

Unveiling the sources and impacts of plastic pollution: A preliminary study at Pattinapakkam Beach, Chennai, India during Cyclone Fengal

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Abstract

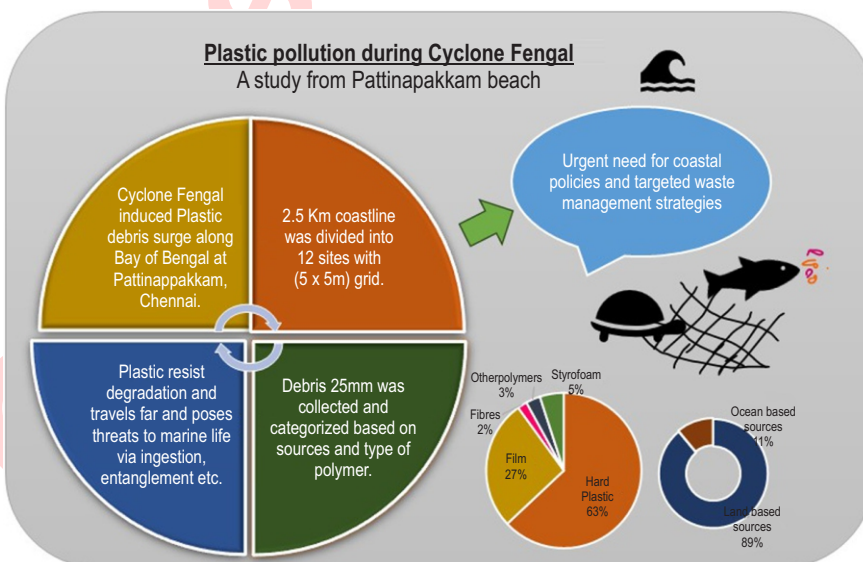
Aim: This study investigates the impacts of Cyclone Fengal (December 2024) on plastic debris accumulation along the South-East coast of Tamil Nadu, India, particularly in Pattinapakkam, Chennai. It aims to understand the composition, sources and ecological implications of cyclone driven plastic pollution.

Methodology: Field work focused on a 2.5 km coastal stretch using systematic grid sampling, dividing the area into 12 sites, each marked by a 5 m × 5 m grid (25m²), ensuring spatial variability. Visible debris larger than 25 mm were collected and categorized by material and polymer type. Statistical analysis (ANOVA) was used to evaluate spatial variation in debris accumulation.

Results: The findings revealed a plastic composition of 63% hard plastics, 27% film, 2% fibres, 5% styrofoam, and 3% other polymers, with polyethylene (PE) dominating at 67.6%. Statistical analysis (ANOVA) confirmed non-significance with a p -value > 0.05. Debris sources were traced to land-based (89%) and ocean-based (11%) origins.

Interpretation: Cyclone-induced winds, storm surges and runoff contribute to increased marine debris accumulation posing significant threats to marine biota via ingestion of weathered plastics, entanglement of fishing nets. In addition, uprooting of seaweeds disrupts ecosystems and reduces the ocean's carbon sink capacity. This study highlights the urgent need for targeted policies and waste management strategies to protect coastal ecosystems.

Key words: Coastal ecosystems, Cyclone Fengal, Marine plastic pollution, Ocean conservation, Plastic debris accumulation



Introduction

Plastic pollution in the ocean is a significant environmental issue emerging from a combination of human activity and natural disasters. Millions tons of plastic litter enter the oceans every year impacting marine biodiversity, human health and integrity of overall marine ecosystem. Human made items discarded in coastal ecosystems, predominantly plastics, are commonly referred as "marine debris". Persistent human activities including improper waste management and increased dependence on single-use plastics together with extreme weather events like cyclones disrupt marine habitats and transport debris into the oceans. Cyclones worsen the situation by redistributing large amount of debris, especially plastics from inland areas to coastal zones (Tsuchiya *et al.*, 2015; Nakajima *et al.*, 2022). Strong winds, heavy rainfall and storm surges caused by these extreme weather events uproot garbage from landfills, unofficial dumpsites and carry to rivers, canals and coastal areas significantly contributing to the already increasing levels of plastic pollution. Urban runoff, inadequate waste management systems, litter from tourists and the increasing amount of plastic waste make urban coastal zones highly susceptible to contamination. When these areas come into contact with cyclones, the transfer of debris from land to sea results in the deposition of plastic waste onto shorelines (Hitchcock, 2020).

Marine litter originates from both land-based and ocean-based sources as a result of maritime operations. An estimated 640,000 tons of fishing gear, often discarded from commercial fishing activity of various types also leads to interactions with marine life while changing the marine environment (Geyer, 2017). These items often end up in the water where they can persist indefinitely. These events illustrate the relationship with human involvement and natural phenomena in the context of ocean pollution and plastic pollution and the consequences for the planet. In addition to shoreline and near shoreline impacts, marine organisms continue to be at risk of harm or death through plastic entanglement and ingestion. Deposition of plastic debris interferes with the function of habitats such as mangroves and coral reefs, which harbour organisms of diverse marine species and provide valuable ecosystem services (e.g. water purification, carbon sequestration) (Garces ordanez *et al.*, 2021). Eventually, this results in loss of biodiversity which would alter the community structures and possibly disrupt functionality of ecosystems.

Plastic materials such as polyethylene (PE), polypropylene (PP) and nylon dominate in the marine systems because of their widespread use and high durability against degradation can be harmful to marine animals (Andrady, 2011; Geyer *et al.*, 2017). The problem is further confounded by microplastics that originate by breakdown of larger plastic materials via photo-oxidation, wave action and biodegradation (Auta *et al.*, 2017). Microplastics (MPs) infiltrate aquatic

ecosystems through wastewater discharge, storm runoff, when swallowed by marine creatures it bioaccumulate and pose dangers to the food web of the marine ecosystem (Thushari and Senevirathna, 2020). MPs exert toxicological effects on marine organisms and adversely affect human health through consumption of seafood. Turtles and seabirds are particularly vulnerable, with research revealing increased plastic ingestion over recent decades (Schuyler *et al.*, 2014). In light of the above, this study investigated the accumulation and distribution of plastic debris at Pattinapakkam beach, Chennai after Cyclone Fengal, focusing the prevalent polymer types, sources of plastic pollution, and its environmental impacts essential for developing effective waste management strategies and mitigating the long-term effects of plastic contamination in marine ecosystems.

Materials and Methods

The study site, Foreshore Estate (13.0301°N, 80.2771°E), also known as Pattinapakkam is a densely populated coastal stretch in Chennai, Tamil Nadu, extending 2.5 km along the Bay of Bengal situated at the southern part of Marina beach (Fig. 1). The study area has a tropical climate, with average temperatures ranging from 20 to 35°C. The rainfall of this region is controlled by the North-east and South-west monsoon, which contributes to around 1400 mm of rainfall, respectively. Pattinapakkam beach is in close proximity to the highly polluted Coovum and Adyar river. This area serves as a major tourist place and is familiar for fishing and hosts a bustling seafood market. However, due to increasing human activity, urban runoff and fishing activity, it has become a debris hotspot for marine debris accumulation, especially plastics.

The impact of Cyclone Fengal, which intensified over the Bay of Bengal on December 1, 2024 had a significant contribution to debris deposition along the coastline. Post cyclone, grid sampling method was employed to assess the distribution and composition of plastic debris. The total area of 2.5 km was divided into 12 sites, each marked by a grid of 5m x 5m. This difference was taken to ensure spatial variability and uniformity between the sites. Visible plastic debris larger than 25mm was collected and categorized based on the material type and polymer composition (Fig. 2; Table 1). The data was expressed in terms of Mean \pm SE and 95% confidence interval was interpreted. One-way ANOVA was applied to analyse the variation in plastic accumulation across sites.

Results and Discussion

Plastics were the most abundant type of debris found ashore during Cyclone Fengal. This study assessed the distribution of plastic debris post-cyclone in Pattinapakkam Beach, Chennai, on the South-east coast of India. Plastic pollution was recorded at all the sites and were categorised

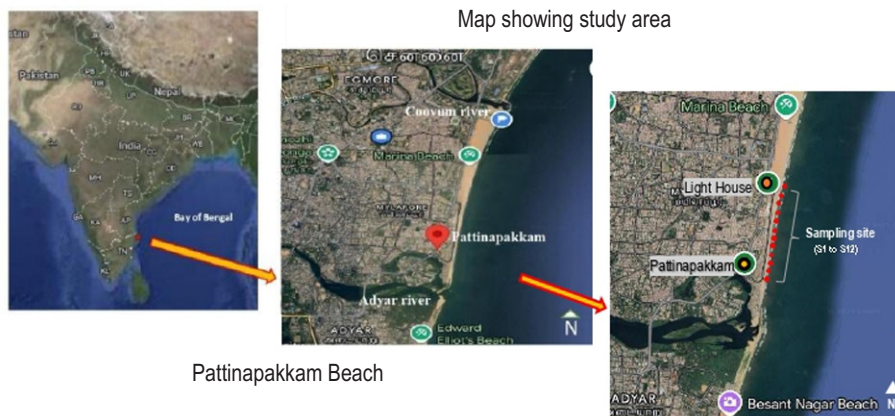


Fig. 1: Map showing the study area and sampling sites (S1–S12) along Pattinapakkam Beach, Chennai, Tamil Nadu, India. Source: Google Earth Pro; sampling points marked by the authors.



Fig. 2: Plastic debris collected from various sampling sites along Pattinapakkam Beach. Source: Field photographs taken by the authors (2024).

accordingly as provided in Table 1. A total of 478 plastic items were collected during the course of study. The mean abundance of overall plastic debris was found to be 53 ± 15.58 post cyclone. Based on this, a 95% confidence interval was calculated, suggesting that the actual mean abundance of plastic debris was

likely as 35.95 items. This range reflects the uncertainty in the estimate and highlights the potential variability in plastic debris distribution. A comparative study showed that hard plastic accounted for 63% of total plastic debris with film and fibre making up 27%. The primary sources of marine plastic debris were

Table 1: Classification of plastic marine debris (Jang *et al.*, 2014; Li *et al.*, 2016)

MATERIAL	PLASTIC TYPE	APPLICATION
Hard plastic	PET	Soft drink bottles, single use water bottles, disinfectant bottles, soap containers, deodorant bottles, shampoo bottles.
	HDPE	Tooth brush, food storage container, reusable water bottles, Kumkum box, face wash, shampoo dispenser, detergent bottles, plunger of syringes, cigarette lighters, water dispenser caps.
	PP	Food packaging box, toys, broomstick, single use spoons, comb, barrel of syringes, ointment, toothbrush bristles, rice bags, marker pen.
	PVC	Flexible toys, slipper strap, cleaning solution containers, rubber gloves.
Film	LDPE	Packaging covers, food wrappers, single use carry bags, juice box, glove
Fiber and Fabric	LDPE	Mesh bags, fishing net, rope
Styrofoam	PS	Thermocol, shuttle cork, medical waste, laboratory containers
Other polymers	PU	Condoms, scrubbers
	EVA	Infusion bags

ocean-based sources (11%) with fishing gear, ropes and packaging waste and land-based sources (89%) such as domestic and industrial waste carried by rivers and runoff (Fig. 3). Of the total, land-based sources had the most significant impact reflecting an abundance of human disturbance at the beach. The high quantity of plastic waste accumulation depends on various factors including lack of proper waste disposal leading to uncontrolled dumping of plastics resulting in increased littering of single-use plastics such as bottles, food wrappers, and disposable cutlery which are later washed into coastal areas by floods (Jambeck, 2015).

Although fishing industries are fundamental to local communities, downstream littering produces excess plastic waste including discarded fishing nets, ropes and plastic packaging in seafood distribution. Additionally, losses in shipping and offshore industries contribute to marine plastic pollution through discharges or poor waste management practices (Gacutan *et al.*, 2022). There are also increased socio-economic impacts caused by these marine debris including loss of fishing opportunities due to cleaning activities from nets and propellers. This acts as an ongoing navigational hazard for shipping due to higher accumulation in the ocean.

The polymer varieties in post-cyclonic sediments were found in different proportions, with Polyethylene (67.7%) and Polyvinyl chloride (17%) being the most prevalent with Ethylene Vinyl Acetate (0.8%) ranging the lowest (Fig. 4). Irregular distribution of these polymer types in the coastal sediments is attributed to cyclonic floods, which act as primary drivers facilitating the transportation and deposition of plastic debris from various sources (Gandhi, 2021). A substantial portion of debris was associated with household waste including bottles used for cleaning products (detergents, disinfectants), personal hygiene items (toothbrushes, shampoo bottles) and bottles containing soft drinks etc. The sheer volume of these debris suggests inefficiency in municipal solid waste collection and disposal services. More importantly, one of the key pathways for plastics entering the marine environment during cyclones is through riverine flow.

Since the study area is located next to the Adyar and Coovum rivers that are heavily polluted, Cyclone Fengal provided significant additional transport of plastic debris from inland areas to the surrounding seas and ocean. Extreme weather events like cyclones can cause large amounts of improperly managed waste to get flushed down from rivers and large amount of plastics to end up on beaches and into the ocean.

Polyethylene was one of the most prevailing polymers in post-cyclonic sediments and is likely related to its widespread application in packaging, fishing gear and consumer products. The extreme buoyancy and durability of PE makes it quite mobile in marine environments and allows it to be transported over long distances through the cyclonic process. PE has a slow degradation rate relative to other polymers, and therefore likely persists in the coastal and ocean habitats much longer than other types of plastics. Additionally, its dominance can be linked to extensive application in plastic bags, containers, and films, which are commonly discarded and easily carried by floodwaters (Schwarz *et al.*, 2019). One-way ANOVA confirmed non-significance with a p-value > 0.05 over various sites showing statistically in significant variation in the quantity or distribution of plastic debris among the 12 sites. However, lack of significant variation suggests uniform conditions, but does not diminishes the potential environmental impacts, hence, proving to have higher levels of human activity in the study area.

Tropical cyclones dramatically modify shoreline dynamics, especially near low-lying coastal areas (Soria *et al.*, 2017). Cyclonic activity such as Fengal, increases the sediment mobility and redistributes debris along the shore and into the marine ecosystems. For seaweed beds, the debris covers plants and potentially reduces light levels for photosynthesis. Impact on carbon-sequestration may alter the complexity of climate regulation by ocean ecosystems. In addition, the sudden displacement of seaweed populations leads to death, with knock-on effects to the coastal ecosystem leading to further death of marine organisms which rely on seaweeds for food and shelter. Plastic debris is also creating habitat for disease carrying

SOURCES OF PLASTIC DEBRIS

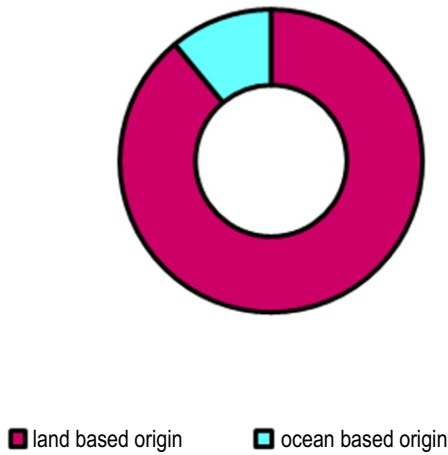


Fig. 3: Sources of plastic.

POLYMER DISTRIBUTION

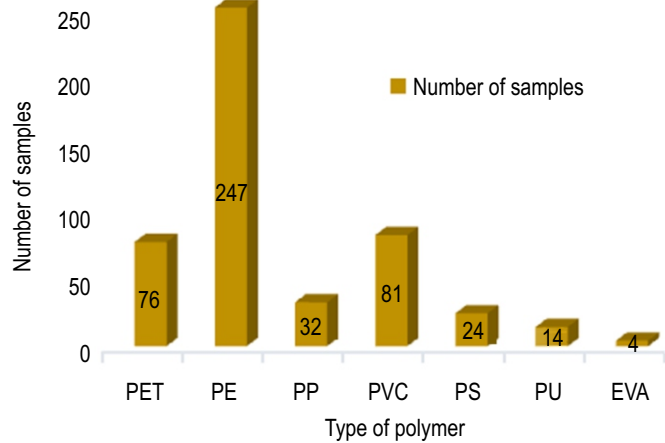


Fig. 4: Distribution of various polymer types.

