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Quantification and polymer characterization of sediment microplastics along the Golden beach, Puri, India

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Microplastics are a class of emerging pollutants of concern detected in beach sediments across the globe. Limited research on the topic has been undertaken in India, despite extensive coastlines and the country's most crowded beaches. The present study is a preliminary study on the quantification and characterization of microplastics in one of the most famous tourist destinations, the Golden beach of Puri, Odisha. An average count of 731±719 particles/kg dry weight of sediment was observed. Though ANOVA revealed a site-wise variation of microplastic types to be significantly different, Tukey posthoc test of the particle's diversity classified according to their major activity contributors did not show significant variation. The fragments were the most abundant fraction with a total count of 2835 particles representing 39 % of the total microplastics, followed by foams (29 %), fibers (14 %), films (11 %), microbeads (5 %), and pellets (2 %) of the total microplastic particles. Color classification revealed white, red, black, blue, green, and transparent microplastics to be abundant in all the sampling sites. Polymer characterization showed the presence of seven types of polymers being, High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyurethane (PU), Polypropylene (PP), Polystyrene (PS), Ethylene-Vinyl Acetate (EVA), and Nylon. These preliminary findings would serve as an eye-opener toward the magnitude of microplastic pollution in the area and help opt for mitigatory measures to avoid further detrimental impacts on the ecosystem.

[**Keywords**: Color classification, FTIR, Morphology, Spatial variation]

Introduction

Plastic particles of size less than 5 mm are termed microplastics (MP)[1]. These microplastics in the marine environment have been detected and inspired several studies across the world. It was estimated that 4.8 to 12.7 million tons of plastics are discarded every year in the oceans[2]. Microplastics are classified as primary microplastics, used as final products in various commercial items like cosmetics, clothing, textiles, detergents, etc.[3] and secondary microplastics, which result from synergistic photo-oxidation and mechanical abrasion of plastic waste[4]. The abundance of these tiny contaminants is of emerging concern in sediments exhibiting environmental risk[5] due to their inherent chemical and physical properties[6].

The risk of microplastics lies in the fact that, due to their small size, they can affect many organisms through the food web and produce chronic biological effects not only in organisms but also in human beings[7]. Several studies reported ingestion of microplastics by zooplankton[8], fish[9], amphipods[10], birds[11], marine mammals[12], bivalves[13] and many other organisms[14] due to their resemblance with food particles, ultimately leading to clogging and compromising the function of the digestive system along with decreased fecundity and mobility, higher oxidative stress, delayed larval development and liver toxicity[5]. Ory *et al.*[15] have found microplastics in the gut of some fish species feeding on planktons along the southeast Pacific coast. Further, Santillán *et al.*[16] has reported the first evidence of microplastics transfer in the food web of marine habitat in the scats of *Lontra feline*, an endangered marine otter and a top predator of the ecosystem. Sathish *et al.*[17] has reported clam *Donax cuneatus* to be a potential bioindicator of microplastics concentration in the water and sediment. Apart from this, studies have confirmed that the microplastics act as vectors for organochlorine pesticides and toxic heavy metals due to their significant adsorptive capacity for the pollutants, particle's large surface area, and hydrophobic nature of pesticides[18]. The conventional sorption mechanisms between the chemical contaminants and the microplastics are electrostatic interactions, hydrophobic interaction, hydrogen bonding, pore filling, Van der Waals forces, and π-π interaction varying with the physico-chemical characteristics of the contaminant and the microplastic particles[19]. The sorption processes are triggered by the mechanical weathering induced abrasion of the microplastic surfaces, which becomes rough, enhanced with pores to accommodate the contaminants[20].

Several studies on the presence, transport, fate, and effects of microplastics in the marine environment worldwide have been conducted in recent years. However, such studies in India have been limited, and notably fewer on the eastern coast. Jayasiri *et al.*[21] have first studied the abundance of microplastics in Mumbai's recreational beaches in India, where the author found the highest count of microplastics. Different activities like fishing, recreational and religious activities have been attributed to be the causative factor. Veerasingam *et al.*[22] investigated the influence of the 2015 flood on the distribution and occurrence of microplastic along the Chennai coast. They concluded that many microplastics washed by the Adyar and Cooum rivers contributed significantly to the contamination of the sea and the beaches. They conducted a similar study along the Goa coast[23] in 2016. Krishnakumar *et al.*[24] have reported polyethylene bottles and fishnet materials to be predominantly abundant in Nallathanni island, Gulf of Mannar Biosphere Reserve, Southeast coast of India. An extensive study was done by Karthik *et al.*[25] along 1076 km of sandy beaches of Tamil Nadu, where they concluded polyethylene and polypropylene to be the dominant plastics. Another extensive study followed this in three different locations *viz*. Girgaon Mumbai (Arabian Sea coast), Tuticorin, and Dhanushkodi (Bay of Bengal coast) by Tiwari *et al.*[26]. Other studies were undertaken in Puducherry and Gulf of Mannar and very recently in three states (Maharashtra, Karnataka, and Goa) by Maharana *et al.*[27].

