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Microplastic prevalence in the beaches of Puducherry, India and its correlation with fishing and tourism/recreational activities

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ABSTRACT

The prevalence of microplastics in the sediments of six beaches of the Puducherry coast in India was studied and its correlation to fishing activities and recreational activities was analysed. On an average, 72.03 ± 19.16 microplastic particles/100 g dry weight of sediments is found to be the microplastic abundance in the study. A Strong positive correlation (Pearson's R = 0.92, p = 0.0103) between fishing activity and microplastic abundance and a weak correlation (Pearson's R = 0.04, p = 0.932) between microplastic abundance and recreational activities is found. Majority (65.12%) of the microplastics belongs to the size bracket of 300 μm-1 mm and only 34.88% were large microplastics (> 1 mm). The Polymers of the microplastics were identified as Polypropylene, HDPE, LDPE, Polystyrene, Polyurethane etc. using Raman spectroscopy. Microplastic fragments comprise 56.32% of the total particles. In terms of colour of the microplastics, white (26.92%) is the most abundant.

1. Introduction

Microplastic is now a widely accounted environmental hazard. Microplastics are widely accepted to be plastic particles of size smaller than 5 mm and as of now, no specific minimum limit has been set in the definition of microplastics. Microplastics form due to the fragmentation of larger plastics and since UV radiation and abrasion of waves are high on the coasts, the process of degradation is more common on the beaches (UNEP, 2018). Some microplastics are also produced primarily for various uses in the industries. Microplastics have been found ubiquitously across the globe in marine (Laglbauer et al., 2014; Blumenröder et al., 2017; Zhao et al., 2018; Naji et al., 2017; Abidli et al., 2017; Tsang et al., 2017; Cauwenberghe et al., 2015; Claessens et al., 2011) and freshwater environments (Peng et al., 2018; Horton et al., 2017; Di and Wang, 2018; Rodrigues et al., 2018; Su et al., 2016), air (Prata, 2018), remote lakes (C. Zhang et al., 2016; K. Zhang et al., 2016), poles (Munari et al., 2017; Kanhai et al., 2018), deep sea sediments (Martin et al., 2017) and ground water (Mintenig et al., 2019). It has also been detected in almost all forms of organisms such as fishes (Ory et al., 2017; Nadal et al., 2016; Compa et al., 2018; Bellas et al., 2016), mussels (Qu et al., 2018; Zhao et al., 2018), crabs (Watts et al., 2016), oysters (Green, 2016), birds (Putnam et al., 2017), crustaceans (Jemec et al., 2016), algae (C. Zhang et al., 2016; K. Zhang et al., 2016 and even, seals (Nelms et al., 2018), whales (Besseling et al., 2015), and Dolphins (Nelms et al., 2019). Plastics became popular only a few decades ago because of its versatility and convenient usability; but plastic production has increased from 15 million tonnes in 1964 to 311 million tonnes in 2014 and this is likely to double in the next 20 years. If the present trend of plastic production and use continues, we shall have more plastic in the oceans than fishes by 2050 (World Economic Forum, 2016). The tiny forms of plastic that is popularly termed as microplastic is even more ubiquitous as it is highly mobile because of its tiny size and it has all the potential to easily enter any ecosystem and food chains.

Fishing activities is a major contributor to microplastic pollution. Modern fishing activities involve a lot of plastic because of their advantages over traditionally used natural materials. Loss by accident, deliberate abandonment, or normal wear and tear of fishing gears (ropes, lines, floats, nets etc.), ancillary items (fish boxes, gloves, strapping bands etc.) and galley waste in the marine environment leaves behind a large amount of plastic fibres and fragments (Lusher et al., 2017). Coastal tourism and recreational activities involve single use plastics largely and this contributes to the problem of microplastics in the coasts (UNEP, 2016).

2. Methodology

2.1. Study site

Pondicherry coast is a fishing hub and the fishing folks of the region depend on it for a living. Puducherry is a small district in the

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Fig. 1. A map of the six beaches from which sediment samples were collected in this study (Courtesy: Google Maps).

Pondicherry Union territory of India. It has a coastline of 23.94 km. This coast consists of 13 fishing villages and it is fishing that brings livelihood to the fishing communities that are clustered around this coastal stretch (MoEF, 2016). Other than fishing activities, the Puducherry beaches are quite aesthetically appreciable and this attracts tourist from around the world. In addition to that, the beaches are also a hotspot for recreational activities and leisure for both local folks and tourists especially on weekends.

For our study, we selected six beaches in the coast of Puducherry viz. Pondicherry University, Boomaiyarpalayam, Auroville, Serenity, Veerampattinam, and Paradise.

2.2. Sampling

Sampling was done at the high tideline of six beaches (Fig. 1). The recently deposited shells and debris identified the high tideline. Six samples each from Pondicherry University, Serenity, Veerampattinam, and Paradise Beaches; and 5 Samples each from Auroville and Boomaiyarpalayam Beaches were collected, depending upon the length of the beaches. A gap of approximately 150 m was maintained between two sampling points to cover the entire length of the beach. A 25cmx25cm quadrat was placed at the sampling point and the upper 1 cm was scooped out using a stainless steel spoon. Samples were wrapped in Papers so as to avoid additional plastic contamination and carried to the laboratory. Sampling was done in the month of January, 2019 (Fig. 2).

2.3. Sample analyses

The bulk sample was dried in the oven at 70 °C for 24 h (Peng et al., 2017). A 100 g subsample was then separated from the bulk and first sieved with 5 mm sieve and then 300 μm sieve. The particles retained on the 300 μm sieve was transferred to a beaker and covered with aluminum foil (Masura et al., 2015).

A supersaturated NaCl solution was prepared by dissolving 360 g of NaCl (Himedia, Mol. Wt. 58.44) in 1 L distilled water. 300 ml of the saturated salt solution (density 1.2 g/cm^3) was added to each beaker containing 100 g of the sample. The sample was then stirred with a glass rod for 2 min so as to loosen all the microplastic particles that might be trapped among sand particles. The solution was allowed to stand for 24 h.

