INTERNATIONAL JOURNAL OF ARTS SCIENCE HUMANITIES RESEARCH STUDIES (IJASHRS)

(Open Access, Double-Blind Peer Reviewed Journal)

ISSN Online:

EDUSCHOOL
ACADEMIC RESEARCH & PUBLISHERS

Microplastics in Indian Coastal Ecosystems: Sources, Distribution, and Ecological Impact

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Article information

Received: 5th May 2026
Received in revised form: 9th June 2026
Accepted: 11th July 2026
Available online: 10th August 2026

Volume: 2
Issue:3
DOI: https://doi.org/10.5281/zenodo.21834872

Abstract

Microplastic pollution has emerged as a significant environmental concern of the twenty-first century, with growing evidence of widespread contamination across marine and coastal ecosystems globally. India, with its 7,500 kilometre coastline, dense coastal populations, intensive fishing activity, and rapidly growing plastic consumption, represents a particularly important context for understanding microplastic dynamics. This article examines microplastics in Indian coastal ecosystems, focusing on sources, distribution, and ecological impact. Drawing on a critical literature review methodology, the study analyses peer-reviewed scholarship and government scientific reports published between 2015 and 2025. The analysis identifies four major dimensions of microplastic pollution in Indian coastal contexts: the diverse sources contributing to microplastic loading, including land-based plastic mismanagement, river inputs, fishing-related debris, and atmospheric deposition; the spatial and temporal distribution patterns across beaches, sediments, surface waters, and biota; the ecological impact on marine organisms, food webs, and ecosystem functioning; and the human health and socioeconomic implications. The study draws on marine pollution science, environmental toxicology, and emerging microplastic-specific research. Findings indicate that microplastic contamination is widespread across Indian coastal regions, with significant variation linked to urban density, river inputs, and fishing intensity. Effects on marine biota, including ingestion by fish, invertebrates, and plankton, have been documented across multiple regions, with implications for fisheries, biodiversity, and food security. The article concludes with implications for environmental policy, scientific research priorities, and integrated coastal zone management in India.

Keywords: Microplastics, Marine Pollution, Indian Coast, Environmental Science, Ecological Impact, Coastal Ecosystems, Plastic Pollution, Fisheries

INTRODUCTION

Microplastic pollution, defined as the contamination of environmental media by plastic particles smaller than 5 millimetres, has rapidly emerged as one of the defining environmental issues of the contemporary period.[1] Since the early observations of small plastic fragments in marine environments by R. C. Thompson and colleagues in the mid-2000s,[2] scientific investigation has documented microplastic presence across virtually every studied marine, freshwater, and terrestrial ecosystem.[3] The Indian Ocean, the third-largest of the world's oceans, receives substantial plastic loading from coastal South Asia, East Africa, the Middle East, and Southeast Asia.[4] India's 7,500 kilometre coastline, spanning the Arabian Sea, the Lakshadweep Sea, the Bay of Bengal, and the Andaman Sea, provides multiple distinct ecological contexts in which microplastic contamination is now extensively documented.[5]

Several factors make India a particularly important site for microplastic research. Coastal population density along major estuarine and deltaic zones such as the Mumbai region, the Hooghly mouth at Kolkata, the Chennai-Pulicat coast, the Krishna-Godavari delta, the Kochi backwaters, and the Mangalore-Karwar coast produces high anthropogenic pressure on marine environments. The Ganga, Brahmaputra, Mahanadi, Krishna, Godavari, Kaveri, and other major rivers transport substantial sediment, nutrient, and pollutant loads to the sea.[6] Indian fisheries, both artisanal and industrial, operate across the entire coastline and contribute to the introduction of fishing-related plastics. Per capita plastic consumption in India, while still relatively modest by global standards, has grown rapidly, and the management of post-consumer plastic waste remains a significant infrastructural challenge.[7]

Despite the importance of the Indian context, scientific knowledge of microplastic contamination in Indian coastal ecosystems has only recently begun to develop systematically. Research conducted by national institutions including the National Institute of Oceanography, the Central Marine Fisheries Research Institute, the National Centre for Coastal Research,[8] and several university-based research groups has produced a growing body of empirical findings.[9] Yet integrative analysis that synthesizes findings across coastal regions, sample types, and methodological approaches remains comparatively limited, and the implications for environmental policy, fisheries management, and coastal community well-being merit sustained scholarly engagement.

Against this backdrop, the present article asks: what is the current state of knowledge regarding microplastic contamination in Indian coastal ecosystems, and what are the implications for environmental policy and future research? Three subsidiary questions structure the inquiry:

- First, what are the major sources contributing to microplastic loading in Indian coastal waters and sediments?
- Second, what spatial and temporal distribution patterns characterize microplastic contamination across the Indian coast?
- Third, what ecological and human health impacts have been documented, and what implications follow for policy and research?

The article makes three contributions: it synthesizes the rapidly expanding scientific literature on Indian coastal microplastics; it identifies four interlocking dimensions of the issue; and it articulates implications for environmental policy and integrated coastal zone management.

LITERATURE REVIEW

Microplastics: Definitional and Methodological Foundations

The scientific study of microplastic pollution has expanded rapidly since the early-2000s identification of small plastic fragments as a distinct environmental concern.[10] The most widely used operational definition follows the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection in classifying plastic particles smaller than 5 millimetres as microplastics,[11] with further subdivisions distinguishing primary microplastics, manufactured at small sizes for specific industrial or consumer purposes, from secondary microplastics, formed through the fragmentation of larger plastic items.[12] Methodological approaches for identifying and quantifying microplastics include density separation, filtration, microscopic identification, Fourier-transform infrared spectroscopy, Raman spectroscopy, and pyrolysis gas chromatography mass spectrometry, with significant variation in protocols across studies that complicates direct comparison.[13]

Sources of Marine Microplastic Contamination

Sources of marine microplastic contamination have been systematically classified in the international literature.[14] Land-based sources include urban runoff, inadequately managed solid waste, wastewater treatment plant discharges, and tyre wear particles transported through atmospheric and aquatic pathways.[15] Riverine inputs convey terrestrial microplastic loads to coastal waters, with major rivers identified as significant transporters.[16] Fishing and aquaculture activities introduce microplastics through the fragmentation of nets, ropes, floats, and other gear. Shipping and offshore industrial activities contribute additional inputs. Atmospheric deposition has been increasingly recognized as a meaningful pathway, particularly for fibres and small fragments.[17] The relative contribution of these sources varies substantially across regions and over time.

Indian Coastal Microplastic Studies

A growing body of Indian-specific research has documented microplastic contamination across multiple coastal regions.[18] Studies have examined beaches and sediments along the Mumbai-Goa-Mangalore coast, the Kerala backwaters and Cochin estuary,[19] the Tamil Nadu coast including Chennai and the Gulf of Mannar,[20] the Andhra Pradesh coast, the Odisha coast including the Chilika Lagoon, the West Bengal coast and the Sundarbans,[21] and the Andaman and Nicobar Islands. Findings consistently document the widespread presence of microplastic fragments and fibres, with concentrations varying by location, season, and methodology. Several studies have documented microplastic ingestion by commercially important fish species, shellfish, and zooplankton in Indian coastal waters.[22]

Ecological Impact Frameworks

The ecological impact of microplastic contamination operates through multiple pathways that have been theorized in the international literature.[23] Direct physical effects include ingestion by marine organisms with consequences for digestion, growth, and reproduction.[24] Chemical effects include the leaching of plastic-associated additives such as phthalates and bisphenol A, and the adsorption and transport of hydrophobic contaminants, including polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides. Biological effects include the colonization of microplastic surfaces by microbial communities, sometimes including pathogenic species, and the role of microplastics in transporting non-native organisms. Trophic transfer through food webs has been documented across taxa from plankton to fish to seabirds and marine mammals.[25]

