Review Article

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Harmful algal blooms in the coastal waters of Bangladesh: an overview

Abstract

Harmful algal blooms (HABs) constitute a global problem, affecting aquatic ecosystems, human health, fisheries and local economies. The Bay of Bengal, along the Bangladesh coast, is exceedingly suffering from pollution or anthropogenic nutrification that influences frequently occurring HAB species. The progression of climate change and eutrophication invigorate HAB trends and responses that in turn affect the respective coastal livelihood and economic growth. *Tripos* spp., *Dinophysis* spp., *Protoperidinium* spp., *Chaetoceros* spp., and *Pseudo-nitzschia* spp. are the common bloom-forming HAB species in the coastal waters of Bangladesh. Despite having huge potentiality for regional and global perspectives, the coastal region of Bangladesh remains relatively unexplored compared to other regions in the context of HABs and their pernicious effects. As a result, harmful algal blooms and the accumulation of algal toxins may interrupt fisheries, aquaculture, aquatic ecosystems and public health in the country. Therefore, proper research on the biology and ecology of harmful algae, biotoxins and their relationship with environmental factors need to be adequately understood to minimize their adverse effects on the noted marine resources of the Bay. This review focused on an overview of the HAB related issues – causes of HABs, their occurrences and abundances, associated environmental factors and adverse effects in the coastal zone of Bangladesh.

Keywords: harmful algae, HABs, environmental factors, coastal waters, Bangladesh

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Introduction

The term "Harmful Algal Blooms (HABs)" is commonly placed as the blooms of harmful or toxic microalgae that occur in massive accumulations of cells.[1] Growing beyond normal concentrations, harmful algae foul water bodies and often produce potent toxins.[2] The onward frequency of harmful algae and the consequent HAB events are the most alarming problems in the world's coastal and marine regions. In modern times, this issue has been a recurrent topic of discussion at all major conferences as HAB causes fearsome impacts on the marine ecosystem, economic growth, human health, tourism as well as living marine resources.[3–5] Due to the diversity of causative organisms, dynamics of bloom and sort of impacts, many countries are faced with a bewildering array of harmful, noxious or toxic algal species. Eutrophication and climate change are nowadays promoting the expansion of HABs to occur constantly, in most water bodies and to be more intense.[6]

Bay of Bengal also has been subjected to the frequently occurring HAB events to a greater extent although received minimal attention in the past regarding bloom context. This bay is one of the world's 64 largest marine ecosystems with illustrious biological diversity and productivity. Being a northeastern part of the Indian Ocean, the Bay of Bengal is bounded by several Asian countries. Materially, many countries in South Asia and Southeast Asia are dependent on the Bay of Bengal including littoral and landlocked countries for maritime usage. HAB problems in the Bay of Bengal have escalated in recent decades in parallel with the use of agricultural fertilizer, the development of aquaculture, a thriving population that altogether stimulate coastal eutrophication, and climate change.

Bangladesh is situated at the northern apex of the Bay of Bengal, shaping the foremost important and eastern neighborhood of the bay's historical namesake region Bengal. It has a convoluted coastline of 734 km involving communities of about 50 million people, nearly one-third of the total population of the country.[7] The Ganges, Brahmaputra and Meghna estuaries in the south, and the Karnaphuli, Halda and Sangu rivers and Arakan ranges shoreline in the southeast, are giving a distinct feature to the whole coastal zones. A network of 230 rivers with their tributaries and distributaries crisscross the country and higher values of nutrient pollution have been observed from rivers in the bottom sediments of the Bay (Figure 1). Besides, a variety of pollutants from different sources (i.e., industrial, municipal and agrochemical wastes and oil pollution are the main sources) have also led to nutrient enrichment and to the consequent algal bloom along the coastal zone of the Bay.

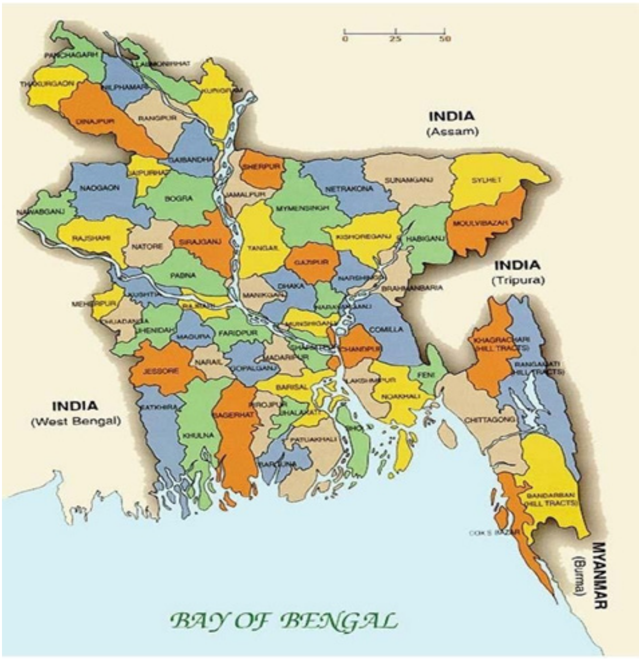

Figure 1 Map of Bangladesh showing the major river systems that end up in the Bay of Bengal (BOBLME-Bangladesh).