Puri, the present study area, popularly known as Lord Jagannath's home, is the coastal district of Odisha, which serves as a prime location for tourists. The hotels and restaurants along the marine drive make the Golden beach one of the prominent holiday destinations for millions of people. Dawn starts with fishing activities carried out by local fishermen every day, and dusk ends with local vendors selling souvenirs and plenty of food items every evening on the beach. Apart from this, devotees leave an enormous amount of solid waste on the beach while taking the holy dip in the sea. Sewerage facility containing wastewater with plastic debris is also discharged into the sea. The objectives of the present study were to study the concentration of microplastic in the sediments along the coastline of the golden beach, their polymer composition and to identify the significant activity-based contributors to the different types of microplastic particles.

Materials and Methods

Study area

The study area, Puri spreads (Lat. 19.79º N, Long. 85.82º E), along the Bay of Bengal (Fig. 1), and has a population density[13] of 488/km^2. Though not an extensive one, the beach forms a part of the northeastern peninsular coast, built by the gradual recession of the coastline and delta forming action of the Mahanadi river[28]. Geologically it is composed of medium-sized quartz-feldspar sand grains. This study covered an entire stretch of 7 km in September, with a relative humidity of 87 %, wind speed of 24 km/h prevailing from the southeast, temperature of 38 ºC, and 50.9 mm rainfall intensity.

Sediment sampling

Ten sediment samples were collected along the golden beach of Puri, following the sampling procedure of Calcutt *et al.*[29]. The principal activities and probable sources of microplastic particles in each sampling point have been identified and presented in Table 1. In locations 1 and 2, significant activity contributing towards microplastic particles was fishing. In locations 3, 4, 9 and 10, the crucial activities were fishing, recreational facilities, and tourism, while in locations 5, 6 and 7, along with fishing, tourism, and recreational facilities, there were temporary beach markets, and in location 8 the major contributor was the wastewater discharge. The samples were collected using quadrats of 1×1 m dimension, laid on a high tide line zone with 0.01 m depth. Consecutive quadrats were laid down at approximately 800 m intervals. Sediments were extracted from quadrats with the help of a steel grab sampler and collected in glass containers. On average, 0.5 kg of sediment sample was collected from each sampling site. The glass containers were tightly sealed, labeled, and transferred to the laboratory for further analysis.

Sample pretreatment and preservation

The labeled glass containers containing sediment samples were preserved in the refrigerator at 4 ºC so