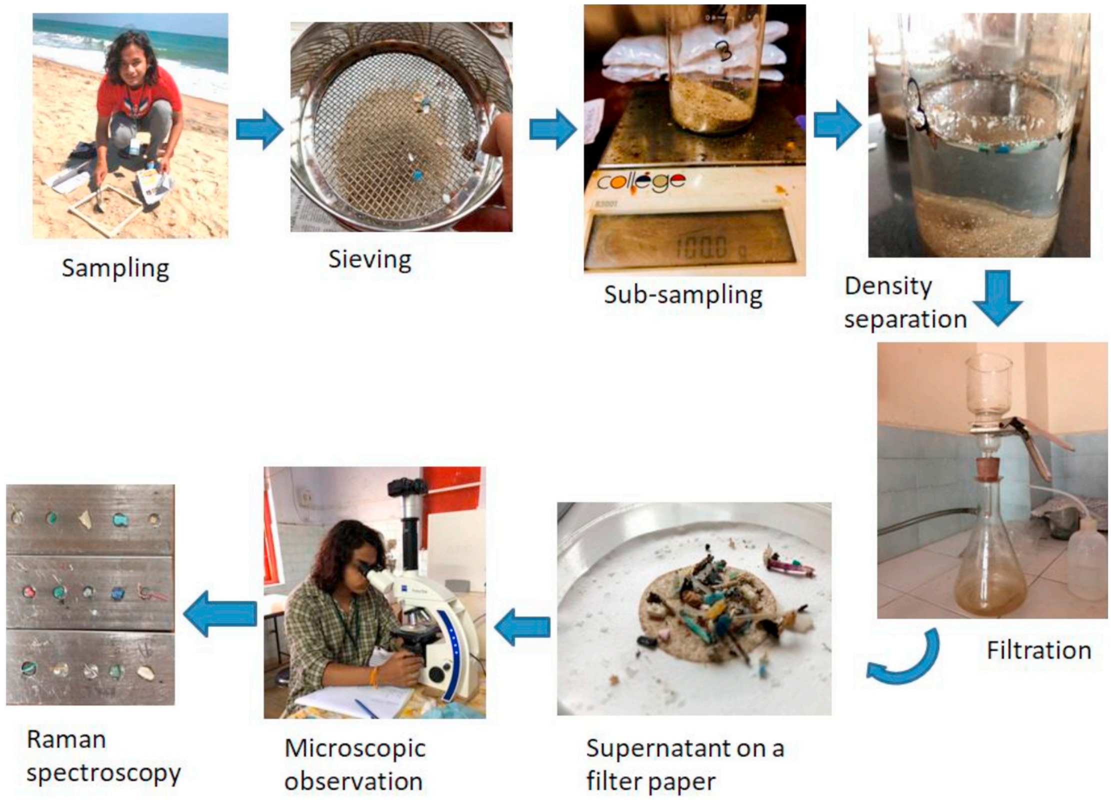

Fig. 2. Graphical representation of the different steps involved in microplastic identification.

The supernatant of the density separation was carefully transferred to a beaker and was filtered using a filtering apparatus aided by a vacuum pump. Whatman Grade 1 filter papers were used to collect the particles in the supernatant. The filter paper was carefully transferred to a petridish and stored for microscopic observation. Prior to microscopic observation, undesirable debris such as sticks, shells, etc. were removed from the filter paper (Munari et al., 2017).

A 40× magnification Zeiss Primo Star microscope was used to observe the filter papers and the microplastics were counted and documented according to the different shapes and colours. The particles were sorted for different shapes as fragments, fibres/lines, foam, pellet and films/sheet (Gies et al., 2018) and for colours as White, Transparent, Brown, Red, Blue, Green, Black, Orange/Yellow, and Pink/Violet. The particles were also categorized into four size groups of the ranges: 300–500 μm, 500–800 μm, 800–1000 μm, 1000–3000 μm, and 3000–5000 μm. The visual identification of microplastics was done following the criteria: a) no branching b) no cellular occurrence c) particles didn't have a metallic shine d) The fibres have a uniform thickness along its length.

A Kruskal Wallis H test was conducted among the findings of the six beaches to see if the microplastic abundance varied significantly among the beaches (Zhao et al., 2015). A Post hoc Tukey test was conducted furthermore to find the beaches between which the abundance varied significantly (Yu et al., 2016).

The saturated NaCl solution was used as blank. Four 300 mL units of the freshly prepared NaCl solution was maintained as blank during the entire process and they were subjected to the filtration and observation processes as conducted for the sediment samples. No particles were observed in the blank samples. To avoid airborne contamination, the laboratory was kept closed at all times during the experimentation period so that there was less air venting in from the outside. The glasswares containing the samples were kept covered at all times with aluminum foils. The surfaces of the workplace were cleaned on a daily basis. The samples were kept locked in shelves when not under processing. We made sure we wore no synthetic garments during the experimentation.

2.4. Raman spectroscopy for polymer identification

A representative sample of 52 particles was selected for Raman spectroscopy for polymer identification. Renishaw InVia Raman spectroscope was used for the procedure and the spectra was scanned for a range of 200–3500 cm^{-1} with 30s acquisition time. The raw spectra were processed using Bio-Rad KnowItAll software for baseline and noise correction and the corrected spectra was matched with the software database for identification of polymers. Since plastics in the environment are subjected to different types of degradation, only a few particles had exact spectral match of the pure polymers.

2.5. Surveillance for fishing and recreational activities

Sources contributing to microplastic pollution can be numerous. However, if broadly viewed, especially in the case of Puducherry beaches, fishing and recreational activities are dominant when it comes to plastic littering. Hence, we selected fishing and recreational activities as the two parameters for correlating the microplastic prevalence with.

Boats parked on the beach or anchored at proximity to the shore were counted and this number was used as an index for the extent of fishing activity that takes place on the beach. Simultaneously, a headcount was conducted by a walkthrough from one end of the beach to the other. This number was used as an index for recreational activities (tourism, leisure, sports etc.) taking place on the beach. The beach surveillance for each beach was done on a Saturday or a Sunday between 5 pm to 6 pm as that has been observed to be the peak hour of human presence at the beaches. This was done simultaneous to the sampling of beach sediments.