Blooms of diatoms, dinoflagellates and cyanobacteria have been repeatedly reported from the coastal waters along the Bay.[8] Dinoflagellates and diatoms are the most common two groups of toxic phytoplankton in the Bangladesh coast, where the recorded harmful algae are mainly *Tripos* spp., *Pseudo-nitzschia* spp., *Skeletonema costatum*, *Trichodesmium erythraeum*, *Microcystis aeruginosa*, *Alexandrium catenella*, *Dinophysis* spp., and *Cucumeridinium* sp. The occurrence and bloom of potentially harmful algal species and their toxins are responsible for different types of fish and shellfish poisonings worldwide[9] that may pose serious life-threatening human illnesses at any time. This suggests that Bangladeshi marine resources are at high risk in the success of the Blue Economic program to fulfil its objective of promoting smart, sustainable and circumfluous growth and employment advantages in Bangladesh's maritime economic activities within the short, medium and long-term frames. The objective of the present work was to compile an inventory of alga species potentially capable of producing harmful blooms along the coastal belt of Bangladesh on a spatial scale. This made it possible to closely study the occurrence of harmful algae, the occurrence of HAB events, and their effects along coastal waters.

Causes of HABs along the coastal waters of Bangladesh: Scientists provide several indicative examples of HABs promoted by eutrophication,[10] climatic fluctuations,[11] coastal aquaculture,[12] transfer of shellfish stocks from one area to a different[13] and have developed greater scientific awareness of toxic species.[14] Hence, urbanization and the concurrent raise of sewage effluents and agricultural and industrial wastes can provoke toxic algal blooms.[15] The coastal zone of Bangladesh has been undergoing some of these multiple vulnerabilities that trigger the occurrence of HABs oftentimes.

In a densely populated country like Bangladesh, wastewater effluents are key contributors to a variety of water pollution problems.[16] Localized oil pollution is severe in the main ports of the country, namely, Chittagong, Khulna, Mongla, Narayangonj, Chandpur, and Barisal. Every day, considerable quantities of oil are carried from these ports into the Bay. The volume of run-off water increases dramatically during the monsoon months due to heavy rainfall, and thus provides nutrients sufficient to convert the coastal waters of Bangladesh to eutrophic conditions.[17] Eutrophication triggers noxious and toxic algal blooms in most cases. As a result, algal blooms and hypoxia have been observed along the coastlines of the Bay of Bengal Large Marine Ecosystem (BOBLME). As a third-ranked aquaculture fish production country in the world and the most promising area for shrimp cultivation (especially, the southwestern portion i.e., Satkhira, Khulna and Bagerhat), Bangladesh is susceptible to an increased awareness of toxic algal species and their impacts.

The potential effects of climate change on coastal waters are well-known regulators of phytoplankton growth, behavior and species succession by playing a key role in aquatic environmental factors.[11] Bangladesh ranked as 5th highest vulnerable country to climate change,[18] facing serious environmental degradation favouring several harmful algal species growths in all niches. Among the many impacts of climate change, rising temperature, acidification and deoxygenation are probably the most prominent.[19] The identical characteristic features of the Bay such as enormous freshwater influx, monsoonal clouds, rainfall and weak surface winds make the area strongly stratified whereas Berdalet et al.[20] stated that multiple HAB species can flourish under well-stratified conditions. It is disclosed that climate-related changes in the intensity of storm events or great floods may break down the natural bio-geographical barriers that restrict the expansion of HAB species and may enhance the transport of invasive HABs to areas presently outside the range. In the Bay of Bengal, the introduction of microalgal biomass to bloom by physical processes like eddies[21] and cyclones[22] are very common.

Occurrence of harmful algae and their blooms in the coastal waters of Bangladesh: In terms of harmful effects, two types of causative organisms: the toxin producers and the high biomass producers can be considered while some HAB species are related to both characteristics. Mainly harmful species belong to six algal classes which include *Dinophyceae, Bacillariophyceae, Haptophyceae, Raphidophyceae, Cyanobacteria* and *Pelagophyceae*; therefore, these differ in terms of morphological, physiological and ecological characteristics.[23] Broadly, bloom species can be classified into three different groups: (1) species that produce harmless water discolorations, but the blooms can grow so dense that on decomposition leads to indiscriminate mortality of marine life due to oxygen depletion, (2) species that produce potent toxins causing a variety of gastrointestinal and neurological illness to humans by finding their way through the food chain, (3) species which are non-toxic to humans; they can clog or damage fish gills by their sharp spines or their production of mucus, and others secrete ichthyotoxic compounds like ROS (Reactive Oxygen Species) or PUFA (Poly-Unsaturated Fatty Acids). Interestingly, some HAB species can be harmful at low concentrations despite attaining high biomass.[24]

HABs in the coastal and marine environments of Bangladesh are caused by a broad range of microscopic algae and cyanobacteria. While estuarine and brackish systems have clenched HABs for thousands of years, the causative algal species propagated from freshwater environments are progressively found in coastal waters where they can vie with other phytoplankton species. