carried out mainly in estuaries, offshore areas, and the open ocean (Collignon et al. 2014) while estuaries have been identified as MPs hotspots (Wright et al. 2013). However, quantification and characterization of MPs in estuarine systems is incompletely understood (Lima et al. 2014; Sadri and Thompson, 2014). Inland rivers and streams bring several toxicants such as metals, pesticides, hydrocarbons, and MPs which may eventually settle to the estuarine floor (Gray et al. 2018). Thus estuaries act as a sink for these toxicants. Other activities such as aquaculture, beach littering, fishing, and shipping also contribute a considerable quantity of MPs deposition into the marine and estuarine environments (Lebreton et al. 2017).

MPs have been observed in estuaries as evidenced in several studies carried out at various global estuaries such as Tamar estuary (Sadri and Thompson, 2014), Yangtze estuary (Zhang et al. 2015), estuaries in the northern Gulf of Mexico (Wessel et al. 2016), Amazon estuary (Pegado et al. 2018), Changjiang estuary (Peng et al. 2017; Xu et al. 2018), Pearl estuary (Yan et al. 2019), Vellar estuary (Nithin et al. 2022) among others.

In estuaries, physical and biological factors synchronize to deteriorate the surface of plastic debris leading to the formation of MPs particles in as early as 8 weeks (Weinstein et al. 2016). During tidal interactions, high tides transfer MPs from seas to estuaries and vice versa during low tides (Bakir et al. 2014). Meanwhile, salinity and temperature undergo constant changes during these tidal interactions which complicate studies on MPs distribution in the estuaries (Bakir et al. 2014). A former study highlights the importance of both natural and anthropogenic processes such as flushing and dredging in the pulse of the released substances like persistent organic pollutants (POPs) from the MPs, which correlates to its residence time in estuaries and marine waters (Bakir et al. 2014). The persistence of MPs in marine environments may cause diverse health hazards to the marine

organisms as they ingest MPs particles actively or passively as food items as observed in fish (Naidoo et al. 2020); mussels (Scott et al. 2019) and other organisms (Hossain et al. 2020). Moreover, it can cause decreased energy reserves (Wright et al. 2013), decreased reproductive output (Au et al. 2015), and affects growth (Wertz, 2015) of various aquatic organisms.

India generates approximately 9.4 million tons of plastic waste annually out of which 60% is recycled and the remaining wastes are disposed of (Ministry of Housing and Urban Affairs, 2019). These discarded wastes enter the estuaries and are deposited into the Arabian Sea in the west and the Bay of Bengal in the east of India. MPs studies on estuaries were sporadic till recent years but have gained impetus in the past few years as evidenced in some global studies (Xu et al. 2018; Yan et al. 2019; Gray et al. 2018). However in India, such studies are scanty (Sarkar et al. 2019; Nithin et al., 2022).

Polymer Hazard Index (PHI) is the measure of the risk of each polymer present in the environment. PHI values help to classify an area on the basis of the polymers present and their risk to the environment. Accordingly, India is categorized in Hazard Level IV to V (Ranjani et al., 2021). PHI must be calculated at each area to determine its hazard status and measures must be implemented to reduce its risk.

The rivers of Cuddalore namely Gadilam and Uppanar are subjected to MPs pollution from various sources such as industries, fishing, municipal and domestic wastes. Only preliminary information about MPs in the Gadilam estuary has been reported by Begum et al. (2020). However, the present study reports various types of MPs profusion in Gadilam and Uppanar which contributes to the detailed scenario on MPs in these estuaries. The primary aim of the present study is the quantification and characterization of MPs which contribute to MP pollution in the estuarine sediment. PHI was also calculated to determine the risk of polymers and categorize the area in terms of Hazard level. For long-term monitoring and mitigation purposes, this study will pose great importance in terms of MPs studies.

Materials and Methods

Description of the study

Gadilam River (Latitude 11°46'19" N and 11 °44'11"N; Longitude 79°47'42" E and 79°47'12"E) is an inlet of the Bay of Bengal and forms an estuary in Cuddalore district of Tamil Nadu, southeast coast of India. Gadilam River runs via Villupuram and Cuddalore districts with a coverage area of about 181.35 Sq. Km. Gadilam estuary is about 2.5 m deep and elevated at 1 m with a tidal influence of up to 6 km. This estuary receives storm-water during rainy seasons while urban

waste discharges occur throughout the year. Southwest and northeast monsoons contribute to rain in these areas. The Cuddalore fishing harbor is situated on the banks of the Gadilam River. Agriculture and fishing activities are predominant in the river upstream (Ambedkar and Muniyan, 2012).

Uppanar River (Latitude 11° 41' 0" and 11° 43' 0" N; Longitude 79° 44' 01" and 79°49' 01" E) is also called as Paravanar River, which originates from Perumal Lake. Uppanar estuary has an average depth of 2.5 m and an elevation of 1 m while the tidal influence is up to 6 Km (Rajaram et al. 2005). This river joins the Gadilam River before opening into the Bay of Bengal. During the past few decades, numerous small and large-scale industries were established by SIPCOT (State Industries Promotion Corporation of Tamil Nadu) consisting of 44 industries including chemicals, pharmaceuticals, paints, and pesticides on the banks of Uppanar River. Southwest and northeast are the major monsoons in these areas during which the estuarine flow increases bringing in terrestrial wastes to the sea (Gopal et al. 2018).