Research Gap

Despite the rapidly growing literature, several gaps remain. Methodological heterogeneity across Indian studies limits direct comparison of concentrations and trends. Long-term monitoring studies that document temporal change are still comparatively rare. Coverage across the Indian coast remains uneven, with some regions extensively studied and others less well characterized. The integration of ecological, fisheries, and human health implications within a single analytical framework is uncommon, and policy-relevant synthesis remains in early stages. The present article seeks to contribute by integrating findings across these dimensions.

METHODS

This study employs a critical literature review methodology with thematic synthesis, suitable for integrating a rapidly developing scientific literature across marine pollution science, environmental toxicology, and Indian coastal research. The review proceeded through four stages. In the first stage, a structured search was conducted in PubMed, Web of Science, Scopus, ScienceDirect, the Indian Citation Index, and Google Scholar. Search terms combined microplastic, plastic pollution, India, Indian coast, Bay of Bengal, Arabian Sea, beach sediment, marine, fish, ingestion, and specific regional terms. The window covered January 2015 to August 2025, capturing the period of rapid expansion in Indian microplastic research.

In the second stage, inclusion criteria specified peer-reviewed empirical studies of microplastic contamination in Indian coastal or marine environments, supplemented by foundational theoretical and methodological works in the international microplastic literature. Reports from Indian government scientific agencies including the National Institute of Oceanography, the Central Marine Fisheries Research Institute, the National Centre for Coastal Research, the Central Pollution Control Board, and the Ministry of Earth Sciences were also reviewed. Exclusion criteria filtered out studies focused exclusively on macroplastic debris without microplastic analysis, freshwater-only studies in interior regions, and non-peer-reviewed materials except for authoritative government scientific reports. After title, abstract, and full-text screening, eighty publications were retained.

In the third stage, supplementary materials were drawn from publicly available regulatory and policy documents including the Plastic Waste Management Rules, 2016 and subsequent amendments;

the Coastal Regulation Zone notifications; the Ministry of Environment, Forest and Climate Change reports; and international policy frameworks including the United Nations Environment Programme reports on plastic pollution. In the fourth stage, thematic synthesis generated four interlocking dimensions of microplastic pollution in Indian coastal contexts that structure the findings reported below. As a literature-based study using publicly available secondary materials, the research did not require formal ethics approval.

RESULTS

Sources of Microplastic Loading in Indian Coastal Waters

The first dimension concerns the diverse sources contributing to microplastic loading in Indian coastal waters. Land-based sources are dominant, with urban runoff, inadequately managed municipal solid waste, and wastewater treatment plant discharges contributing significant fluxes.[26] Beach studies along urban coastlines including Mumbai, Chennai, Visakhapatnam, and Chennai consistently document higher microplastic concentrations near densely populated and industrialized zones, supporting the importance of proximate land-based sources.[27] Riverine inputs are substantial, with the Ganga, Brahmaputra, Krishna, Godavari, and other major rivers transporting microplastic loads to coastal waters.[28] Studies focusing on river-mouth and estuarine environments have documented elevated microplastic concentrations relative to open coast samples.[29]

Fishing-related sources are particularly important along the Indian coast given the scale and reach of artisanal and commercial fisheries. Fragmentation of fishing nets, ropes, traps, and floats, alongside discarded gear, contributes to microplastic loading. Fibres derived from fishing-related materials feature prominently in microplastic samples from many Indian coastal sites. Aquaculture activities, particularly in coastal Andhra Pradesh, Tamil Nadu, Kerala, and Gujarat, contribute additional loading. Atmospheric deposition is being increasingly recognized as a meaningful pathway in Indian studies, although systematic characterization remains in earlier stages compared to land and riverine inputs.