The boasts parked on the beaches were exclusively used for fishing and no other purposes and the people accessing a beach for fishing

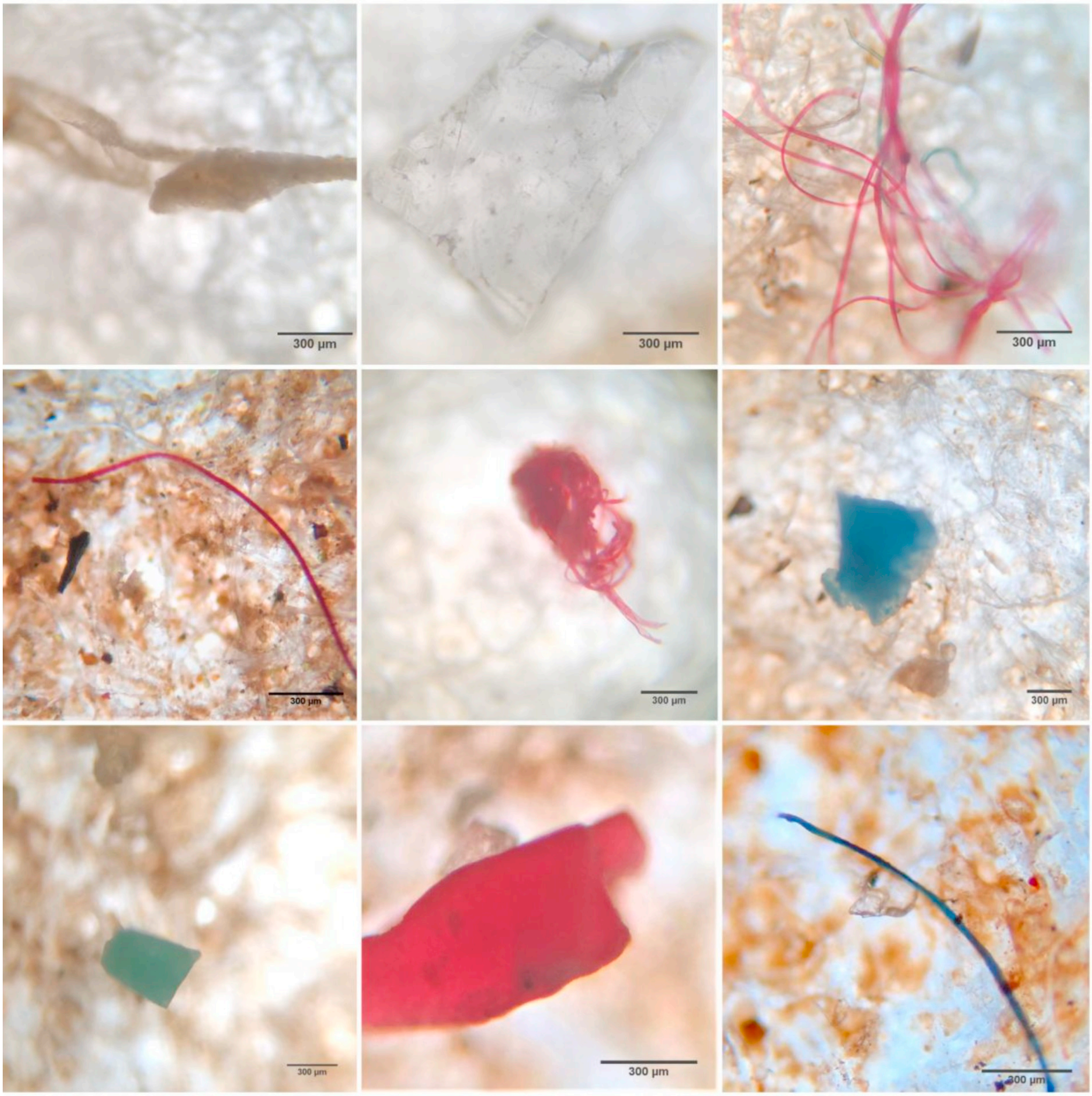

Fig. 3. Microplastics of different shapes and colours observed under the microscope. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Microplastic abundance in each of the samples (S1, S2, S3, S4, S5, S6) of the Six beaches in the Puducherry coast.

	Microplastics/100 g beach sediment							
Beach	S1	S2	S3	S4	S5	S6	Average of each beach (± SE)	Total average (± SE)
Auroville	20	24	15	31	27	–	23.40 ± 3.38	72.03 ± 19.16
Bommayarpalayam	32	12	20	32	23	–	23.80 ± 3.80	
Serenity	152	135	176	98	147	106	135.67 ± 12.00	
Veerampattinam	110	69	154	85	157	64	106.50 ± 16.83	
Paradise	30	34	29	75	47	74	48.17 ± 8.73	
Pondicherry University	114	81	69	75	94	135	94.67 ± 10.38	

purposes were folks from the neighbouring locality which is likely to remain constant. However, the human recreational index, estimated at the most peak hour of the week, is an approximation of the highest degree of human presence in the beaches for activities other than fishing. Fishing takes place in the wee hours of the morning or overnight, and the fisherfolks return around the time of sunrise with their catches.

Correlation (Pearson's R) was calculated to measure the relationship between the boats counted on the beaches and the average microplastic abundance of the related beach. Similar calculation was done for the Human presence and Microplastic abundance. p-Value was calculated for the R-value to measure the significance.

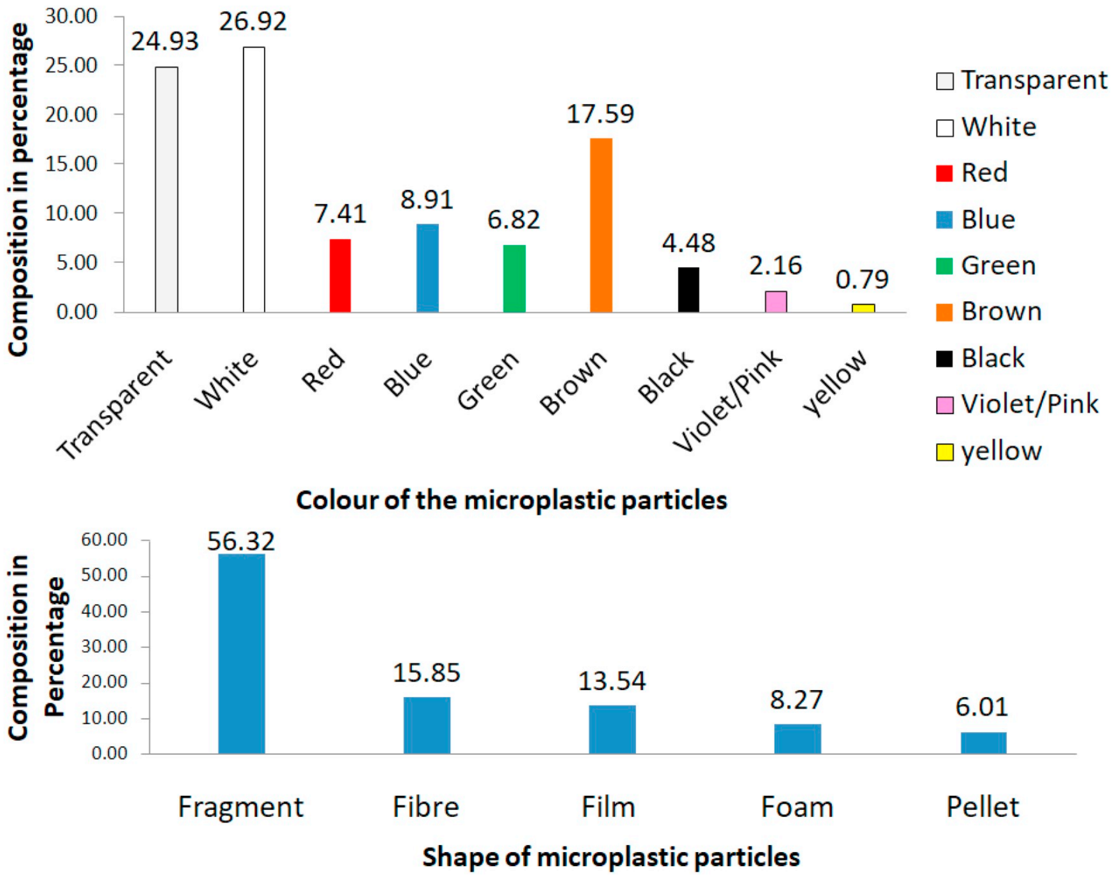

Fig. 4. Microplastic abundance (in percentage) in terms of different colours and shapes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

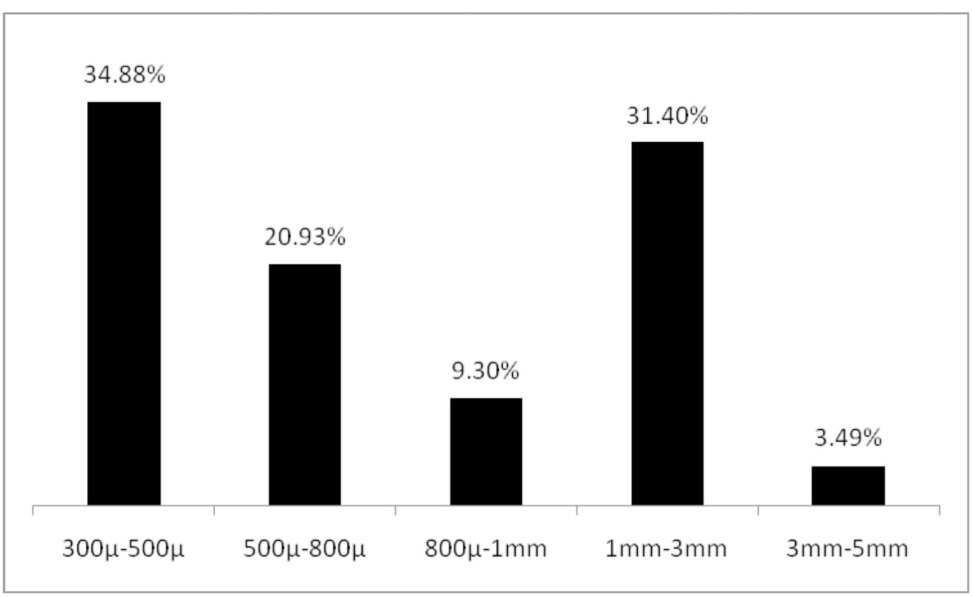

Fig. 5. Proportions of the microplastics belonging to different size classes.

3. Results

3.1. Microplastic abundance

The average microplastic abundance for the 6 beaches on the Puducherry coast is found to be 72.03 ± 19.16 particles/100 g of beach sediment (average of all six beaches) (Fig. 3). The findings for each sample for each of the beaches are shown in Table 1. The minimum count for a sample is 12 particles and that for a beach is 23.40 ± 3.38 particles (beach average); and the highest count for a sample is 176 particles and that for a beach is 135.67 ± 12.00 particles (beach average). All the values above are the reported as particles per 100 g of dry weight of beach sediments.