Sekudewicz et al. (2020) selected three locations in the Vistula River, Poland which were in proximity to the industrial areas and wastewater treatment plants. Likewise in the present study 1 spot was chosen in the Gadilam estuary which was in proximity to the fishing harbour while 1 spot was chosen in the Uppanar estuary which was in proximity to the industrial areas while the estuarine mouth was chosen as the 3rd spot. Similar to Sekudewicz et al. (2020), one time sampling was carried out in the present study. The confluence of Uppanar and Gadilam rivers as well as tidal influence may contribute to higher MPs abundance at the estuarine mouth hence it was chosen as the third sampling site. A detailed map of the sampling locations is given in **Figure 1**.

Sample collection

Sediment samples were collected in June 2019 from the three stations E1, E2, and E3, shown in (**Fig1, Table 1**). The samples were collected using a Van Veen's grab (0.1m²) according to the method described by Ding et al. (2019). From the grab, sediments were transferred using a steel spoon to aluminium bags, labeled and stored at 4 °C until further analysis. Three replicate samples were obtained from each sampling site. All sampling equipment such as grab, steel spoon, and metal trays were washed using distilled water before collection at each site.

Separation and extraction of microplastics from sediment matrix

The samples were transferred to a glass container and 30% H₂O₂ was added, covered and left undisturbed for 5 days to digest the organic matter (Wang et al. 2017). After digestion, the samples were washed thoroughly to remove the chemical residues.

About 100 g of digested sediments were transferred to a glass container and 200 ml of saturated NaCl (density 1.2 g cm^{-3}) was added, stirred for 10 min and left undisturbed for 30 min allowing the contents to settle. The supernatant was sieved through a $125 \mu\text{m}$ metal sieve and the contents of the sieve were transferred into a glass beaker, covered with an aluminium foil and kept until further analysis. To the NaCl treated sediment fraction, a high-density sodium iodide solution (density 1.6 g cm^{-3}) was added and stirred vigorously for 10 min using a magnetic stirrer at 600 rpm and left undisturbed for 1 hour to allow settling. A Millipore vacuum pump with Whatman® GF/C filters (diameter of 47 mm and $45 \mu\text{m}$ pore size) was used to recuperate floating or suspended MPs particles. The filtration unit was rinsed repeatedly to ensure that all particles were recovered. Claessens et al. (2013) suggested the use of a small quantity (40 ml) of 3.3 M NaI solution (density: 1.6 g cm^{-3}) for the maximum recovery of MPs. This two-step extraction procedure was according to the method described by Di and Wang (2018).

The observed salinity in the present study was in the range of 30-31 PSU (**SI Table 1**) which indicates that the density of water in our study area could be in the range of $1-1.2 \text{ g cm}^{-3}$ (Vermaire et al. 2017). Hence, the polymers of higher density settle at the bottom. Therefore, the use of NaCl (density: 1.2 g cm^{-3}) alone may lead to incomplete recovery of MPs. Consequently, NaI (density: 1.6 g cm^{-3}) was also used in MPs extraction in our study.

Particles were identified as plastics based on the following properties viz., i) absence of cellular or organic structures ii) uniform thickness of fibers iii) uniform colouration iv) colourless and white materials should confirm the absence of organic materials (Noren, 2007). Further, dubious particles with semi-synthetic nature were discarded. A got needle test was also performed to confirm the nature of suspected particles (De Witte et al., 2014).

Quantification and Characterization of MPs

The MPs that adhered to the filter paper were observed under a stereozoom microscope (NIKON SMZ1500). A visual assessment at 40 x and 100 x magnifications was also performed to identify MPs according to the physical characteristics (fibers, fragments, films, and others) of the particles based on Free et al. (2014). The MPs were characterized based on a visual evaluation, the bigger particles were analysed using FTIR (IR TRACER 100, Shimadzu, Japan) coupled with attenuated total reflectance (ATR) diamond crystal (Maharana et al. 2020; Veerasingam et al. 2016), whereas, the small-sized particles were characterized by μFTIR (Model: Shimadzu, IR TracerTM-100). Data were analyzed using the software (AIM) attached with Advanced Imaging & Microscopic system (AIM-3800 Infrared Microscope). FTIR absorption spectra were recorded at 100 scans in the

mid-infrared region 4000-700 cm^{-1} at a resolution of 16 cm^{-1} . Polymer types were determined by comparing sample FTIR against known spectra from a database (Shimadzu ATR of polymers library). Three blank filters were checked for eliminating the possibility of MPs contamination by air.

Quality control and quality assurance

The workers wore lab coats (Fan et al. 2019; Bordós et al. 2019) or cotton clothes (Yan et al. 2019) during sample collection and analyses to prevent fiber contamination in the samples. All analyses in the laboratory were carried out in a closed environment such as Laminar Air Flow Chamber (Bordós et al. 2019). Blank filters are run along with the samples to test for airborne contamination and same number and type of microplastics were removed from the raw data (Filgueiras et al. 2021). All materials and equipment used in sample collection and analyses were washed thoroughly with filtered MilliQ water (Zhang et al., 2019a). The glass materials were cleaned with HCl (Liu et al., 2019) while metal equipment were cleaned with ethanol (Verlaan et al., 2019). Glass and metals are used to prevent cross-contamination of microplastics. The use of aluminium foil to carry the collected samples prevents air contamination (Bordós et al. 2019). All work solutions such as MilliQ water, NaI and 30% H_2O_2 were filtered to remove possible microplastic contamination (Fan et al. 2019). All these steps ensure that there is no over-estimation of microplastics. The quality control measures were reviewed in detail by Prata et al. (2021).

Polymer Hazard Index (PHI)

PHI was calculated based on the method described by Ranjani et al. (2021) based on polymer scores provided by Lithner et al. (2011).

PHI is calculated using the formula $\text{PHI} = \sum P_n \times S_n$

where, 'P_n' is the percentage of specific polymer types collected at each sampling location, and 'S_n' is the hazard scores of polymers of MPs obtained from Lithner et al., (2011).

3. Results

Abundance and morphological characteristics of MPs (shape, colour, size)

The sediments collected from all the study sites showed MPs contamination comprising of a variety of shapes, sizes and colours. The MPs abundance in the surface sediments, was highest at the mouth region E3 (51.6 ± 2.05 particles/Kg dw) (n=3), followed by E1 (41.3 ± 2.86 particles/Kg dw) (n=3) and E2 (36.3 ± 3.39 particles/Kg dw) (n=3) stations situated in Uppanar and Gadilam estuaries respectively (**Figure 2**). A broad range of coloured MPs was also observed in our study which

includes red, blue, black, yellow, white, green, grey, and brown (**Figure 3**). Wherein red (30.1-34.5%) was the most abundant colour followed by blue (18.7-28.3%) and black (8.6-22.3%) and others were observed in lower frequencies at all the three locations. The isolated MPs were sorted into different shapes (**Figure 4**), which include fibers, films, fragments, and others (pellets/beads). Fibers (41.7-47.9%) were found to be predominant followed by films (21.2-27.2%) and fragments (18.3-25.5%) at all the three locations. The different size range of MPs recovered from the present study was 100 to 1000 μm (**SI Figure 1**).

Polymeric composition

In this study, a total of 6 types of diverse polymers were identified by FTIR (**Figure 5a**) which include low-density polyethylene (LDPE), polypropylene (PP), styrene/maleic anhydride copolymer (SM), polyvinyl alcohol (PVA), polyvinyl fluoride (PVF) and polyacetal (PA). Wherein, LDPE (39%), PP (35%) and styrene/maleic anhydride copolymer (15%) were the dominant polymers (**Figure 5b**).

Polymer Hazard Index

LDPE (429) and PP (35) have high PHI scores due to their higher abundances in the study area and are categorized as level IV (100-1000) and III (10-100) polymers respectively. Accordingly, they fall under the danger and high risk categories respectively. SM has a hazard score of 1117 hence it is calculated to have a very high PHI (16755) and is categorized as level V (>1000) which indicates that it is an extremely dangerous material. The higher abundance of low toxic materials such as LDPE and PP also contributes to higher risk scores.

Discussion

Abundance and physical properties of MPs

Since Uppanar and Gadilam estuaries converge before opening into the sea, the mouth region receives microplastic concentrations from both the estuaries. Freshwater incursion, as well as the tidal influence, could also have contributed to MPs count at E3 (Bakir et al. 2014). Moreover, a study suggested that the strong tidal currents occurring in estuaries could considerably influence the residence time and transport of MPs (Zhang, 2017). Whereas microplastics abundance at E2 was influenced by domestic and fishery wastes from the fishing harbor located on the banks of Gadilam estuary. MPs abundance at E1 was influenced by domestic and industrial discharges from the SIPCOT industrial area as mentioned above located on the banks of Uppanar estuary. Monsoons play an important role in transporting MPs from land to the sea via estuaries (Hurley et al. 2018). The onset of the southwest monsoon in June along the southeast coast of India contributes to strong

winds. These winds enhance surface currents, which play an essential role in the transfer of MPs from terrestrial sources towards the estuarine mouth (Veerasingam et al. 2016; James et al. 2020). The present study expressed MPs abundance significantly lesser than former global studies (**Table 4**), which include Tampa Bay (McEachern et al. 2019); two estuaries in South Carolina (Gray et al. 2018); Changjiang Estuary (Peng et al. 2017); five estuaries of KwaZulu-Natal, South Africa (Naidoo et al. 2015). The higher abundance of MPs in other studies may be due to population density and anthropogenic activities of the respective areas.

In the present study, fibers were the most abundant shape of microplastics. A few authors expressed views that the breakdown of synthetic materials may contribute to fibers (Hartline et al. 2016; Mason et al. 2016) while Anderson et al. (2017) added that the transport of these synthetic materials by municipal wastes and discharges from sewage treatment plants further enhance the abundance of fibers. Peng et al. (2017) opined that fibers may derive from textiles and fishing nets which may break into microfibers due to wear and tear, weathering, and abrasion (Zhang et al. 2019b; Maes et al. 2017) which are in agreement with our study. Many former studies have discussed the abundance of fibers in diverse environments such as mangroves (Nor and Obbard, 2014); beaches (Laglbauer et al. 2014), and offshore areas (Zhao et al. 2018). Fragmentation of macro-sized plastic products via mechanical and/or photo-degradation into smaller plastics (Shim et al. 2018) may be one of the reasons for the abundance of fragments in our study. Films are present as a result of the degradation of plastic bags and packaging materials (Robin et al. 2020; Shim et al. 2018). The previous reports have stated that fibers, fragments, and films as secondary MPs (Pan et al. 2019; Patchaiyappan et al. 2020). Fibers mostly originate from synthetic textiles while fragments are formed from the fragmentation of larger plastics (Naji et al. 2019) whereas films originate from plastic covers/package materials (Tan et al. 2019; Wang et al. 2016) hence are categorized as secondary MPs. Some of the previous studies (Laglbauer et al. 2014; Wessel et al. 2016; Sruthy and Ramasamy, 2017) also reported an abundance of secondary MPs which is comparable to our study. In the present study an abundance of fibers was observed which were comparable to former studies including Pearl estuary (Yan et al. 2019); Three Gorges Reservoir (Di and Wang, 2018); Changjiang Estuary (Peng et al. 2017). A higher abundance of fibers in the former studies was due to washing of laundry and textile clothes, ropes, and fishing nets which may hold true in our study. The numerical abundance of MPs in the present study is much lesser than former studies on Indian rivers (Sarkar et al. 2019; Amrutha and Warriar, 2020) which could probably be due to higher population density, pilgrimage, tourists, and associated activities which are not present in our study areas.

Colours such as red, blue, black, yellow, white, green, grey, and brown were noticed in the present study which was similar to the colour of MPs obtained from an earlier study at Pondicherry (Dowarah and Devipriya, 2019) which is in close vicinity to our study area. The diversity of colours was possibly due to different sources of MPs (Sathish et al. 2019) which may indicate their actual sources (Nelms et al. 2019). The chief sources of coloured MPs include packaging materials, covers, clothing, fishing nets, and ropes (Kumar et al. 2018) colourful fishing nets like blue or green may also contribute to coloured MPs in the aquatic body. While colourless MPs may exist as resultant of wear and tear of fishing lines and nets (Di and Wang, 2018). Additionally, fading colours such as red and blue may also contribute to colourless MPs (Di and Wang, 2018). Since these colours gradually fade over time, it can be stated that the MPs observed in our study were relatively fresh inputs to the environment.

Coloured MPs resemble prey, which lures the aquatic organisms to ingest these particles (Wright et al. 2013). Predominantly marine organisms are recognized visual predators which accidentally consume coloured MPs (Nelms et al. 2019). Numerous studies have confirmed the presence of coloured MPs in the gut of various organisms such as Greek mussels (Li et al. 2019); *Mugil cephalus* (Cheung et al. 2018) and mollusks (Abidli et al. 2019).

The size range of 100 to 1000 μm was the most common size range observed in some former studies, which also corresponds to the present investigation. Desforges et al. (2014) reported MPs in two size categories (100 to 500 μm and 500 to 1000 μm) whereas Naji et al. (2019) recovered MPs in two size categories (10 to 300 μm and 300 to 1000 μm). The present study is in line with a former study (Naidoo et al. 2015) as they also have reported MPs in the size range of 500 to 1000 μm from estuaries of South Africa. The small size of MPs is the key criteria for consumption by minor biotic forms (Wright et al. 2013) as it results in bioaccumulation of MPs to higher forms of organisms as explained by Farrell and Nelson, (2013). Also, smaller-sized MPs have higher adhesion capacity for the adsorption of harmful pollutants and contaminants like POPs, (PAHs, Alkanes, PCBs, DDTs), heavy metals, etc. probably due to their increased surface area (Velzeboer et al. 2014). Moreover, a larger surface area due to a smaller size may favor the adhesion of microorganisms and subsequently the formation of biofilms. Biofilms adhesion increases polymer density, which causes bio-fouling resulting in the sink of MPs (Harrison et al. 2018).

Source and polymer identification

The type of polymer determines whether the plastic floats or sinks while MPs with a density higher than seawater are deposited in the sediments (Alomar et al. 2016). The lesser dense particles

float on the surface (Suaria and Aliani, 2014). The MPs of lower densities travel longer distances horizontally and thereby settle on the shores while higher density MPs undergo vertical distribution. The rate of MPs degradation and colonization by organisms cause fluctuation in their relative densities which influence vertical or horizontal distribution in the water column (Frère et al. 2018; Zhang, 2017). All polymers found in the present study have a density ranging from 0.861 to 1.410 gcm^{-3} (**SI Table 2**). Some of the common applications of the observed polymers are provided in **SI Table 2**. In a lacustrine environment of Vembanad, Kerala southwest coast of India, Sruthy and Ramasamy (2017) reported the presence of low-density polymers such as LDPE and PP in the sediments. This sinking of low-density polymers could be due to the deposition of biofilms on the surface of MPs (Ivar do Sul and Costa, 2013). The same reason could be applied in our study since several low-density polymers were observed in these estuarine sediments.

Risk Assessments

India has an overall PHI score of above 1000 hence is categorized as level IV to V. In India, states like Tamil Nadu, Kerala and Maharashtra also have PHI scores of above 1000 (Ranjani et al., 2021). The present study shows Cuddalore district of Tamil Nadu to have PHI scores of above 1000 hence this area is also categorized as IV to V. These high risk polymers are known to be consumed by biota such as fish which may be transferred to humans (Pan et al., 2021). Hence, these polymers may equally harm the environment including humans.

Conclusions

The current work aims to exhibit the abundance of microplastics in the estuaries of the Cuddalore coast of southeast India. The work attempts to highlight that estuaries are a major pathway for the transport of microplastics into the oceans as they bring domestic, municipal and industrial discharges into the coastal environment. It was found that the majority of the microplastics retrieved were fibers and fragments which are generally secondary in nature indicating that the source of these microplastics could be away from the point of sampling. It may be noted that Cuddalore coast is a majorly fishing area however the primary source of microplastics at both the study areas could be municipal discharge into the estuaries. Considering the amount of MP debris in these discharges, it is essential to monitor its prevalence. A comprehensive approach to identify the source of these MPs is essential in order to formulate control measures and also extended studies are needed to identify the impacts of MPs on aquatic and human lives.

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Figures

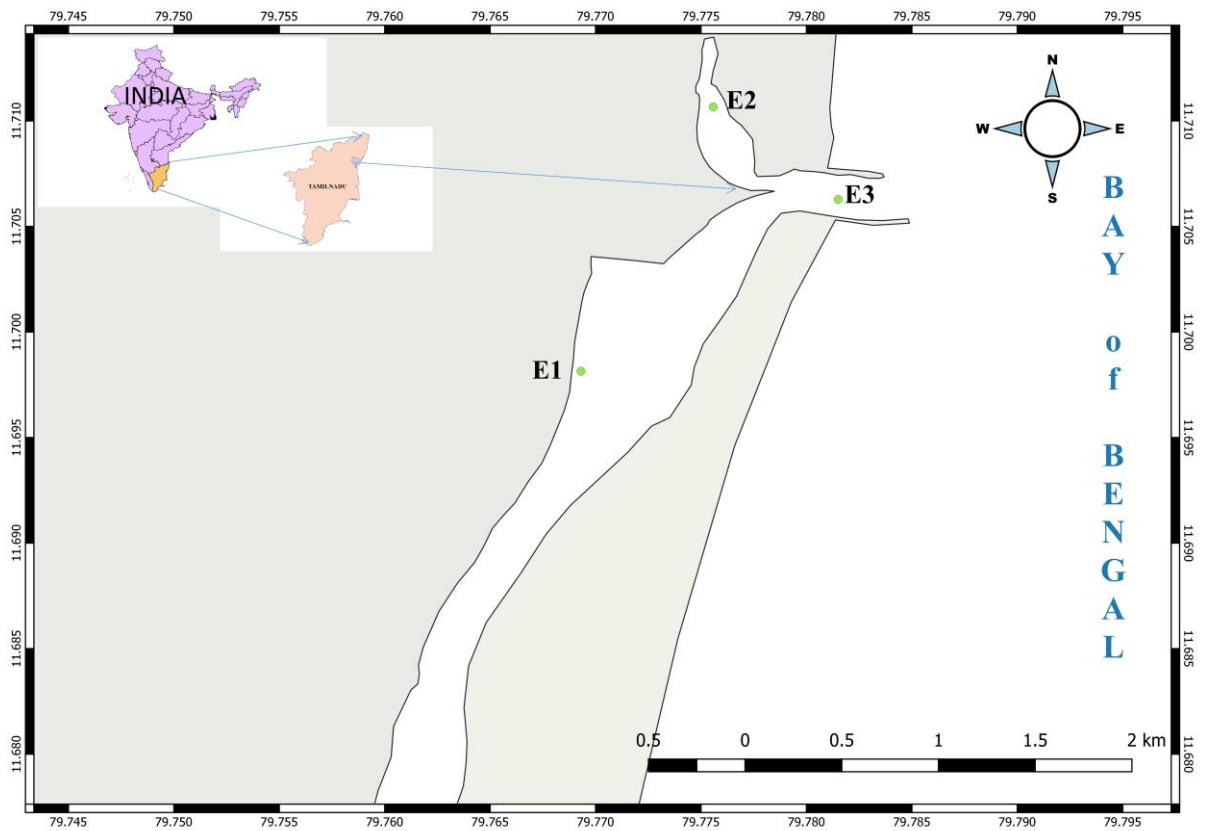


Figure1. The study sites at E1 (Uppanar Estuary), E2 (Gadilam Estuary) and E3 (Estuarine Mouth)

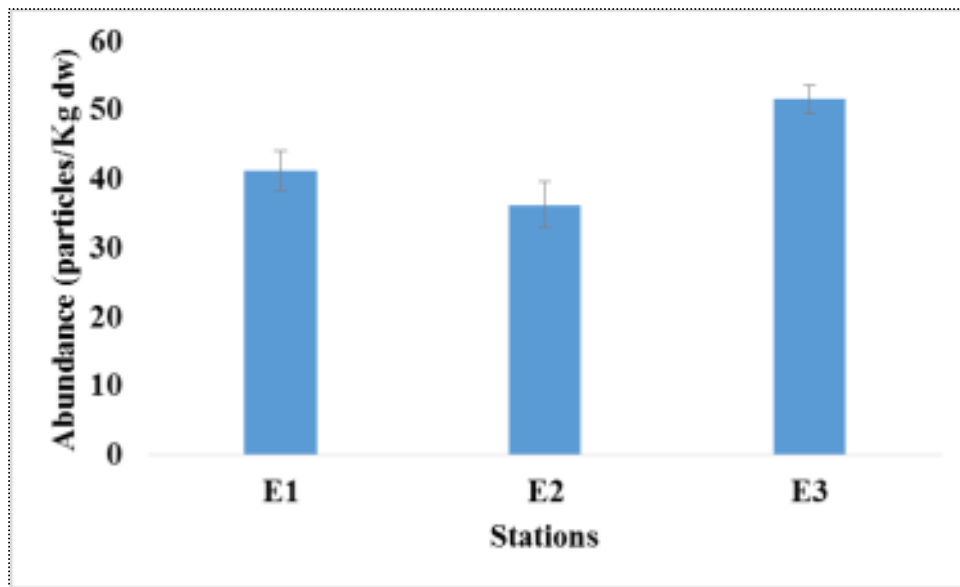


Figure 2. Microplastics abundance (with standard deviation) in the surface sediments of the study sites E1 (Uppanar Estuary), E2 (Gadilam Estuary), E3 (Estuarine Mouth).

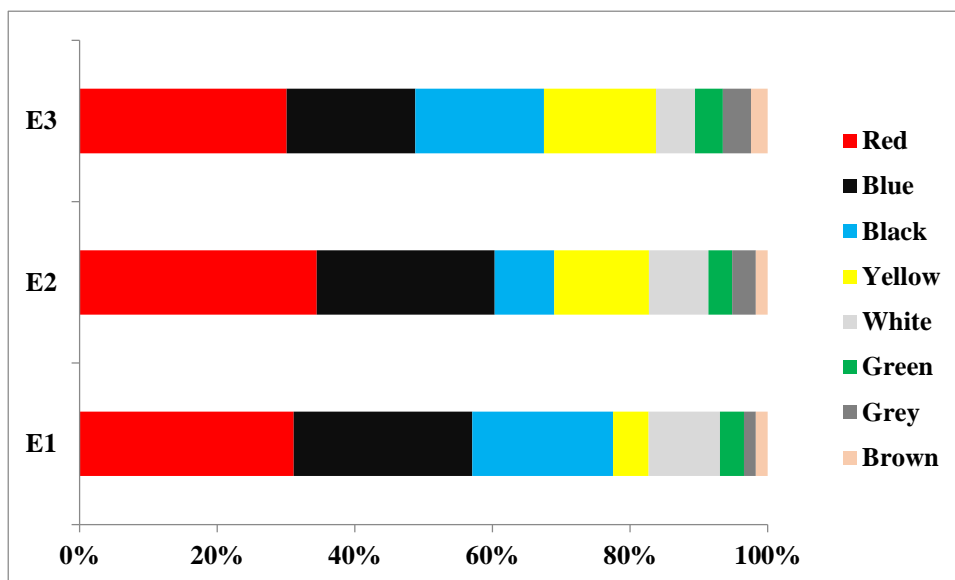


Figure 3. Percentage of different colors of microplastics found in sediments of the study sites E1 (Uppanar Estuary), E2 (Gadilam Estuary), E3 (Estuarine Mouth).

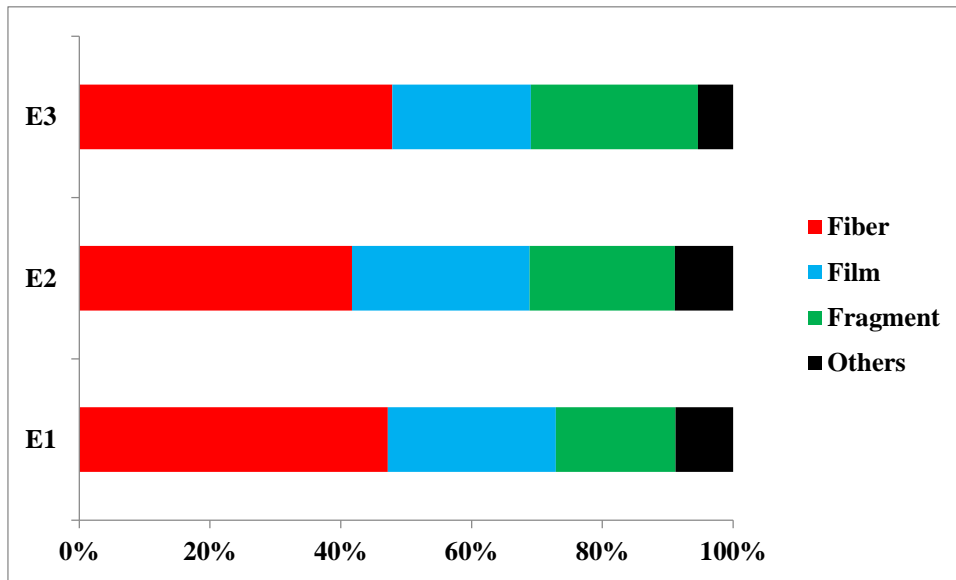


Figure 4. Percentage of different shapes of microplastics in sediments of the study sites E1 (Uppanar Estuary), E2 (Gadilam Estuary), E3 (Estuarine Mouth)