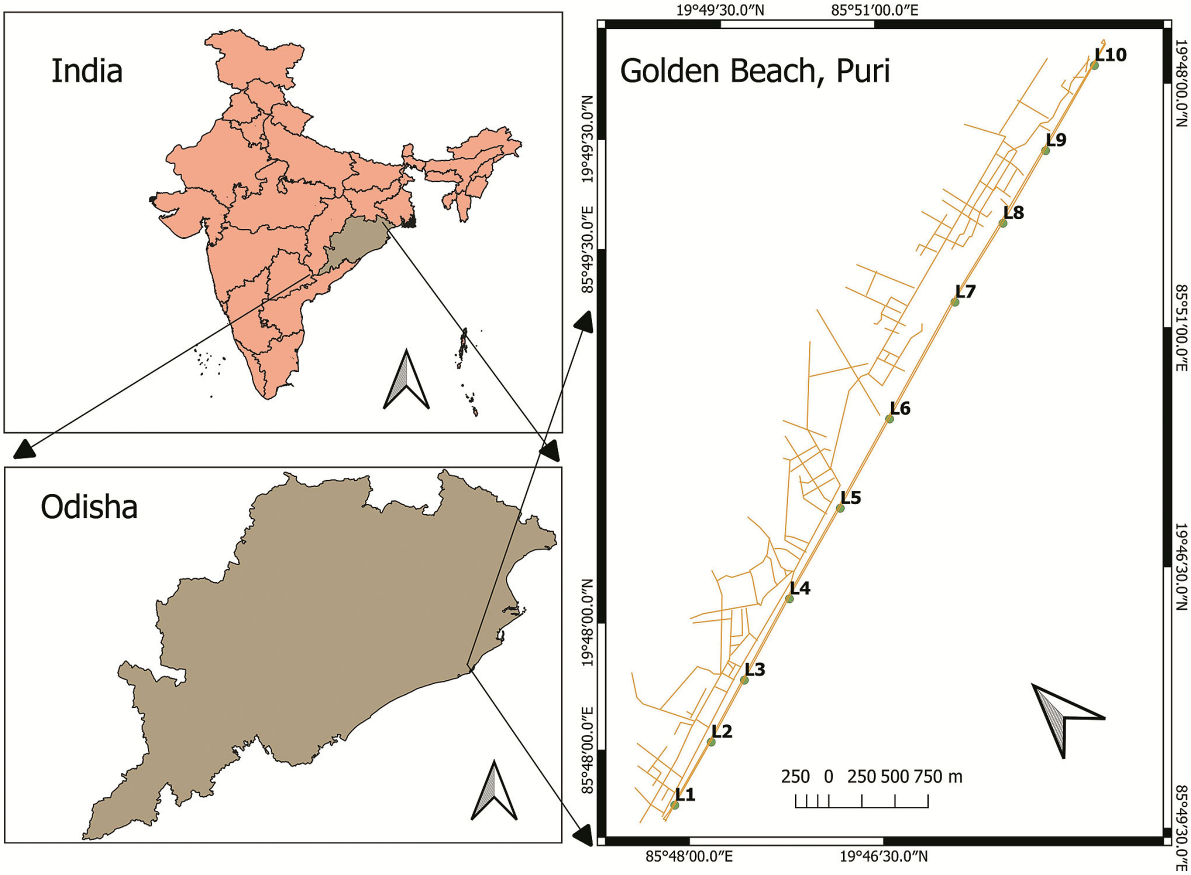

Fig. 1 — Sampling location along the Golden beach, Puri, Odisha, India

Table 1 — Abundance of microplastics per kg of sediment in different sites along the Golden beach, Puri, Odisha

		Sampling locations along the Golden beach of Puri										Statistical figures			
		L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	Total	Average	STDEV	% of total
Types of microplastics	Major activities	F	F	F, R, T	F, R, T	F, R, T, BM	F, R, T, BM	F, R, T, BM	WW	F, R, T	F, R, T				
	Fragments	43	98	163	185	248	496	968	513	58	63	2835	284	295	39
	Films	14	47	34	57	89	128	314	88	21	18	810	81	90	11
	Foams	38	133	218	142	174	260	544	285	278	30	2102	210	148	29
	Fibers	0	0	0	78	132	165	353	209	94	21	1052	105	114	14
	Pellets	0	0	0	0	0	23	78	24	0	0	125	13	25	2
	Microbeads	0	0	0	0	0	57	211	122	0	0	390	39	73	5
	Total	95	278	415	462	643	1129	2468	1241	451	132	7314	731	720	

F – Fishing, R – Recreation, T – Tourism, M – Beach Market, WW – Wastewater discharge

that there should be no change in MPs morphology. Samples were then sieved through a 5 mm sieve. Particles that pass through a 5 mm sieve were collected in a beaker of 1 l capacity. Later the samples were purified from an organic matrix before proceeding for analysis. Wet Peroxide Oxidation (WPO) step was adopted for the purification of sediment samples. Fenton's reagent (H_2O_2+ $FeSO_4.7H_2O$ in 2:1 ratio) and distilled water were added to the beaker containing sieved sediment samples. Then the beaker was covered with aluminum foil and kept at 50 ºC for 24 hrs.

Later, microplastic particles were separated by adding NaCl solution to the beaker, stirred for 1 hour, and then kept undisturbed for 24 hours. Due to the densities difference, all the MPs were got collected at the top surface of water column. This supernatant was extracted and filtered through Whatman filter paper (90 mm dia. and 20 µm pore size). The MPs trapped on the filter paper were kept in the petri dish and labeled accordingly.

Morphological analysis of MPs

Petri dish containing MPs trapped on filter paper was kept under a stereomicroscope (OLYMPUS SZ 61) to quantify MPs. To further enhance their appearance and rule out the organic particles, a particular type of light source and filter (NIGHTSEA Stereo Microscope Fluorescence Adapter, Model **SFA-RB –** Royal Blue (440 – 460 nm) excitation with extended pass filter) was used to render the microplastics fluorescent under the microscope. Morphological characterization (shape, size, and color) was done with OLYMPUS software 2.1, and identified particles were photographed accordingly.

Polymer characterization of MPs

For polymer characterization, random microplastic particles were selected according to their morphology (fragments, films, fibers, foams, beads, and pellets) with the help of tweezers kept in the Eppendorf tube for polymer identification. ATR-FTIR technique (Perkin Elmer's Frontier™ FT-IR) was followed for polymer identification. The diamond probe was initially cleaned, and particles were analyzed one by one. The spectral lines obtained were then compared with reference to polymer library[30]. The polymers were identified based on their functional group present in it. The compared spectral lines were accepted and reported with an 80 % or higher match.

Contamination control of microplastic assessment

Sample preparation and analysis were done in a designated sediment analysis laboratory with closed AC and windows to avoid airborne MPs contamination. Sediment samples were collected with stainless steel grab sampler and stored in glass containers. All the accessories used for collecting, storage, transport, and analysis were of stainless steel and strictly no plastic. Sediment samples were stored and transferred in glass bottles with metallic lids. The Millipore water used for the cleaning process was scrutinized to rule out possibilities of microplastic contamination. The salt solution, which was used for density separation, was also checked for MPs.

Data analysis

Simple statistical calculations for the study were performed in Microsoft Excel 10. To check the variation in the microplastic types based on the contributory factors in terms of significant activities in the vicinity of the sampling points, locations were grouped into four categories as a) fishing zone, b) fishing, recreation, and tourism, c) fishing, recreation, tourism with beach market and d) wastewater discharge zone. Next, the microplastic counts of a specific type (fragments, films, foams, fibers, pellets, and microbeads) belonging to identical major activities were averaged and tested for Single-factor ANOVA followed by Tukey posthoc HSD test.

Results and Discussion

The microplastic abundance of the ten sampling sites along the Golden beach of Puri has been presented in Table 1. MPs abundance was presented as mean ± SD of particles/kg dry weight of sediment. The total count of MPs detected was 7314 particles across 10 locations of Golden beach, varying from 95 particles to 2468 particles/kg. The mean abundance of 731±719 particles/kg dry weight of sediment was observed in the investigation. A single factor ANOVA results indicated significant differences (p-value = 0.037 at 0.05 level significance) between the microplastic diversity among the four classified zones *viz*. (a) fishing zone, b) fishing, recreation, and tourism, c) fishing, recreation, tourism with beach market and d) wastewater discharge zone of major activities. However, the Tukey HSD result test did not reveal any significant difference between the four designated zones. Therefore, the specific influence of crucial activities could not be drawn for the count and for various microplastic particles observed (Table 2).

The high abundance can be attributed to massive tourist influx in the area, the terrestrial bound precipitation runoff and drainage of the city's effluent into the sea[31]. In addition to this, sea-based activities like fishing, trawling, water sports, and transportation also add to the MP load on the beaches[32]. However, according to Andrady *et al.*[33], sea-based source contributes a meager 10 % of plastics compared to 90 % from land-based sources. Several studies on such an abundance of microplastics in beaches across the world have been reported[34]. The degree of abundance has always been found to be positively correlated with the intensity of urbanization[35]. A comparison of the present MP load with beaches having a higher tourist influx has been summarized in Table 3. Results indicated a higher average MP abundance/kg dry weight of sediment in the present study than India's similar beaches. Tiwari *et al.*[25] has reported the microplastic abundance of three beaches, Dhanuskodi and Tuticorin, along the Bay of Bengal

Table 2 — Variation of microplastic particles according to the major activity contributors, ANOVA and Tukey posthoc test

	Fishing (L1 & L2)	Fishing + Recreation + Tourism (L3, L4, L9 & L10)	Fishing + Recreation +Tourism + Beach market (L5, L6 & L7)	Wastewater (L8)
	A	B	C	D
Fragments	71	117	571	513
Films	31	33	177	88
Foams	86	167	326	285
Fibers	0	48	217	209
Pellets	0	0	34	24
Microbeads	0	0	89	122

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	189376.2535	3	63125.42	3.400838	0.037764	3.098391
Within Groups	371234.5093	20	18561.73			
Total	560610.7627	23				

Major activities pairing	Tukey HSD Q Static	Tukey HSD *p*-value	Tukey HSD inference
A Vs B	0.5302	0.8999	Insignificant
A Vs C	3.6726	0.0750	Insignificant
A Vs D	3.1544	0.1491	Insignificant
B Vs C	3.1424	0.1514	Insignificant
B Vs D	2.6242	0.2782	Insignificant
C Vs D	0.5182	0.8999	Insignificant

Table 3 — Abundance of MPs in sediment samples in the current study and similar studies

S. No.	Location	Abundance	Reference
1.	Mumbai, India	220±50/kg	Tiwari *et al.*[20]
2.	Tuticorin, India	181±60/kg	Tiwari *et al.*[20]
3.	Dhanushkodi, India	45±12/kg	Tiwari *et al.*[20]
4.	Mediterranean beaches	85±141/kg	Piperagkas *et al.*[30]
5.	Mediterranean beaches	5±5/kg	Piperagkas *et al.*[30]
6.	Marina beach, Chennai, India	309±184/kg	Sathish *et al.*[35]
7.	Kanyakumari beach, India	126±130/kg	Sathish *et al.*[35]
8.	Tiruchendur, India	232±116/kg	Sathish *et al.*[35]
9.	Alang-Sosiya ship breaking yard, India	81.43±4.03 mg/kg	Reddy *et al.*[33]
10.	Golden Beach, Odisha, India	731±719 MPs/kg	Current study

coast and Girgaon, Mumbai along the Arabian Sea coast, to be varying between 45±12 to 220±50 microplastic particles/kg of sediments. Sathish *et al.*[36] has performed an exciting study of microplastic enumeration in high tide and low tide levels in five coastal locations in Tamil Nadu and found 119±72 to 439±172 MPs/kg of sediments in HTL and 33±30 to 179±68 in LTL, which is also far less than the microplastic concentration of the present study. Reddy *et al.*[37], though he focused his study on small fragments from 10 sampling locations in the Along ship-breaking yard, reported a total of 81 particles/kg of beach sediments. In yet another study by Piperagkas *et al.*[38], in three sandy Mediterranean beaches, microplastics were as low as 85 microplastic particles/kg of sediment in summer and even lower in winter. Apart from these, several other studies have been conducted on microplastic enumeration from beaches globally. Still, the MP count in the present study area is considerably high.

Microplastics persistence in beaches is also influenced by the factors like the slope of the beach, wave dimensions, wind speed, and sampling depth[36] along with the shape, size, and density of MPs in coastal sediments[39]. Furthermore, the rate of photocatalytic and oxidative degradation of the deposited microplastics also influences the abundance of MPs on the beaches[33]. This, in fact, also affects the morphological characteristics of the MPs.

Morphology of the microplastics

In the present study, among the different microplastics, fragments were the most abundant, with a total count of 2835 particles representing 39 % of the total microplastics found in 10 locations. Fragments are generally the disintegrated product of larger plastics for decades under mechanical wear and tear, photochemical reactions, and biodegradation[40].

Significant sources of fragments are known as the hard plastics and packaging materials given to customers while delivering dress materials and other items. Even a high abundance of disposable cups and plates littered by the beach visitors contributes towards more fragments. Previously, transparent plastic fragments were also detected in maximum concentration along the Alang-Sosiya ship-breaking yard, India[41]. This was followed by foams (2102 particles; 29 % of the total microplastic particles), fibers (1052 particles; 14 % of the total microplastic particles), films (810 particles; 11 % of the total microplastic particles), microbeads (390 particles; 5 % of the total microplastic particles) and pellets (125 particles; 2 % of the total microplastic particles; Fig. 2).

Pellets are designated as a significant global concern[42]. Similar results were reported from a study conducted along the beaches of the southeast coast of India by Karthik *et al.*[25], who noted that a significant portion of MPs was fragmented (47 – 50 %) followed

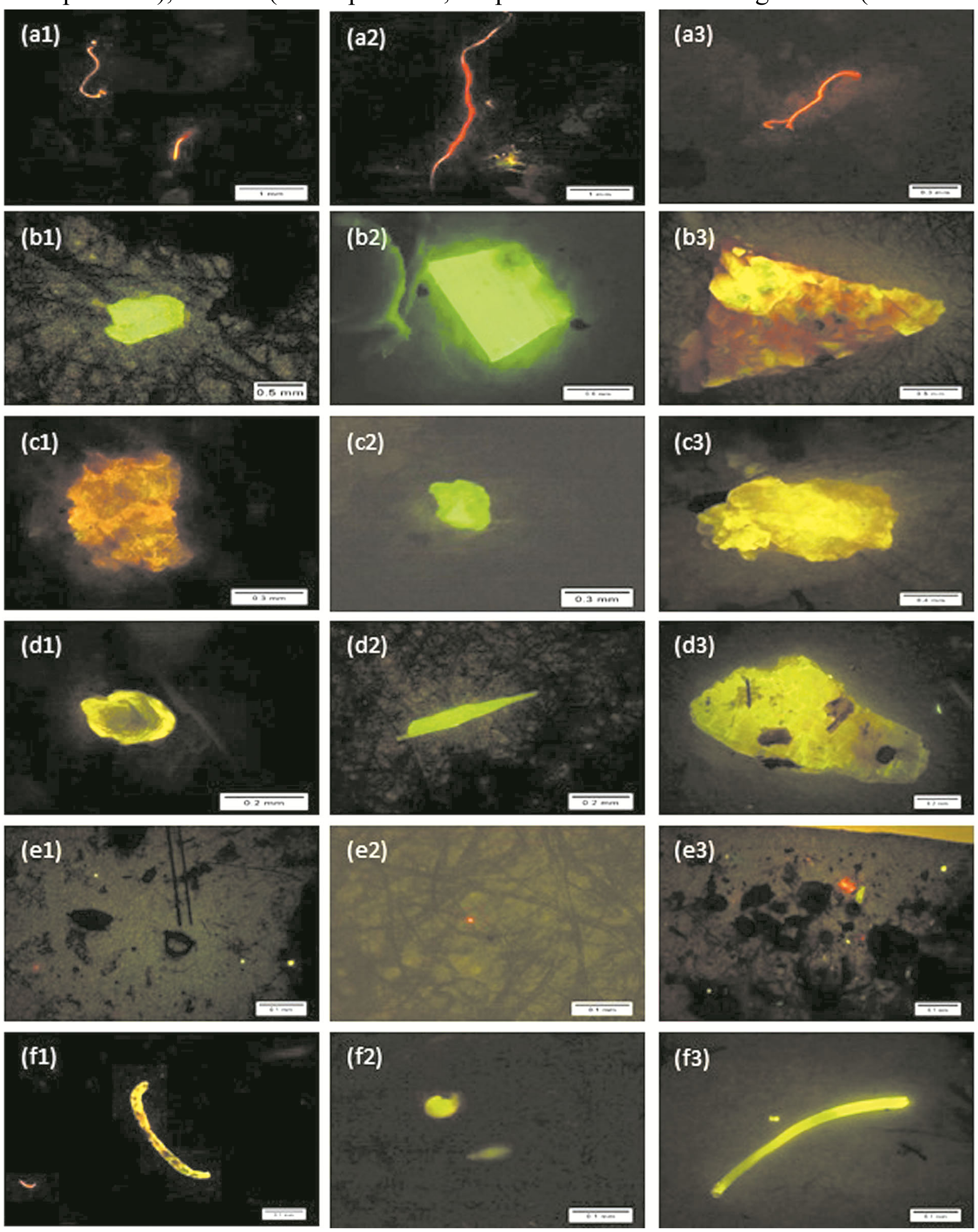

Fig. 2 — Microplastics observed under microscope with fluorescens adapter: (a1 – a3) Fiber, (b1 – b3) Film, (c1 – c3) Foam, (d1 – d3) Fragment, (e1 – e3) Microbeads and (f1 – f3) Pellet

