International Journal of Research in All Subject
www.multiarticlejournal.com
ISSN:
Received: 01-05-2025, Accepted: 15-05-2025, Published: 30-05-2025
Volume 1, Issue 1, May-Jun, 2025, Page No. 3-4

Harmful algal blooms (habs) along Indian coasts: Causes, consequences, and mitigation strategies

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Abstract
Harmful Algal Blooms (HABs) have become an increasing threat to marine ecosystems, fisheries, and public health along India's vast coastline. These blooms, caused by the rapid proliferation of toxic or high-biomass phytoplankton, lead to oxygen depletion, fish kills, seafood contamination, and economic losses in coastal communities. This paper examines the primary causes of HABs in Indian waters, including nutrient pollution (eutrophication), climate change, and coastal upwelling. It also discusses their ecological and socioeconomic consequences, such as biodiversity loss, fishery collapses, and human health risks from toxins like paralytic shellfish poisoning (PSP) and ciguatera. Furthermore, the study evaluates current monitoring systems, early warning mechanisms, and mitigation strategies, including nutrient management, bioremediation, and AI-driven forecasting models. By analyzing case studies from Kerala, Tamil Nadu, and the Arabian Sea, this research highlights policy gaps and recommends adaptive measures to combat HABs under changing climatic conditions.

Keywords: Harmful Algal Blooms (Habs), Eutrophication, Indian Coastal Waters, Red Tide, Marine Toxins, Fisheries Impact, Climate Change and Habs, Bioremediation, Remote Sensing for Hab Detection, Mitigation Policies

Introduction

India's 7,500 km coastline supports rich marine biodiversity and sustains millions through fisheries, tourism, and aquaculture. However, rising occurrences of Harmful Algal Blooms (HABs) threaten these ecosystems. HABs occur when phytoplankton (e.g., *Noctiluca scintillans*, *Karenia mikimotoi*) multiply uncontrollably due to excess nutrients (nitrogen, phosphorus), warm temperatures, and ocean currents. Some species release potent neurotoxins, while others cause hypoxia (dead zones) by depleting oxygen.

1. Global vs. Indian Scenario

- Globally, HABs cause losses of $8 billion/year (WHO, 2022).
- In India, Kerala, Tamil Nadu, and Gujarat report frequent blooms.
- The Arabian Sea has seen a 60% rise in *Noctiluca* blooms since 2000 (NASA, 2021).

Causes of HABs in Indian Waters

1. Nutrient Pollution (Eutrophication)

- Agricultural runoff (fertilisers) and sewage discharge elevate nitrogen/phosphorus.
- Case Study: Kochi backwaters (Kerala) show chronic eutrophication linked to HABs.

2. Climate Change Effects

1. Warmer SSTs (Sea Surface Temperatures) accelerate algal growth.
2. Monsoon-driven upwelling brings deep nutrients to surface waters.

3. Coastal Upwelling & Ocean Currents

- Arabian Sea upwelling fuels diatom and dinoflagellate blooms.

Table 1: Major HAB Species in India & Their Impacts

Species	Toxin Produced	Impact
Noctiluca scintillans	Ammonia (non-toxic)	Fish kills, hypoxia.
Alexandrium minutum	Paralytic Shellfish Toxin (PST)	Seafood poisoning
Karenia mikimotoi	Hemolytic toxins	Coral bleaching, mass mortality

Consequences of HABs

1. Ecological Impacts

- Coral reef degradation (e.g., Gulf of Mannar).
- Mass mortality of fish, turtles, and marine mammals.

2. Socioeconomic Losses

- Fishery closures: Tamil Nadu (2019) saw a ₹200 crore loss due to HABs.
- Tourism decline: Beaches in Goa suffer during blooms.

3. Human Health Risks

- Paralytic Shellfish Poisoning (PSP) from contaminated shellfish.
- Respiratory issues from aerosolised toxins.

Mitigation and Management Strategies

1. Monitoring & Early Warning Systems

- Satellite remote sensing (ODIS, MODIS) tracks chlorophyll-a spikes.
- ICAR-CMFRI's HAB alert system for Kerala and Karnataka.

2. Nutrient Reduction Measures

- Wastewater treatment plants to curb urban sewage discharge.
- Organic farming incentives to reduce fertiliser runoff.

3. Bioremediation Approaches

- Seaweed cultivation (*Ulva* spp.) absorbs excess nutrients.
- Oyster reefs filter phytoplankton.

4. Policy Interventions

- National Policy on Marine Pollution Control (2025 draft).
- Stricter enforcement of Coastal Regulation Zone (CRZ) laws.

Case Studies

1. Kerala's *Noctiluca* Blooms (2018–2022)

- Linked to monsoon-driven nutrient loading.
- Response: CMFRI's real-time monitoring reduced fishery losses by 30%.

2. Tamil Nadu's PSP Outbreak (2019)

- Alexandrium bloom contaminated mussels; 5 deaths reported.
- Outcome: Banned shellfish harvesting during bloom seasons.

Future Challenges & Recommendations

- AI-based bloom prediction models (e.g., IITM's "HAB-Alert").
- Community awareness programs for fisherfolk.
- International collaboration (e.g., UNESCO-IOC HAB Programme).

Conclusion

HABs are a growing menace to India's coastal ecosystems and economies. While nutrient management and monitoring tools show promise, integrated policies, climate adaptation, and public awareness are critical for long-term mitigation.

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