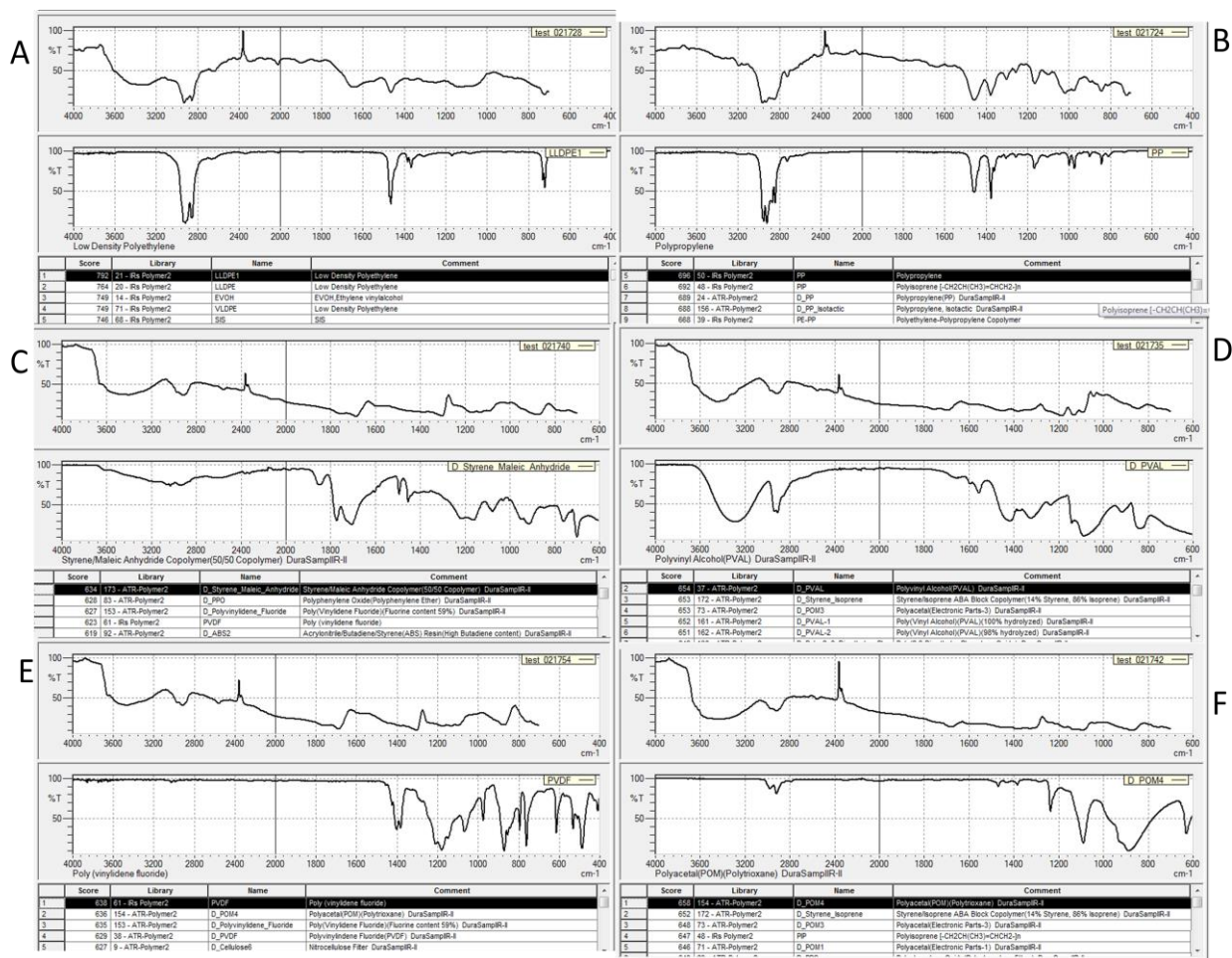


Figure 5a. Predominant Microplastics polymers identified by μ FTIR. A- Low Density Polyethylene; B- Polypropylene; C- Styrene Maleic Anhydride; D- Polyvinyl Alcohol; E- Polyvinyl Fluoride; F- Polyacetal