by fibers (24 – 27 %) and foams (10 – 19 %). However, Sathish *et al.*[36] reported fibers dominating the five coastal areas in Tamil Nadu, India. Microbeads and pellets were the least abundant in most of the investigation carried out on coastal sediments. The abundance of foamy plastics in the study area next to fragments might be due to their use in the transportation of fish and buoys due to their insulating and floating properties. It is also widely used for automobile components and building implements[43].

The color classification in this study revealed that white, red, black, blue, green, and transparent microplastics were abundant in all the sampling sites. A significant source of transparent particles is plastic bags used extensively by the people in tourist places for carrying food items and other commodities. In addition to it, colored particles also lose their color after prolonged exposure to sunlight[44]. The impact of colored microplastics on aquatic life is more because they are more likely to be ingested by marine organisms once they enter the water due to wave action. Similar results were reported by Sathish *et al.*[36]. However, an investigation was done by Vidyasagar *et al.*[45] on Rameswaram Island, India, where he found the maximum abundance of white-colored MPs (43.4 %) followed by green-colored MPs (21.6 %) and blue colored MPs (16.9 %). Human-induced activities like shipbreaking are known to be the leading factor to the accumulation of transparent MPs (15.8 %) in sediments[40].

Polymer characteristics of the microplastics

A total of seven types of the polymer could be identified from the microplastics isolated randomly from the study area samples. The type of polymers identified was High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyurethane (PU), Polypropylene (PP), Polystyrene (PS), Ethylene-Vinyl Acetate (EVA) and Nylon (Fig. 3). The data confirms that PP, PE (High density and Low density), and PS were relatively abundant polymers in the sediments of Golden beach, Puri. These classes of polymers were identified in the fragments and foams. A similar observation was reported from the beaches of the southeast coast of India[25] in which PP, PE, and PS were the most abundant polymer type identified. PE possesses high strength and flexibility, and as a result, it degrades slowly in the natural aquatic environment and becomes highly persistent in nature[33]. PE-type MPs can originate from carrying bags, bottles, or a covering of wires. Other risks associated with PE type MPs (HDPE and LDPE) are that they can be a vector for pathogens and harmful chemicals, resulting in contamination of the food web. In the present study, HDPE was confirmed by the presence of spectral bands 2915, 2845 cm^{-1} (assignment C-H stretch moiety), 1472, 1462 cm^{-1} (assignment CH_2 bend), and 730, 717 cm^{-1} (assignment CH_2 rock; Fig. 3)[30]. Similarly, PU was confirmed by the presence of the absorbance bands like 2865 cm^{-1} (assignment C — H stretch), 1731 cm^{-1} (assignment C = O stretch), 1531 cm^{-1} (assignment C — N stretch), 1451 cm^{-1} (assignment CH_2 bend), 1223 cm^{-1} (assignment C(=O)O stretch; Fig. 3)[30].

PP was another polymer type found in the microbeads. Its presence was confirmed by the reference spectral bands 2950, 2915, 2838 cm^{-1} (assignment C-H stretch), 1455, 1377 cm^{-1} (assignment CH_2 bend), 1166 cm^{-1} (assignment C — H bend, CH_3 rock, C — C stretch), 997 cm^{-1} (assignment CH_3 rock, CH_3 bend, CH bend), 972 cm^{-1} (CH_3 rock, C — C stretch), 840 cm^{-1} (assignment CH_2 rock, C — CH_2 stretch), 808 cm^{-1} (assignment CH_2 rock, C — C stretch, C — CH stretch; Fig. 3)[30]. PPs are widely used to produce fishing gears, sportswear, plastic tools, furnishing, and pipes. However, due to its low density, low UV resistance, and oxidative resistance, PP exposed to sunlight degrades easily and is less persistent in the aquatic environment[29]. PP has high strength and rigidity. It is a highly preferred polymer for the furnishing industry to the automotive industry and is extensively used to manufacture packaging materials. Besides, these polymers are hydrophobic, due to which the formation of biofilms by microorganisms is evident in the aquatic environment[43], which itself raises the risk in the food chain. Kirstein *et al*.[46] reported that pathogens such as *Vibrio cholerae* and *Vibrio vulnificus* form a biofilm on PP. A study conducted by Viršek *et al*.[47] on *Aeromonas salmonicidia* (a fish pathogen species) reported that the human body could be infected by fish accumulating PP microplastics. The dominance of PP and PE has been found previously in various ecosystems[48]. A study conducted along the Alang-Sosiya ship-breaking yard, India, also confirmed PS, PU, and Nylon in the coastal sediments[41]. PP was also detected in a significant amount in the Gulf of Mannar's coral island, followed by PE, PS, and Nylon[48].