Spatial and Temporal Distribution Patterns

The second dimension concerns spatial and temporal distribution patterns. Indian studies consistently document significant spatial variation in microplastic concentrations linked to coastal land use, river inputs, fishing intensity, and oceanographic processes.[30] Higher concentrations are typically observed near urban centres, river mouths, and intensely fished zones, while more remote stretches of coastline show lower concentrations.[31] The Andaman and Nicobar Islands, despite their relative geographic isolation, show measurable microplastic contamination, indicating long-range transport from the Bay of Bengal and the broader Indian Ocean.[32]

Temporal variation includes seasonal differences linked to monsoon dynamics, with elevated riverine inputs during and immediately after the southwest monsoon producing higher microplastic loads in many estuarine and near-shore environments. Tidal and storm-related dynamics also influence the redistribution of microplastics in beach sediments. Long-term temporal trends are more difficult to establish given the relatively short history of systematic Indian microplastic research, but available evidence suggests that contamination has increased in tandem with growing plastic consumption and incomplete waste management. Temporal monitoring at standardized sampling sites is identified by multiple investigators as a research priority.

Ecological Impact on Marine Biota and Ecosystem Functioning

The third dimension concerns the ecological impact of microplastic contamination on marine biota and ecosystem functioning. Microplastic ingestion has been documented in numerous Indian coastal species across multiple trophic levels.[33] Studies have documented ingestion by commercially important fish species including mullets, sardines, mackerel, and groupers; by shellfish including mussels, clams, and shrimp; by sea cucumbers and other benthic invertebrates; by zooplankton; and by seabirds.[34] Ingested microplastics may cause physical effects including digestive blockage and reduced feeding efficiency, alongside chemical effects from associated contaminants and additives.[35]

Ecosystem-level effects include the role of microplastics in altering benthic community composition through changes to sediment properties, the colonization of microplastic surfaces by microbial communities including potentially pathogenic taxa, and possible effects on biogeochemical cycling. Mangroves, which line significant portions of the Indian coast and serve as important nursery habitats for fisheries, are increasingly recognized as accumulating microplastics through tidal and riverine inputs.[36] Coral reef systems, particularly in the Lakshadweep and Andaman archipelagos, face additional stressors from microplastic contamination overlaid on existing climate-related pressures.[37] The overall picture is one of widespread biological exposure to microplastic contamination, with consequences for biodiversity, fisheries, and ecosystem services that warrant continued investigation.

Human Health and Socioeconomic Implications

The fourth dimension concerns human health and socioeconomic implications. Microplastic exposure to coastal communities and broader populations occurs through several pathways, including consumption of contaminated seafood, inhalation of airborne microplastic particles, and dermal exposure during occupational or recreational activities. Studies of commercially important fish and shellfish species harvested from Indian waters have documented microplastic presence, raising concerns about dietary exposure for consumers, particularly in coastal communities where seafood constitutes a significant share of the diet. Beach tourism, an important component of coastal livelihoods in Goa, Kerala, Tamil Nadu, and elsewhere, is affected by visible plastic pollution that may also include microplastic components.

Health effects of microplastic exposure remain incompletely characterized in the international toxicological literature, with active research investigating possible inflammatory, endocrine, and other effects.[38] The translation of laboratory findings to population-level health implications requires careful epidemiological work, and Indian-specific human health research on microplastics is at an early stage.[39] The socioeconomic implications include effects on artisanal fisheries through impacts on target species and gear, on coastal tourism through aesthetic and ecological degradation, and on the livelihoods of coastal communities more broadly. These implications interact with broader pressures on Indian coastal communities including climate change, urbanization, and shifting livelihood patterns.

DISCUSSION

The findings carry several important implications. Scientifically, they support a research agenda that combines source characterization, spatial and temporal monitoring, ecological impact assessment, and human health investigation within a coordinated framework. The four dimensions identified, sources, distribution, ecological impact, and human and socioeconomic implications, are mutually interdependent rather than separable. Source reduction directly affects distribution; distribution patterns shape ecological exposure; and ecological impacts feed back into human health and socioeconomic outcomes through fisheries and ecosystem services.