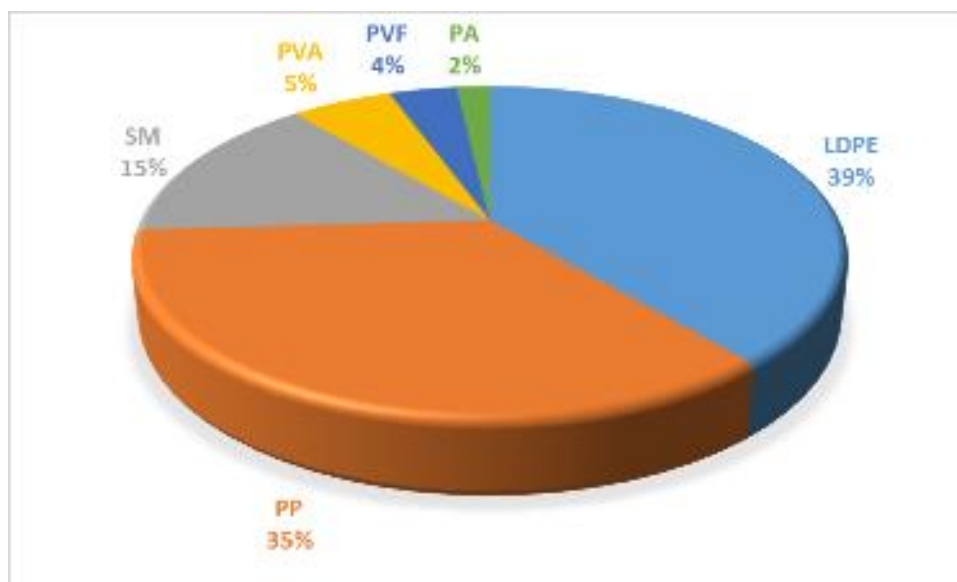


Figure 5b. Percentage composition of microplastic polymers. Abbreviations of the polymers are as follows LDPE-Low Density Polyethylene; PP-Polypropylene; SM-Styrene/Maleic Anhydride Copolymer; PVA-Polyvinyl alcohol; PVF-Polyvinyl Fluoride; PA-Polyacetyl.

TABLES

Table 1. Abundance of microplastics at sampling locations in Uppanar estuary (E1); Gadilum estuary (E2) and estuarine mouth (E3). The abundance values are expressed as particles per kilogram of dry weight (particles/Kg dw)

Stations	Description	Latitude	Longitude	Abundance (particles/Kg dw)
E1	Uppanar Estuary	11°41'53.33"N	79°46'9.50"E	41.3±2.86
E2	Gadilam Estuary	11°42'38.40"N	79°46'30.93"E	36.3±3.39
E3	Estuarine Mouth	11°42'22.61"N	79°46'53.44"E	51.6±2.05

Table 2. Risk assessment scores at Cuddalore region

	PHI	Hazard category	PLI	Hazard category	PRI	Hazard category	Classification
Hazard scores and category	<10	I	<10	I	<150	I	Low
	10-100	II	10-20	-	150-600	II	Medium
	100-1000	III	20-30	II	600-1200	III	High
	>1000	IV	>30	III	>1200	IV	Danger
Station							Overall Classification of the region
Cuddalore	128-172	III	1-1.19	I	130-435	II	Low to High

PHI- polymer hazard index; PLI- pollution load index; PRI- potential ecological risk index

Supplementary Information

SITable 1 Atmospheric temperature, Surface Water temperature and Salinity at the time of collection in the study sites E1 (Uppanar Estuary), E2 (Gadilam Estuary), E3 (Estuarine Mouth)

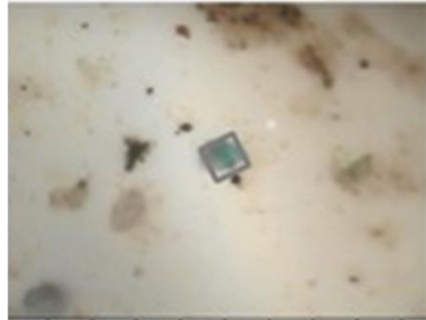
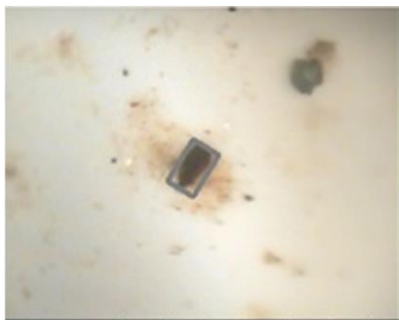
Stations	Atmosphere Temperature (°C)	Surface Water Temperature (°C)	Salinity (PSU)
E1	30.3	29.8	31.4
E2	29.5	30.1	30.8
E3	30.1	30.5	31.7

SITable 2 Polymer composition, density and applications of microplastics recovered from sampling sites the study sites E1 (Uppanar Estuary), E2 (Gadilam Estuary), E3 (Estuarine Mouth)

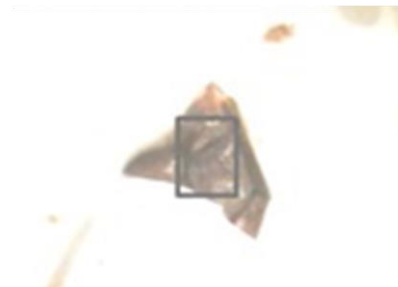
Polymer	Density (g cm ⁻³)	Applications	References
Polypropylene (PP)	0.861	Containers, buckets, covers, plastic bags etc	Ebnesajjad, 2012; Solomon and Palanisamy, 2014; Bayer et al., 2017; Polymer Properties Database
Low Density Polyethylene (LDPE)	0.919-0.924	Containers, buckets, covers, plastic bags etc	
Polyacetyl (PA)	1.09	Automotive and machinery parts	
Polyvinyl alcohol (PVA)	1.300	ropes, agricultural and fishing nets	
Styrene/Maleic Anhydride Copolymer	1.080	Drinking cups, packaging materials etc	
Polyvinyl fluoride (PVF)	1.340	UV resistant coating in architectural and aircraft industry	



Fibers (Scale: 100 μm)



Fragments (Scale: 100 μm)



Films (Scale: 100 μm)

SI Figure 1 Microplastics observed under a stereozoom microscope fitted with AIM software attached with Advanced Imaging & Microscopic system (AIM-3800 Infrared Microscope)