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Microplastics in India: A Review of Chemical Perspectives and Finding the Antidote in Policies

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Abstract The world grapples with an overwhelming burden of plastic pollution, as evidenced by its annual production exceeding 430 million tonnes. Alarming statistics reveal that two-thirds of this production comprises short-lived items that swiftly transform into waste, inundating our oceans and, alarmingly, infiltrating the human food chain (source: UNEP). The relentless influx of microplastics, estimated at an annual emission rate of 3 million tonnes and an accumulated ocean floor presence of 14 million tonnes, poses a grave threat in our rapidly evolving world. It disrupts the everyday functioning of both humans and other organisms, while also wreaking havoc on our natural environment and its crucial components. This review article illuminates the extensive research conducted to shed spotlight on this particular menace in a distinctive geographical context, namely India. It zooms in on the ramifications for water bodies and coastline pollution, which have created a cascade of problems for both the environment and the local biodiversity. Towards its conclusion, the article underscores policy recommendations put forth by esteemed organizations like the United Nations Environment Programme (UNEP) and the Organisation for Economic Co-operation and Development (OECD), along with the corresponding actions taken by countries in alignment with these recommendations. Moreover, the article meticulously synthesizes qualitative and quantitative data extracted from a myriad of research and review articles, with a particular emphasis on the topography of India. In summary, this review article sheds light on the pressing issue of plastic pollution, with a special focus on microplastics, and its repercussions on the distinctive landscape of India. It underscores the significance of policy decisions and their effective implementation to address this urgent environmental crisis. Plastic pollution remains a global challenge, necessitating collective efforts at both national and international levels to mitigate its far-reaching consequences.

Keywords: *microplastics,indian topography,chemical impact,marine environment, policies'review*

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1. Introduction

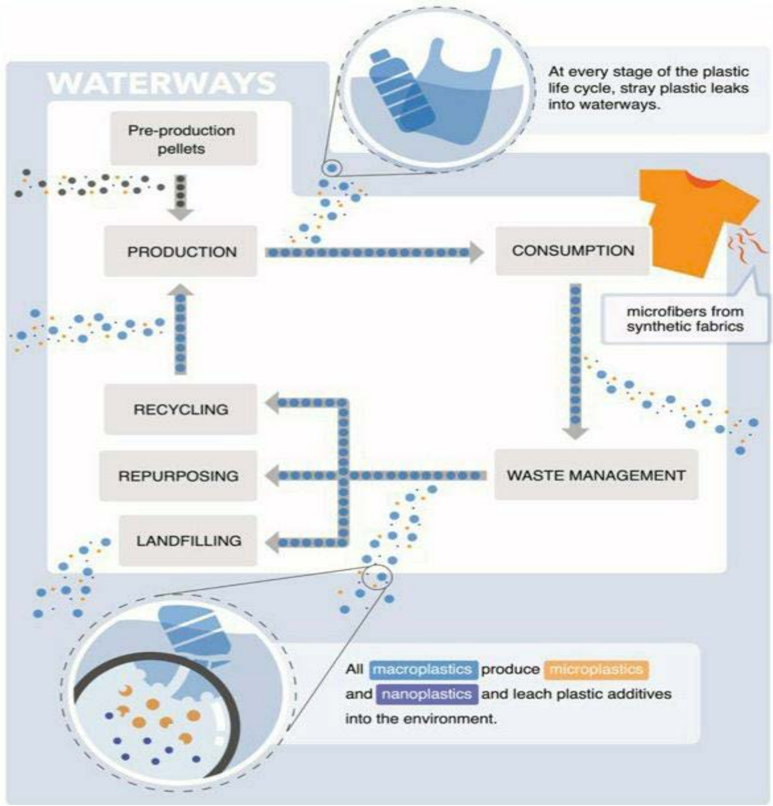
Plastics, since their inception in the modern world, have evolved into a pervasive and integral aspect of human existence and the global landscape. The groundbreaking discovery of Bakelite, the first synthetic plastic, in 1907, marked a pivotal moment in the realm of polymer science. [1] Plastics, owing to their exceptional durability, malleability, and cost-effectiveness, have found extensive utility across a spectrum of industries, encompassing textiles, automotive manufacturing, tire production, and printing, among others. However, the very attributes that rendered them invaluable have brought them into direct conflict with environmental preservation ideals.

Their remarkable resistance to degradation, coupled with poor waste management practices and their non-biodegradable nature, predisposes plastics to undergo photodegradation and fragment into smaller particles upon exposure to sunlight. These minute fragments, collectively known as microplastics, typically measuring less than 5mm, exhibit diverse characteristics, including varying shapes, colors, chemical compositions, sizes, and origins, thereby complicating their identification and treatment. Plastics are categorized by size as nano (1000 nm), micro (1000 mm), meso (10 mm), and macro (1 cm). [1]

As the prevalence of plastics has grown over time, they have emerged as a major contributor to a plethora of pervasive issues. They persist not only in immediate environments but also in remote regions like the Arctic, exerting substantial impacts on both human and ecological realms. The polymers found in microplastics are the primary culprits behind these environmental risks. With projections indicating an increase in plastic pollution in the future, concerns about their release during transportation and production processes have escalated, further exacerbating the persistence of microplastics alongside those already released.

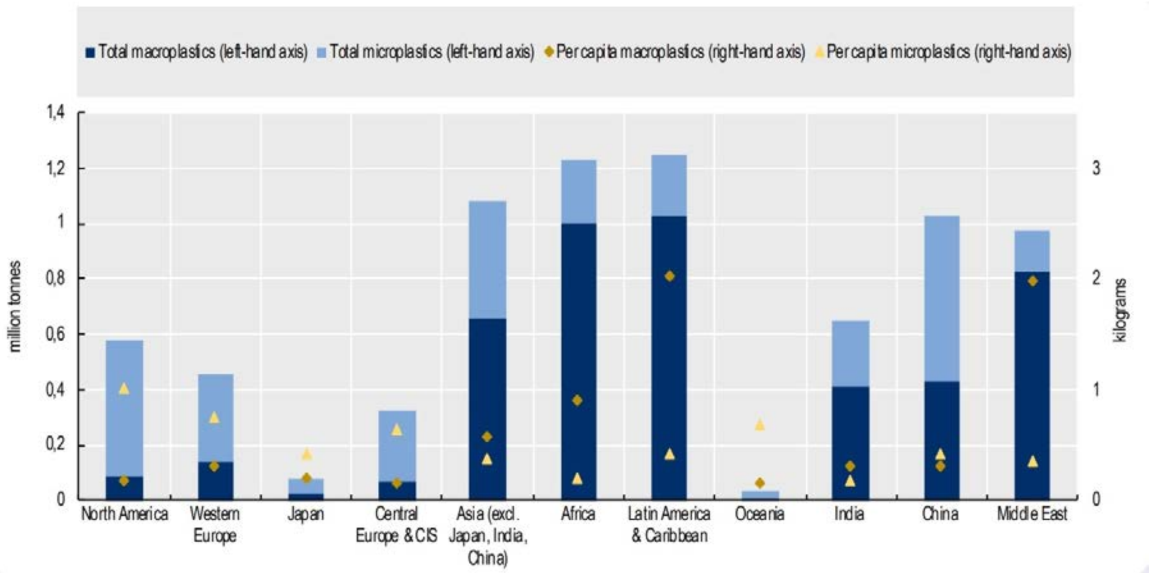
Although research concerning the influence of microplastics on marine life and ecosystems remains ongoing, their deleterious effects on marine environments are well-established. In coastal and marine settings, microplastics inflict severe harm on marine organisms, disrupt fisheries, contribute to the mortality of marine creatures through entanglement and ingestion of plastic fragments, facilitate the leaching of toxic chemicals, and introduce alterations at the cellular level. Microplastics possess the potential to perturb cell chemistry by inducing unintended mutations and toxicity within cells, thereby even affecting the composition of DNA. [3]

The annual global production of plastic products has soared from a mere 1.5 million tons in the 1950s to a staggering 335 million tons in 2016 (PlasticsEurope, 2018). This exponential growth underscores the urgent need for comprehensive strategies to address the escalating challenges posed by plastic pollution in our modern world. [4]



Ref: Schmaltz, E., Melvin, E. C., Diana, Z., Gunady, E. F., Rittschof, D., Somarelli, J. A., ... & Dunphy-Daly, M. M. (2020). Plastic pollution solutions: emerging technologies to prevent and collect marine plastic pollution. *Environment international*, *144*, 106067.

Figure 1. Sources of marine pollution throughout the plastic lifecycle. [22]



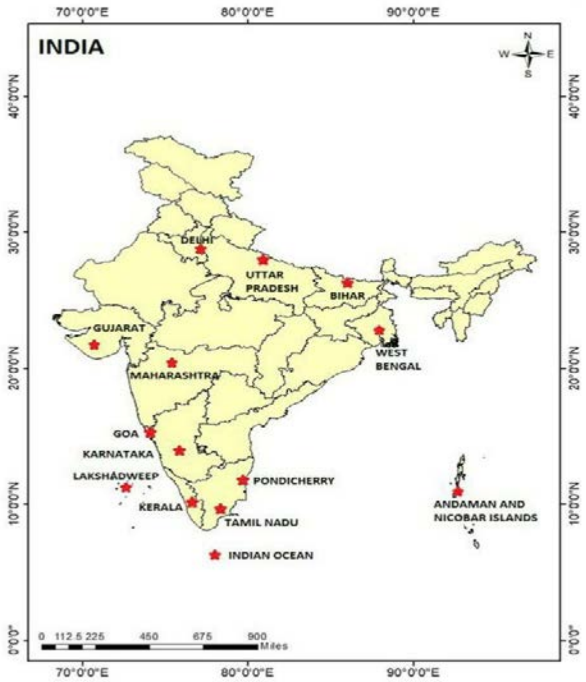
Ref: Policies to Reduce Microplastics Pollution in Water - OECD https://www.oecd.org/environment/waste/policy-highlights-policies-to-reduce-microplastics-pollution-in-water-focus-textiles-and-tyres.pdf

Figure 2. Geographical distribution of annual losses of macro and micro plastics (Mt) [2]

The plastics industry in India is rapidly expanding, with Western India emerging as the largest consumer, accounting for 47% of the total consumption. This substantial usage is primarily concentrated in states such as Gujarat, Maharashtra, Madhya Pradesh, Daman and Diu, Chhattisgarh, and Dadra and Nagar Haveli. [1]

In India as a whole, the annual per capita consumption of plastics stands at approximately 11 kg . India plays a significant role in the generation of plastic waste, contributing approximately 26 million metric tons annually. This places India at the forefront of the global community involved in plastic waste generation. [1]

The sources of this plastic production are multifaceted. Firstly, during industrial production, plastics are generated, and there is also a risk of accidental spillages that can release plastics into the environment. Secondly, during the use phase of products, microplastics are intentionally incorporated into items such as cosmetics, and these microplastics are subsequently discharged into sewage systems or directly into the environment. Thirdly, synthetic products undergo wear and tear during their continued use, resulting in the release of microfibers, such as those from textiles during washing, tire wear particles from road transport, and the chipping of paint from buildings. For instance, it is estimated that around 22 million tonnes of microfibers from synthetic textiles will enter the environment by 2050 due to this phenomenon. [2]



Ref: Vaid, M., Mehra, K., & Gupta, A. (2021). Microplastics as contaminants in Indian environment: a review. *Environmental Science and Pollution Research*, 1-28.

Figure 3. Microplastic studies conducted in different parts of India (highlighted with a red star)[1]

Various types of plastics are encountered in marine ecosystems, each with its distinct characteristics: [1]

- Low-density polyethylene (LDPE): This polymer is derived from ethylene (CH2=CH2) and exhibits a less tightly packed and organized structure.

- High-density polyethylene (HDPE): In contrast to LDPE, HDPE possesses a denser and more organized molecular structure.

- Polypropylene (PP): PP is another common plastic found in marine environments.

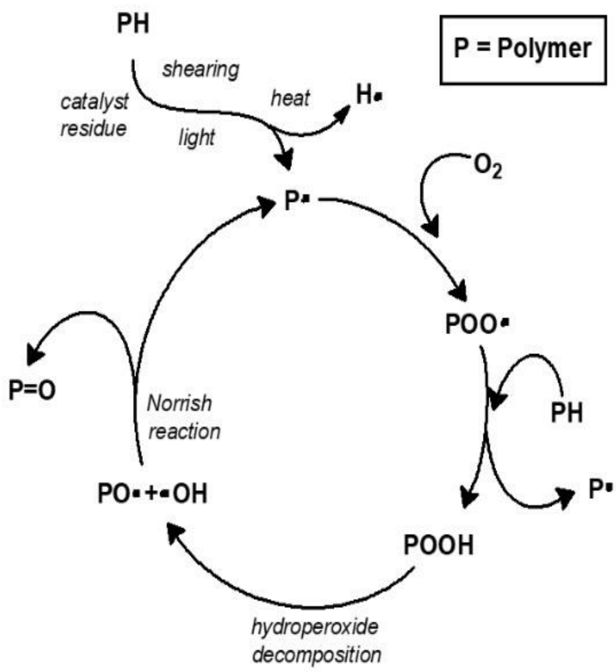
- Polystyrene (PS): This type of plastic is also present in marine ecosystems.

- Polyethylene terephthalate (PET): PET is recognized as a plastic type prevalent in marine settings.

- Polyvinyl chloride (PVC): PVC is among the plastics encountered in marine ecosystems.

The sources of microplastic pollution in marine environments predominantly originate from terrestrial sources such as beach litter, contributing to approximately 80% of the issue. [1] Notably, the fishing industry significantly relies on plastic equipment, primarily composed of polyethylene (PE), polypropylene (PP), and nylon materials, which are often disposed of carelessly at sea. As a result, approximately 18% of marine plastic debris is attributed to the fishing industry, while the remaining portion is primarily sourced from land-based origins, including beach litter.[1] Additionally, virgin resin pellets may unintentionally find their way into marine environments during ocean transport or via industrial runoff.

The formation of microplastics is driven by oxidative photodegradation, a process initiated by the combined effects of light and oxygen. This process causes polymer chains to break and become brittle over time, ultimately leading to the creation of microplastic particles. In the case of textiles, a similar phenomenon is referred to as "phototendering." [5,6,7] This degradation process significantly contributes to the proliferation of microplastics in marine ecosystems.



Ref: Chien, J. C. W. (1965). On the possible initiation of photooxidation by charge-transfer excitation. *The Journal of Physical Chemistry*, *69*(12), 4317-4325.

