Harmful Algal Blooms in Indian Waters

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Planktonic microorganisms in the global oceans are crucial as the main sustenance for filter-feeding organisms. Hence, the normal proliferation of the plankton species is beneficial for fisheries and aquaculture. Nevertheless, under certain circumstances, algal blooms can result in adverse consequences, leading to significant economic losses in aquaculture, fisheries, and tourism operations. While not all algal blooms are harmful, some produce toxins or other harmful substances that can pose serious threats to various organisms.

Algal blooms causing a discoloration of seawater are commonly known as 'red tide.' Harmful Algal Blooms (HABs) refer to the rapid and excessive growth of certain types of algae in aquatic environments, such as freshwater and marine ecosystems, producing adverse or detrimental consequences on aquatic life and humans. HABs pose risks to human health if they contaminate drinking water or if people consume seafood that has been exposed to these toxins. The Key characteristics of HABs include algal overgrowth and toxin production. HABs involve an unusually high concentration of algae, often creating a visible discoloration of the water. The excessive growth is typically fueled by factors such as nutrient enrichment (e.g., nitrogen and phosphorus), warm temperatures, and sunlight. The most crucial factors contributing to the rise of harmful algal blooms are recognized to be low nitrogen/phosphorus ratios and elevated temperatures.

HABs have been on the rise globally in recent decades, exhibiting increased frequency, prolonged duration, expanded regional coverage, and greater economic repercussions. These trends are attributed to factors such as heightened coastal eutrophication and climate change, as well as the introduction of invasive species through ballast water exchange. It is a global phenomenon, reported from over 30 countries including India (Padmakumar et al., 2012).In India, the instances of bloom occurrences reported before and after the 1950s show a notable increase in their numbers (D'Silva et al., 2012).

India, being a prominent maritime nation, featured a vast coastline. The country's marine environment encompasses various complex habitats, fostering a rich diversity of flora and fauna. Moreover, India's expansive marine environment serves as a crucial source of sustenance for a substantial population, providing livelihoods for over 3.5 million individuals and contributing significantly to the country's economy (Nayak, 2017). Nevertheless, the persistent occurrences of microalgal blooms, including HABs, pose a threat to these ecosystems and the associated economic, social, and ecological services they offer.

Coastal habitats, characterized by their shallow depths and proximity to land, are particularly sensitive to changes in environmental conditions. This susceptibility stems from factors such as variations in water temperature, salinity levels, nutrient inputs, and human activities like pollution and coastal development. The Indian fishing industry relies significantly on the coastal region for its marine resources, making it particularly vulnerable to limitations imposed by red tides and harmful microalgae (Padmakumar et al., 2012). Several investigations depicted that about 39 different species were accountable for causing blooms in Indian waters (D'Silva et al., 2012). *Noctiluca* (dinophyceae) and *Trichodesmium*(cyanophyceae) were identified as the dominant bloom-forming genera. Efforts to manage and mitigate Harmful Algal Blooms often involve monitoring water quality, studying environmental factors that contribute to bloom formation, and implementing measures to reduce nutrient inputs into water bodies. Rapid detection and response are crucial to minimizing the potential harm associated with HABs.

Different types of HABs

Algal blooms have the potential to generate various toxins. A variety of microalgal groups, including dinoflagellates and diatoms, can give rise to HAB, with many of them producing toxins that can adversely affect both aquatic life and human health. Typically, bloom-forming species can be divided into three primary groups;

1.Species that are capable of producing water discolorations that are generally harmless. Under certain circumstances, especially within sheltered bays, these organisms can proliferate to such an extent that they result in widespread fatalities of fish and invertebrates. This adverse impact occurs due to oxygen depletion caused by the overwhelming proliferation of these algae under certain circumstances.

E.g. Dinoflagellates:*Noctiluca scintillans*, *Gonyaulaxpolygramma*, *Trichodesmiumerythraeum*

2.Species that generate powerful toxins capable of infiltrating the food chain and inducing a range of gastrointestinal and neurological ailments in humans.

Dinoflagellates are often cited as the most toxic algae, but diatoms and cyanobacteria can also produce harmful chemicals.The neurotoxic and hepatotoxic metabolites from cyanobacteria endanger both humans and animals, accumulating in fish livers and kidneys. (Sonak et al., 2018).Monitoring and understanding the prevalence of these toxins in aquatic environments are crucial for safeguarding the health of both aquatic ecosystems and human populations. The different toxin associated problems are detailed in Table 1.

3.Non-toxic to humans, yet harmful to fish and invertebrates by gill damage or blockage.These microalgal blooms are normally harmless to human. But the incidence of the blooms is detrimental in sheltered bays and in aquaculture systems. These blooms seriously affect the feeding responses and respiratory mechanisms.

E.g. *Gymnodinium Mikimoto*; *Chrysochromulina*spp.,*Chaetoceros*sp., and *Prymnesium*spp.

Table 1: Types of toxins produced due to algal blooms and its related problem

Name	Causative species	Type of toxins	Toxin pathway	Remarks
PSP	*Gymnodiniumcatenatum*, *Alexandrium spp.*, *Pyrodiniumbahamense*	Saxitoxins, gonyautoxins, neosaxitoxin, C-Toxin	Consumption of contaminated shellfishes like mussels, clams and fishes like sardines, etc.	Incidence of PSP reported in east and west coasts of India
DSP	*Dinophysis*spp., and*Procentrum*spp.	okadaic acid and its derivatives (lipophilic toxins)	Consumption of contaminated shellfishes	DSP in infected shellfishes were reported from Karnataka (Karunasagar et al., 1989). It is characterised by gastrointestinal symptoms
ASP	*Nitzschia*spp.	Domoic acid	Consumption of contaminated shellfishes	Causes gastrointestinal and neurological disorders
CFP	*Prorocentrum*sp., *Ostreopsis*spp., *Amphidinium* sp., *Thecadinium* sp.	Ciguatoxins / maitotoxin	Consumption of contaminated small algae-eating fish	Characterized by cardiovascular and neurological symptoms
NSP	*Kerenia brevis*	Brevetoxins	Consumption of contaminated shellfishes and seagrasses	Characterized by cardiovascular, respiratory and neurological symptoms. It affects both aquatic animals like dolphins, mantis, sea turtles, etc., and humans. Also, associated with massive fish kills

Need of Addressing HABs

1) Ecological Impact: HABs can disrupt the ecological balance of aquatic ecosystems. The rapid growth of algae can lead to hypoxic conditions in the water, negatively affecting fish and other aquatic organisms. This disruption can have cascading effects on the entire food web, impacting biodiversity and ecosystem health.

2) Fisheries and Aquaculture: HABs can have serious economic consequences for the coastal fishing industry due to substantial impacts on the wild fish populations. Algal blooms also leadto the closure of fishing groundsaffecting the livelihoods of those dependent on fisheries and aquaculture. The global shellfish aquaculture is reported with the incidence of algal bloom related fish deaths due to damage of gill tissues (Hallegraeff, 1993).

3) Public Health Concerns: Monitoring and managing HABs are essential to ensuring the safety of seafood and protecting public health. To date, there have been four cases of Paralytic Shellfish Poisoning (PSP) reported in the coastal areas of Tamil Nadu (1 case), Mangalore (2 cases), and Kerala (1 case) (Table 2)(D'silva et al., 2012).

4) Tourism Impact: Coastal tourism is an essential part of India's economy. HABs can lead to the discoloration of water, foul odors, and the presence of harmful toxins, negatively impacting the aesthetics of coastal areas. This can deter tourists and have economic consequences for communities relying on tourism.

Table 2: Human health impact of HABs reported in India

State	Year	Incident	Plankton sp.	Remarks
Tamil Nadu (Valayar village)	1981	PSP like – death of 3-person, 35 hospitalisations	Not identified	Consumption of *Meretrixcasta*
Kerala (Vizhinjam)	1997	PSP like – 7 death and 500 hospitalisations	Not identified	Consumption of *Perna indica*
Karnataka (Mangalore)	2015	CFP – 2 hospitalisations	*Gamberdiscus*sp. (suspected)	Consumption of snapper
Kerala (Trivandrum)	2016	CFP – 6 hospitalisations	*Gamberdiscus*sp. (suspected)	Consumption of snapper
Kerala (Malabar coast)	2005	Stench from sea – 200 children hospitalised	*Heladosphaera* sp., *Karenia brevis*	Neurotoxin

Causes of HABs

The causative factor of algal bloom varies with the environmental settings of different regions.

- Coastal pollution

Coastal pollution, stemming from diverse sources such as domestic and industrial effluents, stands out as a significant contributor to HABs due to cultural eutrophication (caused by increase in human population). The introduction of pollutants into coastal waters, including nutrients from sewage, surface runoff and industrial discharges, can lead to a phenomenon known as eutrophication. Eutrophication involves an excessive accumulation of nutrients, such as nitrogen and phosphorus, in aquatic ecosystems. The native flora and fauna may be forced out as the environment becomes more nutrient-rich, with substances like nitrates and phosphates increasing.Changes in water temperature and fluctuating phosphorous-nitrogen ratio creates conditions conducive to the growth of cyanobacteria. The escalating eutrophication, driven by increased nitrogen and phosphorus inputs, results in a high nutrient-to-silicate ratio, favoring non-diatom species, including several harmful flagellates.

- Dust Storms and Metals

Cyanobacteria, like certain types of *Trichodesmium* sp., utilize iron (Fe) sourced from dust particles to convert atmospheric nitrogen into a usable form in coastal waters. Hence, this creates a conducive environment for the proliferation of toxic algae and the occurrence of red tide. The deposition of dust can induce changes in water chemistry and temperature, leading to water column stratification that favors the growth of harmful algae, enabling them to outcompete less harmful species. Additionally, the blooming of *Lyngbya* species is promoted by a synergistic combination of iron and phosphorus, enhancing their photosynthetic activity.

Furthermore, heavy metals like cadmium (Cd) and lead (Pb) deposited in water bodies, often originating from untreated nutrient-rich effluents in aquacultural activities, can contribute to algal blooms. The presence of these metals from aquaculture practices can further disrupt the ecological balance, potentially leading to the proliferation of harmful algae.

- Climate change

Variations in temperature play a crucial role in shaping circulation patterns. The changing conditions leads to changes in the physical composition of the water column and extended stratification periods. These changes favor the occurrence of HABs. Climate change processes, such as shifts in precipitation patterns, can independently enhance nutrient loading rates, thereby accelerating algal blooms caused by eutrophication. Instances have been observed where HABs intensify as water temperatures approach levels conducive to maximal growth. Consequently, climate change may contribute to the increased frequency and intensity of HABs in certain coastal ecosystems (Gobler et al., 2020).

Several recent studies have highlighted a common occurrence of HABs alongside other stressors linked to climate change. These stressors may include factors such as changes in temperature, nutrient runoff, and altered oceanic currents. Furthermore, the impact of climate change on environmental conditions can potentially exacerbate the frequency and severity of HAB outbreaks. Given these findings, it is becoming more pertinent to recognize HABs not only as isolated events but also as co-stressors that interact with and compound the effects of climate change on aquatic ecosystems.

- Upwelling and monsoon pattern

The occurrence of micro-algal blooms along the coasts of India is influenced significantly by factors such as upwelling and monsoon patterns. The withdrawal of the monsoon and the onset of the post-monsoon season create favorable conditions for bloom formation. Pre-monsoon conditions, characterized by warm waters and low nutrient concentrations, particularly favor *Trichodesmium* blooms in the West coast. On the west coast, the upwelling events contributing to blooms.

Weak spells of rain during the summer can cause abrupt changes in salinity and temperature, triggering micro-algal blooms. This phenomenon is observed in the west coast, especially in Kerala, where the blooms of *skeletonema* (preferring low salinity) and the raphidophyte *Chattonella marina* (preferring low temperature) are favored during the summer season. The break in the monsoon provides an opportunity for certain phytoplankton species like *Cochlodinium*sp. and *Gymnodinium* sp. to bloom. Despite favorable conditions, blooms are less common on the west coast during the monsoon season.Research indicates that with the beginning of the northeast monsoon, there is an influx of lower salinity waters from the Bay of Bengal into the coastal regions of southwest India. This may promote the growth of specific bloom-forming species.