Kruskal Wallis H value is 25.91, the p-value for which is 0.000093

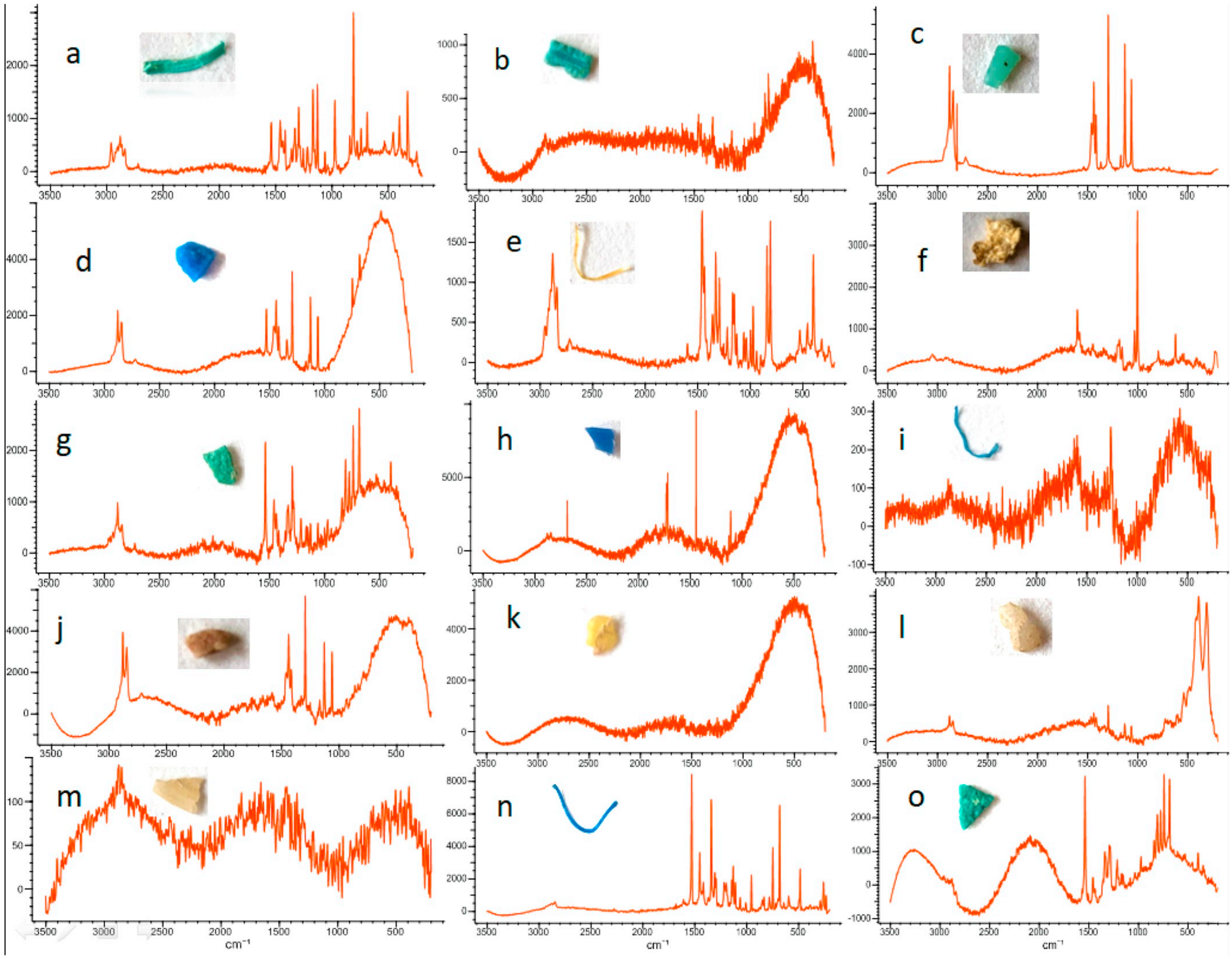

Fig. 6. Raman spectra of different microplastic particles. The polymers identified from these spectra are: a) Polypropylene, b) Polyester urethane, c) High Density Polyethylene (HDPE), d) Low Density Polyethylene (LDPE), e) Polypropylene acrylic acid, f) Polystyrene, g) Cellulose acetate, h) Poly (N-vinyl carbazole) (PVK), i) Polymer Resin, j) Polyvinyl behenate, k) Polyvinyl chloride (PVC), l) Ethylene Acrylic acid copolymer (EAA), m) Acrylonitrile/Styrene copolymer; and two polymer dyes: n) Irgalite Blue, and o) Hostasol Green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

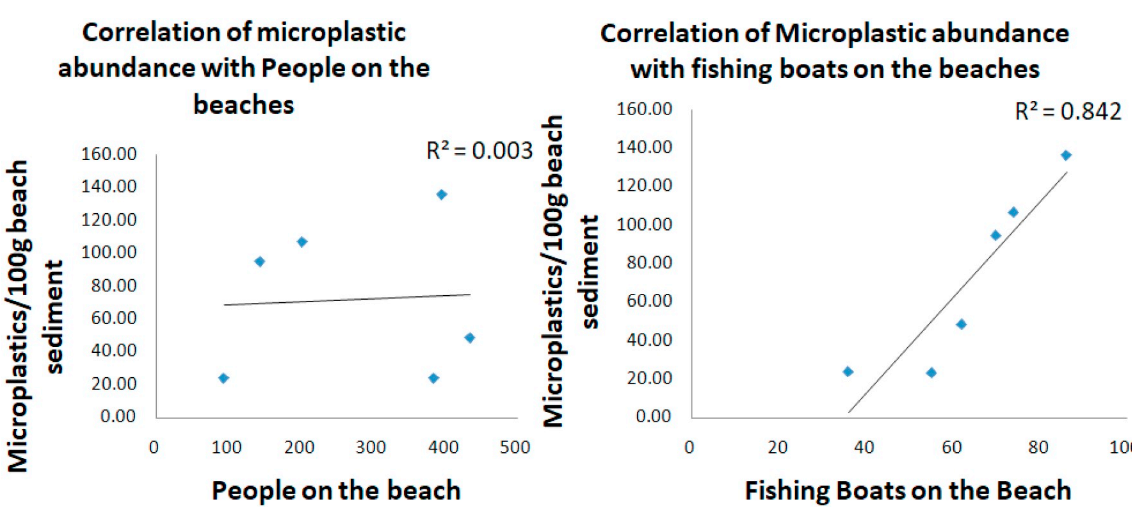

Fig. 7. Correlation of microplastic abundance on the beaches with the Fishing boats and People present in them. The Y-axes represents the microplastics/100 g of beach sediments, X-axes represent Fishing Boats, and People present in the beaches.

Table 2
Number of fishing boats on the beaches and the number of people present during the peak hour of the weekend.