Figure 4. The cyclic mechanism of autoxidation [5]

Chain initiation

$$\text{Polymer} \longrightarrow P\bullet + P\bullet$$

Chain propagation

$$P\bullet + O_2 \longrightarrow POO\bullet$$
$$POO\bullet + PH \longrightarrow POOH + P\bullet$$

Chain branching

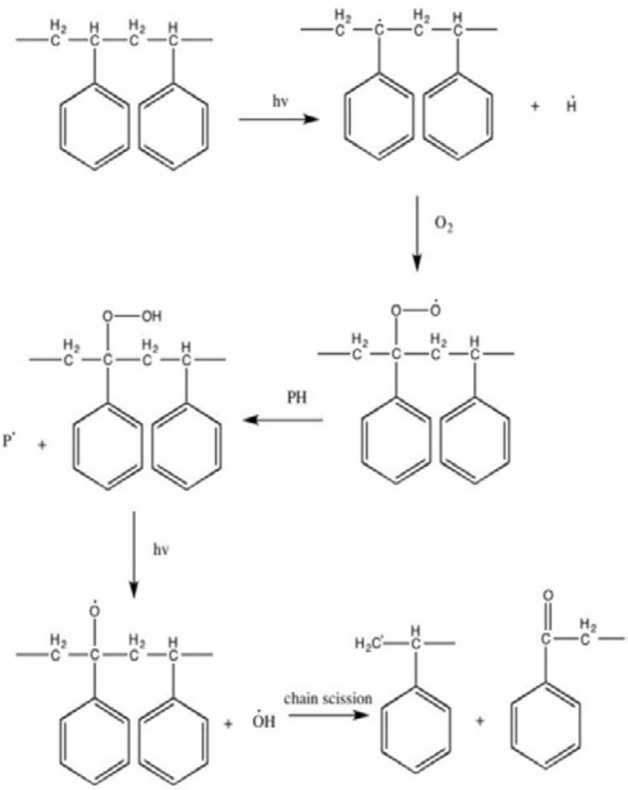
$$POOH \longrightarrow PO\bullet + OH\bullet$$
$$PH + OH\bullet \longrightarrow P\bullet + H_2O$$
$$PO\bullet \longrightarrow \text{Chain scission reactions}$$

Termination

$$POO\bullet + POO\bullet \longrightarrow \text{cross linking reaction to non-radical product}$$
$$POO\bullet + P\bullet \longrightarrow \text{cross linking reaction to non-radical product}$$
$$P\bullet + P\bullet \longrightarrow \text{cross linking reaction to non-radical product}$$

Ref: Smith, L. M., Aitken, H. M., & Coote, M. L. (2018). The fate of the peroxyl radical in autoxidation: how does polymer degradation really occur?. *Accounts of chemical research*, *51*(9), 2006-2013.

Figure 5. mechanism of oxidation of polymer [6]



Ref: Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene. *SpringerPlus*, *2*(1), 1-32.

Figure 6. Propagation steps in degradation of polystyrene [7]

2. Microplastics Along the Southeast and Southwest Coastline of India

South east coast

Plastics have become one of the most prevalent and enduring pollutants, infiltrating oceans and beaches globally through various channels, including river transport, atmospheric dispersion, beach littering, and direct introduction at sea via aquaculture, shipping, and fishing activities. In recent decades, plastics have emerged as a prominent component of marine debris, transcending geographical and temporal boundaries. Substantial volumes of plastic waste consistently mar aquatic environments, encompassing beaches, ocean waters, deep-sea sediments, freshwater lakes, and tributaries—a consequence primarily attributed to inadequate waste management practices.

The principal contributors to plastic pollution stem from both sea-based and land-based sources. Sea-based sources encompass shipping, fishing, and transportation activities, while land-based sources involve tourism, industrial discharges, and riverine inputs into coastal and oceanic regions. In general, minute plastic particles, either intentionally manufactured to be microscopic (known as primary microplastics) or resulting from the breakdown (through physical, chemical, and biological degradation) of larger plastic items, find their way into marine environments. [11] Notable processes contributing to microplastic formation include oxidative degradation triggered by UV solar radiation, thermal breakdown, and chemical degradation, often followed by microbial action. [11]

Specifically, in the context of beaches in southeast India, particularly in Tamil Nadu, which boasts the longest coastline spanning 1,076 kilometers, a comprehensive study was conducted across 25 beaches. [11] This investigation considered both point and non-point sources, including industries, tourism, and agriculture. The findings revealed that the average microplastic concentration along the coast of Tamil Nadu was approximately 46.6 ± 37.2 particles per square meter, a figure comparable to that reported by Jayasiri for the Mumbai coast in India (68.83 particles per square meter). [10] Notably, secondary microplastics, comprising 48% fragments and 24% fibers, dominated the samples. Fourier-transform infrared (FTIR) analysis identified four major polymer types, with polyethylene (PE) exhibiting the highest prevalence, followed by polypropylene (PP), polystyrene (PS), and nylon (NY). PE, widely used in plastic bottles, bags, and films, mainly originates from packaging and the degradation of rigid plastics. In contrast, PP, known for its low UV resistance and oxidative susceptibility, is used for various applications, including sports equipment, furnishings, pipes, and fishing nets. Microplastics such as PE and PP, along with polyester fibers, were also detected in the digestive systems of fish found at river mouths, highlighting the risks of toxic contamination and posing significant threats to endocrine health. [9,10,11]