The third prominent type of polymer detected as per the spectral absorption bands was Polystyrene

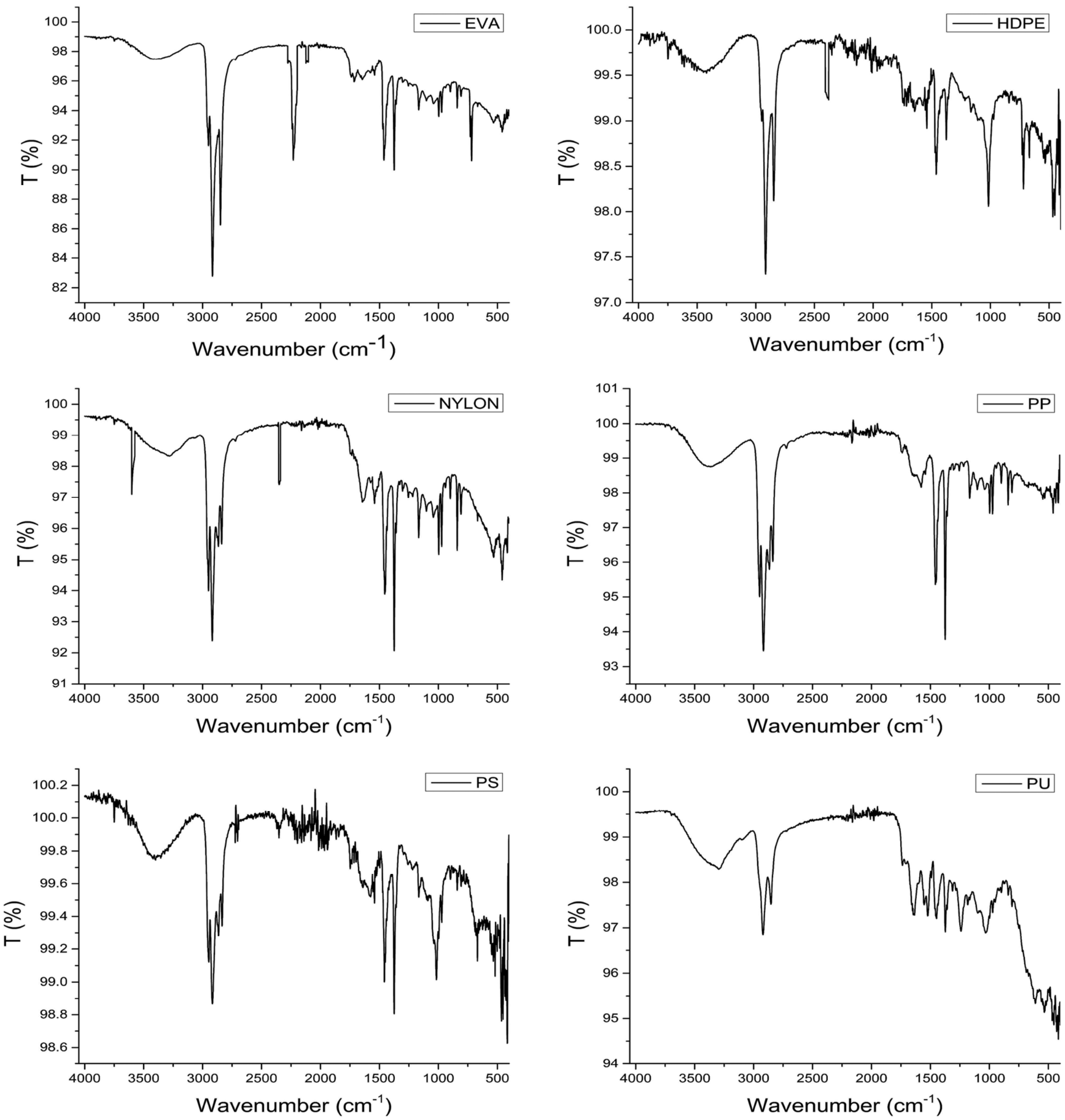

Fig. 3 — FT-IR spectra of polymer type identified in the sediment samples of Golden beach, Puri, Odisha