Beach	Microplastic/ 100 g	Boats sighted (Fishing activity index)	People present (Recreational activity index)
Auroville	23.4	55	384
Boomaiyarpalayam	23.8	36	93
Serenity	135.67	86	396
Veerampattinam	106.5	74	202
Paradise	48.17	62	434
University	94.67	70	143

($\alpha = 0.05$) which suggests that the findings vary distinctly among the beaches. Post hoc Tukey Test showed that the microplastic levels varied significantly at $p < 0.01$ between the following beach combinations: Auroville vs. Veerampattinam ($p = 0.0010$), Auroville vs. Serenity ($p = 0.0010$), Auroville vs. University ($p = 0.0012$), Paradise vs. Serenity ($p = 0.0010$), Paradise vs. Veerampattinam ($p = 0.0065$), Boomaiyarpalayam vs. Veerampattinam ($p = 0.0010$), Boomaiyarpalayam vs. Serenity ($p = 0.0010$) and Boomaiyarpalayam vs. University ($p = 0.0013$).

3.2. Classification of microplastics

In terms of shapes, microplastic abundance is in the order of fragment (56.32%), fibres (15.85%), film/sheet (13.54%), foam (8.27%), and pellet (6.01%). The abundance of microplastic particles in terms of colours is in the order of white (26.92%), transparent (24.93%), brown (17.59%), blue (8.91%), red (7.41%), green (6.82%), black (4.48%), pink (2.16%), and yellow (0.79%) (Fig. 4).

The proportion of the microplastic particles in the size ranges of 300-500µm, 500-800µm, 800-1000µm, 1000-3000µm, and 3000-5000µm are 34.88%, 20.93%, 9.30%, 31.40%, and 3.49% respectively (Fig. 5). Large microplastics i.e. microplastics larger than 1 mm in size constitute 34.88% of the particles identified in this study.

3.3. Raman spectroscopy

Of the 52 representative particles, 47 particles could be confirmed as polymers from their respective polymers. These spectra varied from the spectra of the pure polymers to certain degrees and the software database was used to find the best spectral match from the components, peaks, or functional groups of the spectra. 13 polymers could be identified from the spectra viz. Polypropylene (PP), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polystyrene (PS), Styrene acrylonitrile copolymer, Cellulose acetate, Polymer Resin, Polyvinyl behenate, Ethylene Acrylic acid copolymer (EAA), Poly (ester urethane), Polypropylene acrylic acid(6%), Poly (N-vinyl carbazole) (PVK), and Poly vinyl chloride (PVC). Of the identified spectra, two were of dyes used for polymer coloration. They are Irgalite Blue and Hostasol Green and the dye colours were consistent with the colour of the microplastic particles (Fig. 6).

3.4. Correlation with fishing and recreational activities

The correlation of Fishing activities with the microplastic abundance was found to be strong with Pearson's R-value of 0.9176 and it was significant at $\alpha = 0.05$ ($p = 0.0099$). The correlation of the recreational activities with the microplastic abundance for the beaches had a poor but positive correlation with Pearson's R-value of 0.0548 and this was not significant at $\alpha = 0.05$ ($p = 0.9179$) (Fig. 7).

4. Discussion

The findings in this study are moderate compared to the findings in some of the studies done similarly for beach sediments (Table 3). Fishing activity is a major source of microplastic in these beaches as these beaches are majorly used as fishing bases by the local fishing villages situated around them. Also, the beaches lack any form of garbage disposal and cleaning system as they do not come under any municipal jurisdiction and the village governance have not taken any serious step for its mitigation. The fragmentation of plastics in the beaches is high because of two reasons: a) UV radiation is likely to be high as the beaches are tropical, and b) The east coast of India is a very active coast and the wave action is very high.

Post hoc Tukey test suggests that the levels of microplastic abundance vary significantly between two sets of beaches: (Auroville, Paradise, Boomaiyarpalayam) vs. (University, Serenity, Veerampattinam). If we look at the fishing index (Table 2), the first sets are low on fishing activities as compared to the second set of beaches. In this study, fishing activities is clearly a determining factor for microplastic prevalence on the beaches, as the fishing index and microplastic

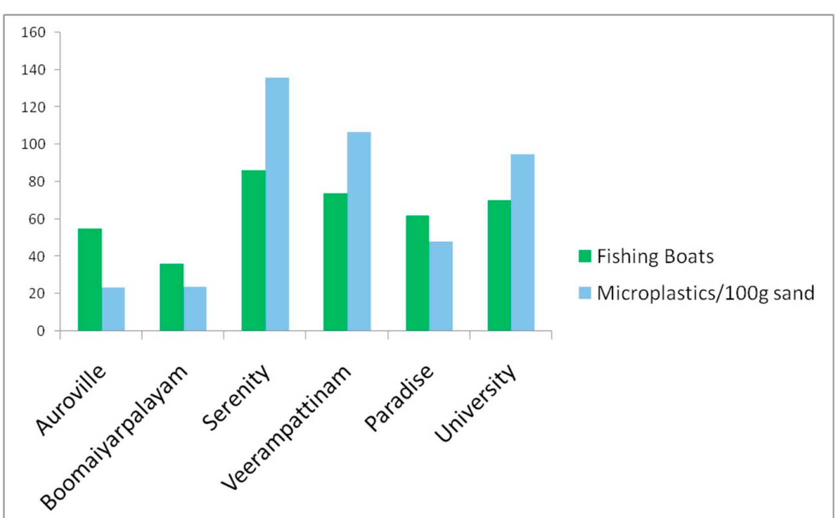

Fig. 8. Bar diagram showing the microplastic abundance in beaches varying in similar trend with the fishing index.

Table 3
Microplastic abundance reported in various studies conducted across the world.