South west coast

As reported by Lebreton, the Ganges River in India has earned the dubious distinction of being the world's second most polluted river, discharging a staggering 1.05×10^5 tons of plastic annually into the Indian Ocean. [12]

MP's have shown their presence in all the samples collected throughout the stretch of north Indian river-Jhelum in the sizes of 5mm to 300um indicating their continued weathering which has further found its way into drinking water of people, especially downstream areas. [13] Investigations into the river systems in southern India, stemming from the Ganges, such as the Kosathalaiyar and Adyar rivers in major cities like Chennai, have revealed elevated levels of microplastics. These heightened levels are attributed to informal settlements by migrant populations along the riverbanks, the prevalence of industries, and inadequate waste management and wastewater treatment practices. [12]

Microscopic analysis, validated by blank samples, identified 447 microplastic particles, with fibrous materials accounting for 64.1% of the total. The estimated annual input of a staggering 11.6 trillion microplastic particles via the Adyar River into the Bay of Bengal is cause for alarm and significantly surpasses the input from the Ganges, as documented by Napper. [12] Another study delved into the microplastic scenario along the west coast, with a particular focus on the Kerala coastline, given its substantial contribution to the national economy. Various sites were sampled, taking into account different activities such as tourism, fishing, urbanization, and shipping. A total of 339 microplastic particles were quantified in these coastal waters, with their abundance varying between 0.22 and 3.58 particles per cubic meter, averaging 1.25 ± 0.88 particles per cubic meter (n = 14). [14]

Fourier-transform infrared (FTIR) analysis unveiled notable variations in polymer types among samples collected from sediment, water, and marine fish. Polyethylene emerged as the most prevalent plastic type in beach sediment, coastal waters, and fish samples, reflecting its widespread use as packaging material, aligning with global studies. Polypropylene (PP) followed as the next abundant plastic type found in both beach sediment and coastal waters, but it was absent in fish gut samples (21.4% of which contained microplastics). [15]

The substantial presence of polyethylene (PE) fibers in coastal waters and the digestive tracts of fish underscores the high potential for toxicity due to leaching and the bioaccumulation of plastic additives in this coastal environment. Additionally, the high sorption rate of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) by polyethylene poses an additional threat of bio-magnification in the tertiary consumers of the food chain. [15]

Among the various isolated microplastic materials gathered from the coastal environment, polyethylene exhibited the highest mean elemental concentrations of Cd, Cr, Hg, and Pb, while polystyrene (PS) recorded the highest mean elemental concentrations of Fe, Sb, Ti, and Zn. This study underscores the potential of plastic debris as a source of toxic metals to aquatic organisms and the marine food chain, amplifying concerns regarding environmental contamination. [15]

Ecological risk analysis

The ecological risk posed by microplastics (MPs) found in coastal sediments has been evaluated using a comprehensive analysis of metadata, employing three key indices: the Polymer Hazard Index (PHI), Pollution Load Index (PLI), and Potential Ecological Risk Index (PERI). [16] These indices provide a quantitative assessment of sediment quality and the associated threat levels. In this context, the coastal regions of Tamil Nadu, Maharashtra, and Kerala exhibited notably high PHI values, exceeding 1000. [16] This elevated risk is primarily attributed to the presence of polymers such as polyamide (PA) and polystyrene (PS), which carry high hazard scores. According to PLI values, sediments along the West Coast of India (WCI) were found to be moderately contaminated with MPs, while those along the East Coast of India (ECI) showed comparatively lower contamination levels. [16] The PERI values indicated a substantial ecological risk in both terrestrial and marine sediments along the Indian coast, arising from the combined presence of various MP polymers in the sediment matrix. This underscores the significance of the ecological challenges posed by these polymers. The distribution and transportation of MPs are significantly influenced by the unique ocean dynamics and monsoon climate patterns in the northern Indian Ocean. [16] Additionally, the abundance and composition of various polymer types of MPs along the Indian coast are closely linked to diverse human activities on both land and sea, further complicating the ecological risks associated with these pollutants.

Ref: Robin, R. S., Karthik, R., Purvaja, R., Ganguly, D., Anandavelu, I., Mugilarasan, M., & Ramesh, R. (2020). Holistic assessment of microplastics in various coastal environmental matrices, southwest coast of India. Science of the Total Environment, 703, 134947.