(PS). The fragments and foams were found to be belonging to this class. It was marked by the presence of 3024 cm^{-1} (assignment Aromatic C — H stretch), 2847 cm^{-1} (assignment C — H stretch), 1601 and 1492 cm^{-1} (assignment Aromatic ring stretch), 1451 cm^{-1} (assignment CH_2 bend), 1027 cm^{-1} (assignment Aromatic CH bend), 694 cm^{-1} (assignment Aromatic CH out of plane bend), and 537 cm^{-1} (assignment Aromatic ring out of plane bend; Fig. 3)[30]. PS has excellent thermal insulation, which makes them suitable for the manufacturing of disposable plates and cups. Most of the disposable items or single-use items are manufactured from PS. Since Golden beach is a prominent tourist destination, PS was detected in every sampling location. These PS-type MPs harm the environment. There is evidence of the ecotoxicology of PS on humans[49]. Jin *et al.*[50] showed that PS leads to microbiota dysbiosis in mice as well as hepatic disorder. The ecotoxicological impact of PS has been well documented in several studies. For instance, when PS was exposed to *Calanus helgolandicus* and *Tigriopus japonicas* (marine copepods) decrease in survival and fecundity was observed[9]. Furthermore, increased neurotoxicity and genotoxicity were observed in *Scrobicularia plana* when exposed to PS type MPs[49].

EVA was the least abundant polymer identified and detected only in the pellets. It was confirmed by the presence of the absorption bands like 2917, 2848 cm^{-1} (assignment C — H stretch), 1740 cm^{-1} (assignment C = O stretch), 1469 cm^{-1} (assignment CH_2 bend, CH_3 bend), 1241 cm^{-1} (assignment C(=O)O stretch), 1020 cm^{-1} (assignment C — O stretch), and 720 cm^{-1} (assignment CH_2 rock; Fig. 3)[30]. EVA is generally used to produce textiles, adhesives, bookbinders, and plastic films. Very few studies confirm the presence of EVA-type MPs in beach sediments.

Nylon (Polyamide) was confirmed in the fibers present in the sediment samples due to their polymeric composition of 3298 cm^{-1} (assignment N — H stretch), 2932 and 2858 cm^{-1} (assignment CH stretch), 1634 cm^{-1} (assignment C = O stretch), 1538 cm^{-1} (assignment NH bend, C — N stretch), 1464, 1372, and 1199 cm^{-1} (assignment CH_2 bend), and 687 cm^{-1} (assignment NH bend, C = O bend; Fig. 3)[30]. Nylon MPs have generally been observed in surface water and offshore sediments due to their fishing activity[33]. Nylon micro-fibers have also been recorded as ingested by *Nephrops norvegicus* from several Irish continental shelf[50], implying its high chances of exposure at an international scale. Cole *et al.*[49] studied Nylon microplastics effect on lipid accumulation and molting in a cold-water copepod. They have observed microplastics to reduce feeding and accumulation of stymie lipid and accelerated premature molting in a boreal copepod.

Hence the mentioned observations hint at the fact that the Golden beach of Puri, which is well known for its tourism around the year, is becoming an accumulation zone for a variety of primary and secondary microplastics to the extent that it would be negatively affecting the structure and functional attributes of the ecosystem.

Possible impacts on ecosystem

The presence of microplastics directly impacts various organisms in freshwater and marine habitats through their uptake in the food web and indirectly by offering suitable binding sites for heavy metals, hydrophobic persistent organic pollutants, and pathogens with multiple drug resistance. In addition to this, the various polymers identified in the present study are also known to be releasing degraded monomers and additives, which negatively impact marine organisms[50]. Different detrimental effects on the exposed organisms range from reduced energy to early mortality, including immunity impairment, oxidative damage, inhibited growth, and inflammatory responses[51]. Histological aberrations were observed in clams exposed to PVC and PS[10], while PE microspheres dampened the predatory behavior of *Pomatoschistus microps* juveniles[1]. Rainieri *et al.*[8] stated the adverse effect of LDPE plastic particles with adsorbed chemical contaminants on the liver of Zebrafish. They concluded that exposure to such particles caused increased oxidative stress and antioxidant enzyme synthesis with decreased growth rate, fecundity, lifespan, reproduction time, and body size.

Conclusion

The present study's overall findings have shown a considerable amount of microplastic pollution to be happening in the Golden beach sediments of Puri. A mean microplastics concentration of 731 particles/kg dry weight of sediments was observed including fragments, fibers, foams, microbeads, and pellets. Further morphological investigations revealed the particles to be of various colors. The microplastic types site-wise variation was significantly different, though conclusive results related to the major contributors were not found significant. Polymer characterization revealed seven types of polymers like high and low-density polyethylene, polypropylene, polyurethane, polystyrene, ethylene-vinyl acetate, and Nylon, each class having its own set of adverse impacts on organisms living in such ecosystem. The findings also suggested probable sources like fishing, trawling, commercial activities on the beach, and discharge of untreated or partly treated effluents in the vicinity to be the causes for such microplastic abundance. These findings would help control microplastic contamination in the study area or similar areas of the globe by applying checks to the causative factors and saving the vulnerable ecosystems. It also paves the way for further research on the microplastic mobilization, deposition, and impacts on the ecosystems indigenous species.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Author Contributions

VS has contributed in formal analysis, methodology, visualization, validation, and writing - original draft. SC has been engaged in conceptualization, process, supervision, writing - review & editing, and validation; while PC has helped in writing - review & editing.

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