Location	Microplastic in sediments	Reference
Shanghai	802 ± 594 particles/kg	Peng et al., 2018
Thames River	349.50 ± 303.00 particles/kg	Horton et al., 2017
Three Gorges Reservoir	25–300 particles/kg	Di and Wang, 2018
Antua River, Portugal	225.25 ± 109.52 particles/kg	Rodrigues et al., 2018
Taihu Lake	11–234.61 particles/kg	Su et al., 2016
Slovenia shoreline	Infralittoral zone: 155.6 particles/kg Shoreline: 133.3 particles/kg	Laglbauer et al., 2014
Scapa Flow, Scotland	730–2300 particles/kg	Blumenröder et al., 2017
Bohai Sea, North Yellow Sea, South yellow sea	171.8 ± 55.4 particles/kg, 123.6 ± 71.6 particles/kg, 72 ± 27.2 particles/kg	Zhao et al., 2018
Persian gulf, Iran	61 ± 49 particles/kg	Naji et al., 2017
Bizerte Lagoon, Tunisia	7960 ± 6840 particles/kg	Abidli et al., 2017
Hong Kong Marine Environment	49–297 particles/kg	Tsang et al., 2017
French Belgian Dutch coastline	6 ± 5.7 particles/kg	Cauwenberghe et al., 2015
Bostanu, Persian Gulf	1258 ± 291 particles/kg	Naji et al., 2016
Gorsozan, Persian Gulf	122 ± 23 particles/kg	Naji et al., 2016
Belgium	91.9/kg	Claessens et al., 2011
Puducherry Coast	720.30 ± 191.60 particles/kg	Present study

abundance follows a similar trend (Fig. 8). Fishing activities are consistent on a beach as a more or less fixed population accesses them for fishing. These would be people living in the locality around a beach. The people using the beach for leisure are not consistent. This parameter didn't show a particular trend in correlation with the levels of microplastic prevalence on the beaches. Modern day fishing sees the use of synthetics and traditional practices of using natural materials have been wiped out (Fig. 12). Wooden boats used for fishing have completely been replaced by plastic boats. Coconut fibres are no longer used for nets, ropes, and line.

Environmentally existing microplastics undergo degradation, biofilm formation etc. These factors interfere with the acquisition of Raman spectra of the particles (Claro et al., 2016). It is seen that the raw spectra is hard to analyse. Also, the dyes and additives have their own spectra that interfere with the spectra of the polymer of the microplastics. Fig. 9 shows biofilm on a plastic particle as observed under a microscope. To aid polymer identification, the raw spectra needs processing for the correction of background noise from fluorescence by biofilm and other contamination. Fig. 10 illustrates the difference between a raw spectra and a processed spectra. The raw spectra is a resultant of interferences of noise, fluorescence, and contamination. The percentage spectral matches between the Raman spectra of the particles we isolated and the standard reference spectra of different polymers are described in Fig. 11.

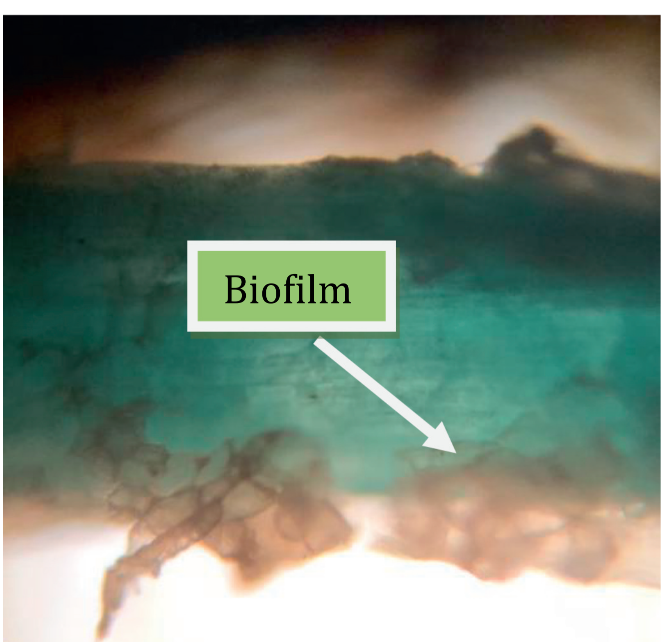

Fig. 9. Biofilm formation on the surface of a microplastic particle as observed under a microscope.

In this study, two dyes (Irgalite blue and Hostasol green) are identified and we can see that the colours of the identified dyes are consistent with the colours of the particles they were detected in (Fig. 6). Dyeing of polymers becomes a necessity when the consumer market is concerned. However, environmentally, dyes and additives are harmful as they leach out from the particles and pose threat to biota.

The specific density of PVC ranges between 1.1 and 1.45 g/cm^3 and hence NaCl solution (density 1.2 g/cm^3) is not ideal for the separation of PVC. However, occasional isolation of PVC by NaCl is not totally absent from literature (Vianello et al., 2013). In a review conducted by Kedzierski et al. (2017), 11% of the studies have been found to be able to isolate PVC using NaCl solution. Microplastics undergo degradation in the environment that causes loss of molecular weight and changes in other physical properties of plastics (Crawford and Quinn, 2017) and this could create an inconsistency between the properties of virgin and environmentally occurring plastics.

Most of the polymers identified in this study such as PP, PE, HDPE, LDPE, PET etc. are used in the manufacture of various fishing equipments and gears. These polymers are also used in the production of single use plastics. PE is used in plastic bags and containers; PP in Rope, bottle caps, fishing gears, strapping; PS in cool boxes, containers, and floats; PVC is used in pipes and containers; Polymer resin is used in boats and textiles; PA in ropes, nets etc.; and cellulose acetate in glass frames, textiles, toys etc. (Lusher et al., 2017) .

5. Conclusion and future prospects

This study highlights that Puducherry coast of India is not devoid of microplastic pollution. Our studies suggest that fishing activities is a major determining factor for microplastic prevalence in the beaches, especially in the Puducherry coastline which is a major fishing hub. The East coast of India is a highly dynamic coastline and is hit by tsunamis and cyclones from time to time and hence, the physiography of the beaches is always changing. Keeping that in consideration, it would be