Figure 7. Stereomicroscopic images of different types of microplastic particles found in the coastal waters, beach sediments and fish gut along Kerala coast [15]

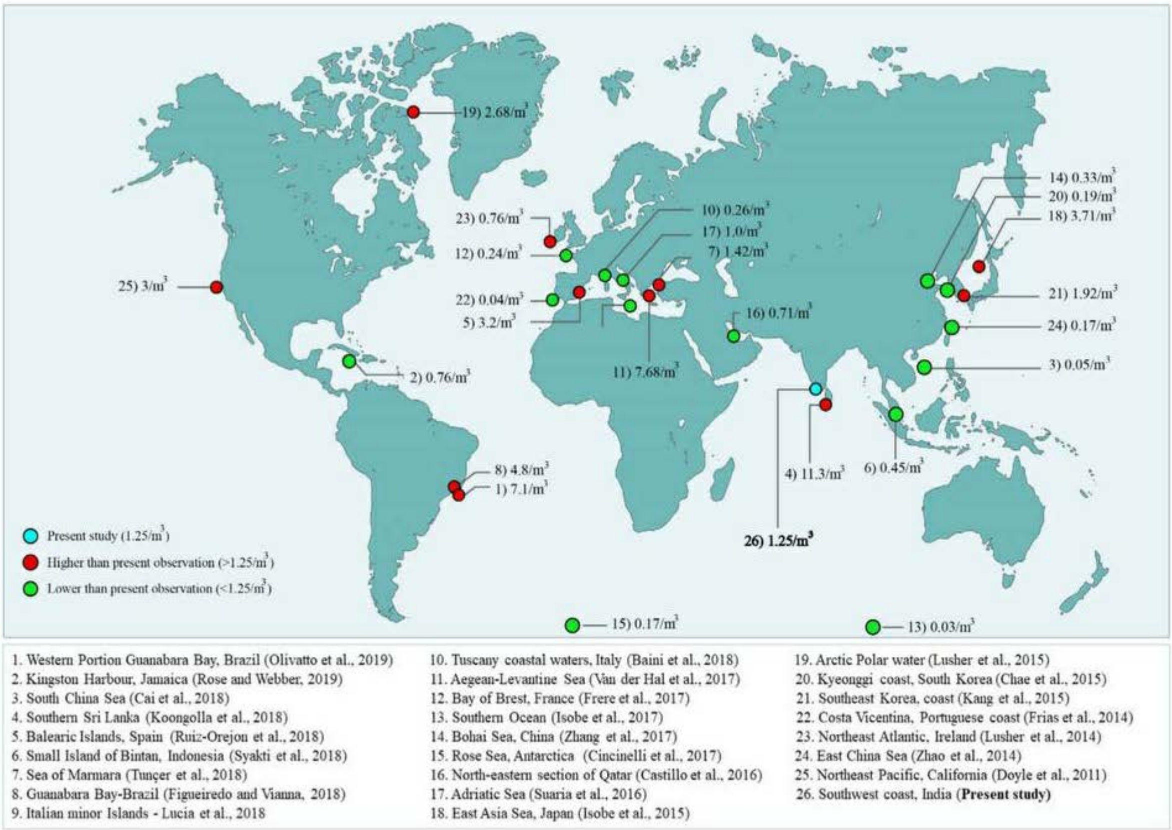


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Figure 8. global distribution of mean microplastic particles(particles/m^3) in the coastal waters and comparison with present study [15]

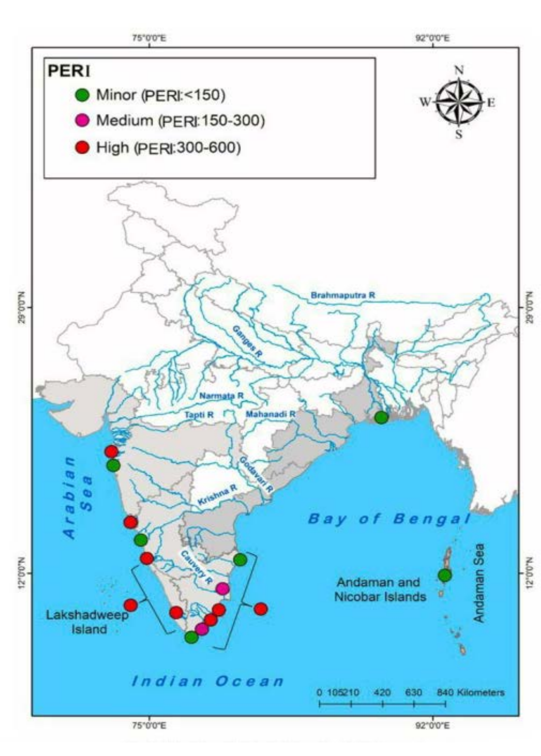

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Figure 9. Potential Ecological Risk Index along the Indian coast [16]

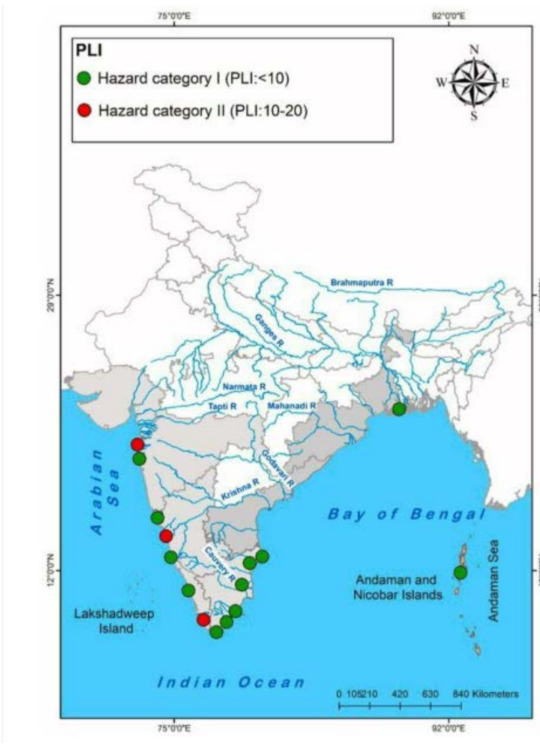

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Figure 10. Pollution Load Index along the Indian coast [16]