The Bay of Bengal is characterized by lower biological productivity compared to the Arabian Sea, attributed to strong stratification preventing nutrient transport from deeper layers to the surface. In BOB, the blooms happen during the pre-monsoon season mostly dominated by diatom and cyanobacterial blooms. The dinoflagellate, *Noctiluca scintillans, also* happen more frequently during the summer (Hegde et al., 2008) and it might form bloom events during the cyclone-prone seasons.

- Ballast water

The bioinvasion from other world oceans, necessitating thorough research into the spread of species responsible for HABs. Ballast water is considered a major carrier for spreading HABspecies in maritime nations such as India.

Monitoring and Early Detection

The rise inHAB occurrences has heightened public awareness, leading to an increased demand for monitoring efforts. Consequently, there is a growing emphasis on early detection methods for identifying bloom species, understanding the conditions that favours algal-blooms, and identifying the harmful toxins associated with these blooms. The lack of readiness for substantial range expansions or the proliferation of HAB issues in inadequately monitored areas is anticipated to pose a major challenge for human society in the future (Hallegraeff, 2010).

Remote sensing acts as a versatile tool for globally detecting and monitoring HABs.A novel bio-optical algorithm has been devised to precisely gauge chlorophyll-a (Chl-a) concentrations, facilitating the identification and mapping of algal blooms in the visually complex waters of the Arabian Sea (Shanmugam, 2011). Initially formulated with Sea-viewing Wide Field-of-view Sensor (SeaWiFS) bands, this algorithm has since been adjusted for compatibility with Moderate Resolution Imaging Spectroradiometer (MODIS)/Aqua data. The Indian National Centre for Ocean Information Services (INCOIS) has taken the initiative to modify and adapt the Red Tide Indices to create the Bloom Index (BI) specifically tailored for Indian waters. This adaptation enhances the capability to monitor and assess algal blooms in Indian marine environments.

Regular monitoring of the physical, chemical, and biological parameters along the Indian coast is a critical practice for developing forecasting and warning systems related to HABs and the subsequent impacts on fish mortality. By systematically collecting data on factors such as water temperature, nutrient levels, and algal species composition, scientists and environmental agencies can detect early signs of HAB development.

Conclusion

HABs represent a complex ecological phenomenon with far-reaching impacts on both marine ecosystems and human communities. The consequences of HABs include environmental disturbances, significant mortality among aquatic fauna, alterations in traditional fishing practices, and substantial risks to human health. Two notable examples of human health risks associated with HABs are PSP and CSP, both of which can lead to severe health issues and, in extreme cases, even death. Efficient management and decision-making regarding Harmful Algal Bloom (HAB) occurrences along the Indian coastline require a thorough understanding of the specific environmental conditions involved. Factors such as water temperature, nutrient levels, and oceanographic conditions contribute to the initiation and proliferation of these blooms. By gaining insight into these factors, authorities can develop comprehensive management plans to mitigate the impact of HABs on both aquatic ecosystems and human activities.

Surveillance programs play a crucial role in monitoring the levels of phycotoxins, harmful substances produced by certain algae during blooms, in the environment and local seafood. Regular testing and analysis help identify areas prone to toxin accumulation, enabling timely interventions to protect public health. Additionally, implementing sustainable environmental practices is key to preventing and managing HABs. This may involve measures such as controlling nutrient runoff, managing aquaculture practices, and promoting ecosystem balance. It is essential to conduct studies focused on comprehending the primary environmental factor or factors that contribute to HABs, at regional levels. This knowledge is crucial for more effective environmental health management.

In summary, a multidimensional approach that combines knowledge of environmental factors, surveillance programs for toxin levels, and sustainable practices is vital for curbing the occurrences of HABs. By taking proactive measures, authorities can work towards preserving marine ecosystems, protecting aquatic life, and ensuring the safety of seafood consumption for local communities.

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