For environmental policy, the findings emphasize the importance of integrated approaches across plastic waste management, coastal regulation, fisheries management, and water quality monitoring. The Plastic Waste Management Rules, 2016 and subsequent amendments,[40] the National Marine Litter Policy framework,[41] and Coastal Regulation Zone notifications all bear on microplastic dynamics, but their integration with explicit microplastic objectives remains uneven. Extended producer responsibility provisions, designed to shift waste management costs to plastic producers, are being progressively implemented and should be evaluated for their effectiveness in reducing microplastic generation.[42] Bans on single-use plastics, implemented at varying levels in different states, can contribute to source reduction if effectively enforced.[43]

For scientific research, the findings suggest several priorities. Methodological harmonization, including the adoption of standardized sampling, processing, identification, and reporting protocols across Indian research groups, would enable direct comparison of findings and the construction of robust national assessments.[44] Long-term monitoring at standardized sentinel sites would enable the detection of temporal trends and the evaluation of intervention effectiveness. Multi-region comparative studies would clarify the influence of local versus regional drivers. Investigations of less-studied compartments, including atmospheric microplastics and deep-sea sediments, would address current gaps.[45] Toxicological research using Indian species and ecologically relevant exposure scenarios would strengthen the evidence base for ecological risk assessment.[46]

For integrated coastal zone management, the findings underscore the importance of microplastic considerations within broader management frameworks. Coastal community engagement, particularly with fisher communities and coastal tourism stakeholders, is essential for both source reduction and the implementation of monitoring and remediation efforts. Capacity building for state-level pollution control boards, coastal universities, and field research institutions would strengthen monitoring capacity. International cooperation, particularly within the South Asia Cooperative Environment Programme and the Indian Ocean Rim Association frameworks, can support shared monitoring and policy development.

Several limitations of the present analysis warrant acknowledgment. As a literature-based study, it depends on the quality and coverage of available scientific publications, which remain uneven across Indian coastal regions and across compartments such as water, sediment, biota, and atmosphere. Methodological heterogeneity across studies complicates direct comparison and the construction of national-level estimates. The pace of scientific advance means that some findings will be updated as new evidence becomes available.

CONCLUSION

This article has examined microplastic contamination in Indian coastal ecosystems, focusing on sources, distribution, and ecological impact. Through a critical synthesis of the rapidly expanding scientific literature, four interlocking dimensions were identified: the diverse sources contributing to microplastic loading; the spatial and temporal distribution patterns across Indian coastal regions; the ecological impact on marine biota and ecosystem functioning; and the human health and socioeconomic implications. Together these dimensions describe a widespread environmental concern with significant implications for biodiversity, fisheries, public health, and coastal livelihoods.

Three broader conclusions follow. First, microplastic contamination is widely documented across Indian coastal regions, with significant spatial variation linked to land use, river inputs, fishing activity, and oceanographic processes. Second, ecological exposure of marine biota is well established, with implications for biodiversity, fisheries productivity, and food web dynamics that warrant continued investigation. Third, integrated responses are required across plastic waste management, coastal regulation, fisheries management, and scientific monitoring to address the issue effectively.

Several directions for future research are warranted. Methodologically harmonized national-scale assessments would enable robust characterization of contamination across the Indian coast. Long-term monitoring at sentinel sites would document temporal change and intervention effectiveness. Toxicological research using Indian species and ecologically relevant exposure scenarios would advance ecological risk assessment. Studies of human health implications, including dietary exposure modelling and population-level health investigations, would inform public health policy. Research on the socioeconomic implications for coastal communities, particularly artisanal fisher and tourism-dependent populations, would support equity-oriented policy. By advancing such an agenda, environmental science can contribute meaningfully to addressing one of the most consequential environmental challenges facing India's coastal regions.

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