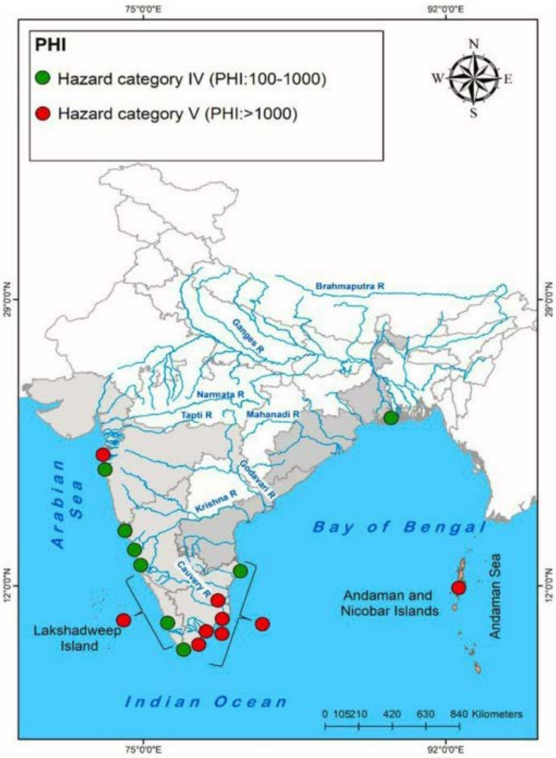


Fig. 5. Polymer hazard index along the Indian coast.

Ref: Ranjani, M., Veerasingam, S., Venkatachalapathy, R., Mugilarasan, M., Bagaev, A., Mukhanov, V., & Vethamony, P. J. M. P. B. (2021). Assessment of potential ecological risk of microplastics in the coastal sediments of India: a meta-analysis. *Marine Pollution Bulletin*, *163*, 111969.

Figure 11. Polymer Hazard Index along the Indian coast [16]

Assessing Human Health Risks: A Special Focus on Salt Consumption

The research encompassed an analysis of ten different Indian commercial salt brands, revealing the presence of microplastics (MPs) in various forms, including fragments, fibers, and pellets. Utilizing Fourier-Transform Infrared Spectroscopy (FT-IR), the study identified a prevalent abundance of MPs composed of cellophane (CP), polystyrene (PR), polyamide (PA), and polyarylether (PAR). [17]

To assess the potential toxic effects of these MPs, experiments were conducted using human embryonic kidney cells (HEK-293) through the MTT Assay. It's noteworthy that, according to World Health organization (WHO) guidelines, adults typically consume over 5 grams of salt daily, translating to an estimated ingestion of approximately 1000 microparticles from table salt alone each year. [17] During the course of experimentation, cells treated with MPs exhibited detachment and mortality within 24 hours. The MPs disrupted the epithelial cell layer, leading to damage to the cell membrane and consequent release of cytoplasmic constituents, ultimately inducing apoptosis. [17]

Furthermore, it was observed that ingestion of less than 10% of MPs resulted in notable health impacts in the form of inflammation in organisms. Mammalian models also experienced hindered growth of healthy cells due to damage to the immune system. Conversely, the accumulation of MPs in tissues such as the liver, kidney, and gut led to impairments in energy and lipid metabolism in mice. Additionally, MPs were found to potentially compromise the antioxidant defense mechanisms in mice, shedding light on the need for further research in this area. [17]

The routes of ingestion have been further highlighted thorough dominant pathways of drinking water,air inhalation and food consumption ,where the actual numbers have been supposed to be tangibly greater than the experimental evidences.The major source of microplastic ingestion in human body has been through food especially raw materials like vegetables,fruits etc and ostensibly through air and water but in insignificant amounts.The average daily exposure ranged from 122.25 ± 177.38 mg to 202.80 ± 294.25 mg per person, with most of it attributed to food ingestion. [18]

Charting the Path Forward: Initiatives for the Future

Recognizing the pervasive threat posed by microplastics to both human life and the environment, a collective effort involving OECD and non-OECD nations, as well as concerted actions by the United Nations (UN) and its affiliated organizations, has been initiated to adopt conscious strategies for mitigation and adaptation.