microorganisms like *Escherichia coli*. *E. coli* can form a stable biofilm on most plastics and is believed to influence pathogen dispersion into marine environments, especially if the plastic waste reaches surface water via activities like bathing etc. (Vethaak et al., 2016). Plastic pollution raises a significant ecological hazard for earth impacting the marine habitat, biodiversity and human health. Plastic ingestion by marine organisms causes starvation, injury and reduce reproductive success (Auta, 2017). The slow degradation of plastic leads to an extended presence in the environment reducing physical, chemical and biological degradation with the key degradation effects as photodegradation by sunlight, tide and wave effects and chemical leaching associated with the release of hazardous additives such as plasticizers and heavy metals (Andrady, 2011). In the long run, plastics absorb persistent organic pollutants (POPs), which accumulate in marine food webs, posing health risks to aquatic life and humans (Clukey et al., 2018). The partial breakdown of plastics may still leave persistent microplastic fragments in the environment, which is further transported by ocean currents, wind, and storm water runoff and have been detected in the marine ecosystems.

Plastic debris has been identified within human-consumable seafood as well. Evidence of microplastics in a variety of fish and shellfish purchased from the local market has been found in several investigations (Li et al., 2015; Rochman et al., 2015; Karami et al., 2018). Ingested plastics in a variety of marine organisms demonstrate intestinal blockages, inhibited enzyme secretions and reproductive failures (Wright et al., 2013). These plastics being toxic are subsequently ascended through food chain due to biomagnification and raises concern for potential human effect (Wang et al., 2019). Human ingestion of these microplastics, through eating contaminated seafood and

the potential health effects related to microplastics (Naidoo and Rajkaran, 2020). *In vitro* studies using human cerebral and epithelial cells have highlighted the potential effects of micro and nanoplastics cytotoxicity at the cellular level concerning oxidative stress (Schirinzi et al., 2017). Furthermore, their interactions with the immune system possibly result in immunotoxicity causing adverse effects such as immunosuppression, immune stimulation and abnormal inflammatory responses (Barboza et al., 2018).

Recent study by Zhou and Mizuno (2026), concluded that the major threat are the suspended pollutants that cause dynamic changes regarding environmental safety. It is to be noted that removal of debris can aid in the natural recovery of the marine ecosystem (Maldini et al., 2026). There is still a little-known clarity with reference to the practical application of marine debris identification and tracking (Galappaththi et al., 2025). Microplastics which attach themselves with marine organisms can lead to some diseases, disrupts nutrient recycling and reduce biodiversity (Nama et al., 2023; Abejo et al., 2025). These observations reinforce the need for local capacity building up to reduce the long-term impacts of plastic pollution.

To reduce marine pollution, it is essential to limit the usage of single-use plastic and promote bio-based and recyclable alternatives, tracking and recycling of old fishing nets and installing filters in rivers or storm water outlets. India has appropriated its initiatives in expectation of achieving the global expectations such as the UN Sustainable Development Goal (SDG) Target 14.1 eliminating Marine litter by 2025. MARPOL annex V provides regulations regarding marine litter, especially with ship-generated waste. Global efforts such as the Global Partnership on Marine Litter (GPML) and the Clean Seas campaign also aims to outreach the public on the issue of marine

pollution (Stoll *et al.*, 2022). The G7 and G20 Action Plans focus on stakeholder participation, waste minimization, and sensitization campaigns. Solid Waste Management Rules (2024) as well as Plastic Waste Management Rules (2021) in India require segregation of waste, recycling of waste and Extended Producer Responsibility (EPR) in order to limit plastic waste. Enhancing waste collection methods, stricter enactment of regulations and raising awareness through community cleanups is a most optimal way to minimize the battle against marine pollutants.

The marine and coastal ecosystems are complex and dynamic ecosystems that offer ecological and commercial values with services by maintaining human wellbeing. Presently, all oceans and many coastal zones are negatively impacted by various types of natural and anthropogenic activities. Urbanization and industrialization are identified as key drivers for human-induced pollution, including plastic debris accumulation in the marine and coastal habitats. The present study emphasizes the significant role of cyclonic events in the redistribution of marine plastic debris along the Chennai coastline. The occurrence of household plastic waste in post-cyclonic sediments suggests that both land-based and ocean-based sources contribute to the pollution problem. Riverine flow serves as a major conduit for plastic waste transport during extreme weather events, further exacerbating pollution levels. Given the rising frequency of cyclones and increasing plastic pollution, there is a pressing need for improved waste management strategies, beach litter policies, and mitigation measures to address marine plastic debris in the coastal areas.

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