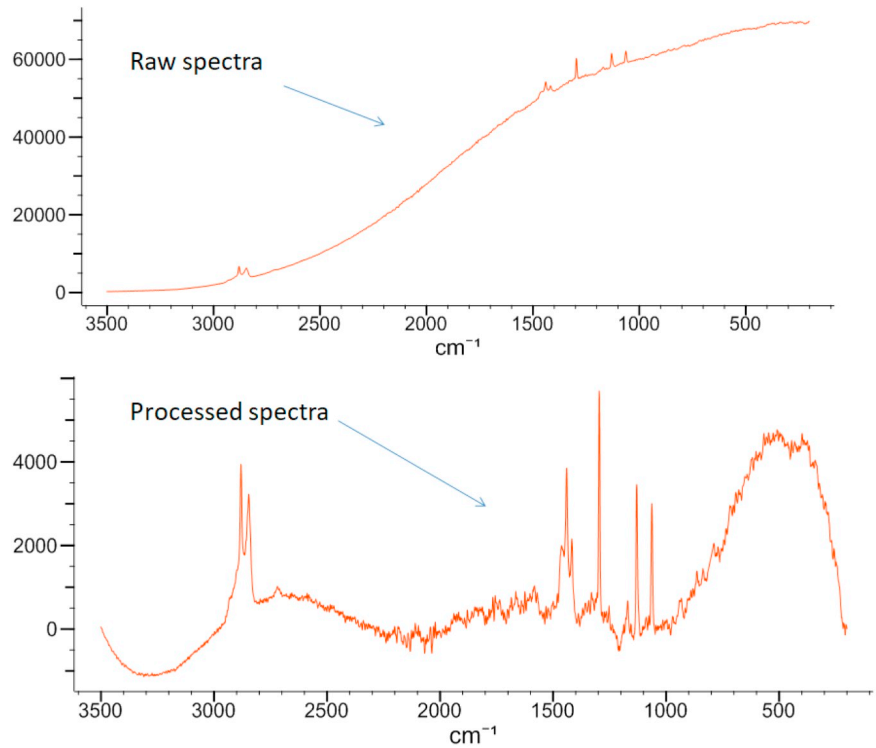

Fig. 10. Comparison between a raw spectra and a processed spectra.

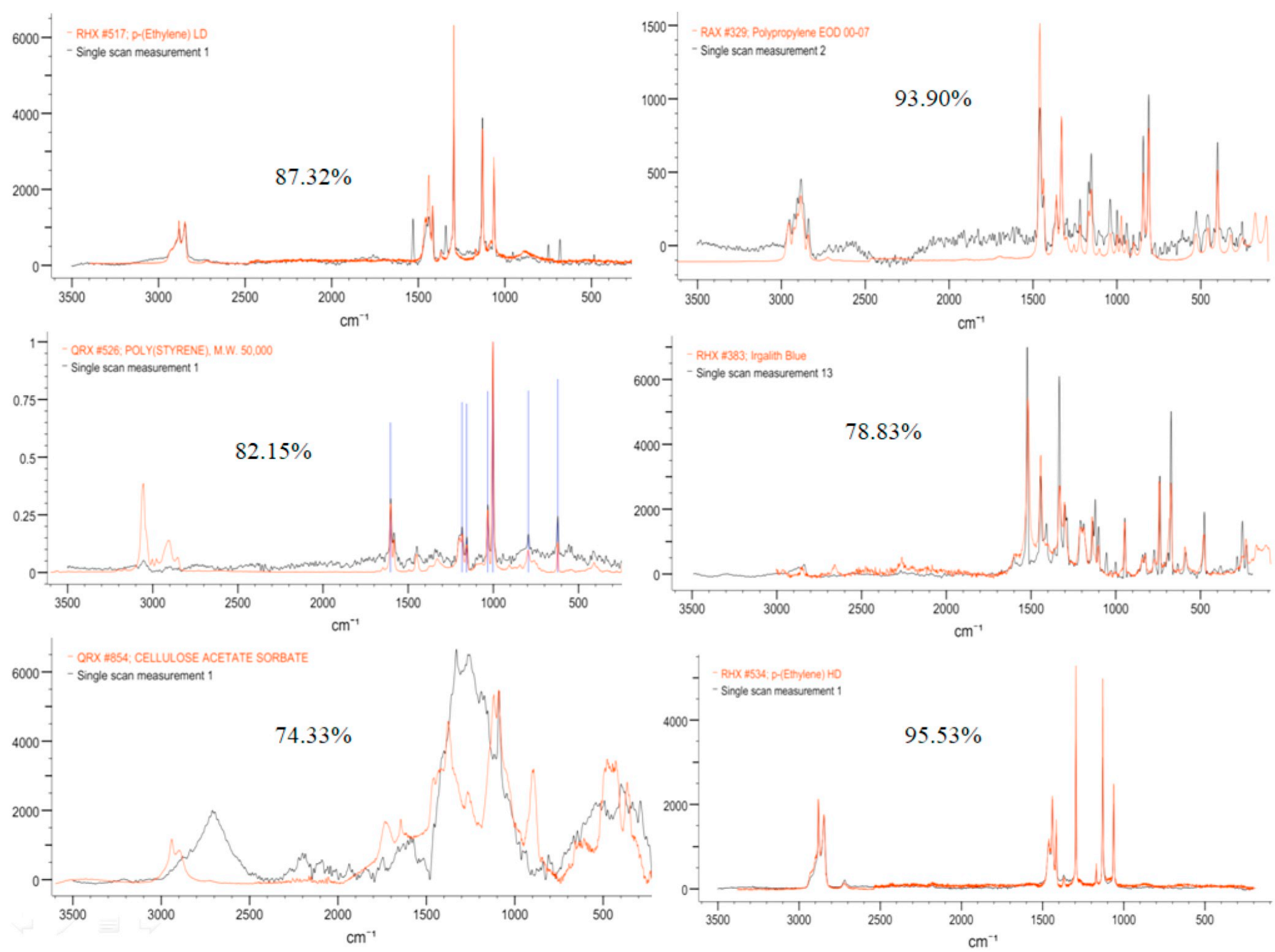

Fig. 11. Percentage spectral matches between standard Raman spectra of polymers (Red) and particles we isolated (Black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 12. Fishing boats parked on Veerampattinam beach. Various synthetic equipments used in fishing can be seen.

really insightful to see how the microplastic prevalence varies seasonally. Also the fishing activities and tourism are of a different scale at a different point of time in the year and it would be interesting to see how these factors correlate to the problem of microplastic on a seasonal scale.

Further study is also required to study the prevalence of microplastics in the biota of this region and the impacts it may have on them. Studies pertaining to the transfer of microplastics through the trophic food chains in these areas are also a need of the hour. In addition, the prevalence at the under-sea sediments, as that could be a potential sink for microplastics, requires to be studied. A social experiment is also much needed to test the awareness regarding these factors and to take measures for raising awareness among the local communities.

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