For instance, in the United States, many states have taken measures to ban single-use plastics, aligning with the broader global efforts. Similarly, the European Union member states imposed a ban on single-use plastics starting from July 2021. In India, the 'plastic waste management rules' have imposed legal restrictions on the use of single-use plastics, prohibiting the manufacture, stocking, distribution, or sale of carry bags made from virgin or recyclable plastics. Moreover, the thickness of plastic carry bags has been increased, from 50 to 75 microns, and then to 120 microns, effective as of December 31, 2022. [20]

Furthermore, the UN Plastic Collective (UPC) is a voluntary initiative launched by the UN Environment Programme (UNEP) in collaboration with the Confederation of Indian Industry and WWF-India. This collective aims to minimize the negative impacts of plastics on the ecological and social well-being of the planet. A UNEP report from 2021 titled 'From Pollution to Solution' has cautioned against the potential genetic and physiological alterations caused by the chemicals in microplastics in both humans, particularly women, and marine life. It underscores the urgency of prioritizing action in this nascent field.

UNEP has also launched the Clean Seas Campaign, which seeks to drive change at the consumer, policymaker, and business levels by forging alliances with organizations such as the World Health Organization (WHO) and others [21] This campaign addresses microplastic pollution stemming from various industries, including cigarettes, cosmetics, and fashion, with the aim of promoting sustainability and collaborative efforts to combat this issue.

In the context of OECD countries, their approach to addressing the microplastic issue involves several key factors: [2]

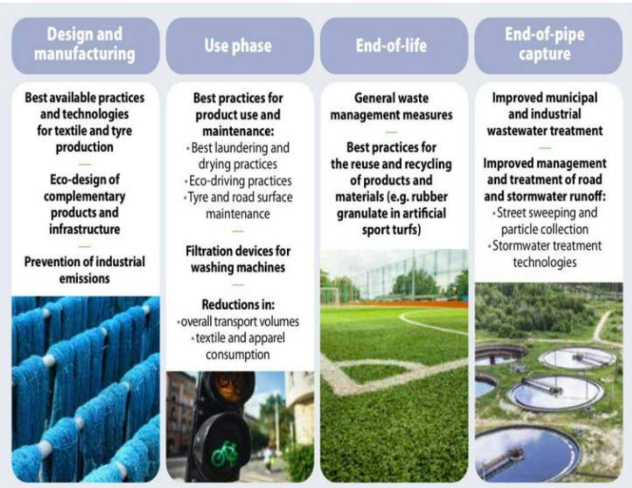
1. Support for Research: OECD countries invest in research projects to close knowledge gaps on microplastic occurrence, risks to the environment and human health, and mitigation solutions. They also facilitate data sharing through multi-stakeholder platforms to support research and encourage cross-industry collaboration.

2. Harmonization: Efforts are made to harmonize definitions and methods for sampling and characterizing microplastics, simplifying data aggregation.

3. Consumer Education: OECD countries leverage consumer education and awareness-raising initiatives to influence consumer behavior towards sustainable product use, reducing microplastic emissions during product usage.

4. Regulatory Interventions: Some OECD nations introduce ad-hoc regulations, such as product requirements for washing machines, particularly those used in households, commercial establishments, or industries. For example, Australia and France have mandated the phased introduction of microfiber filters on new washing machines.

For developing countries like India, addressing challenges such as climate change and pollution presents a complex dilemma, as they must balance the imperative of development and economic welfare for their large populations with the pressing need for climate protection. This necessitates strict regulations and checks on climate financing from developed countries, which have historically contributed significantly to the climate crisis. Additionally, there is a growing need to fill research gaps and standardize data to inform more effective policymaking. Furthermore, consumers must be made aware of their role in sustainable and responsible product consumption, especially in a world characterized by rapidly changing fashion trends and a disposable consumer culture.



Ref: Policies to Reduce Microplastics Pollution in Water – OECD [2] https://www.oecd.org/environment/waste/policy-highlights-policies-to-reduce-microplastics-pollution-in-water-focus-textiles-and-tyres.pdf

Figure 12. Overview of Microplastic mitigation entry points and actions (for textiles and tyres)

3. Conclusion

The review article provides an extensive overview of various aspects of microplastic pollution research in Indian marine environments, alongside an examination of existing policy frameworks both in India and worldwide aimed at addressing this overarching challenge of climate change. While sources and causes of microplastic pollution and climate change have been identified, as evidenced in recent events like the UN Global Stocktake ahead of the G-20 Summit and COP-28, there remains a pressing need for extensive collaboration and cooperation between developing and developed nations in terms of climate financing and technology transfer to effectively address region-specific issues. Additionally, there is a call for standardization of criteria to harmonize datasets collected from various research endeavors. This standardization is essential to ensure the development of efficient and financially viable policies within India. The review article underscores the growing urgency of addressing the microplastic issue on both micro and macro scales, calling for a systematic approach that combines technology implementation with heightened public awareness. The article emphasizes that the responsibility for mitigating microplastic pollution extends not only to policymakers and the formulation of stringent policies but also to the conscious decision-making of the general populace in terms of consumption and sustainability, particularly in reducing microplastic production at the demand side. Furthermore, the article advocates for extending mitigation efforts to encompass all species, including humans at the apex of the ecological pyramid, while simultaneously regulating industries and holding them accountable to reduce the supply-side contribution to microplastic pollution.

Conflict of Interest Statement

The authors confirm that their work has not received financial support from any organizations. Upon manuscript submission, no conflicts of interest need to be declared.

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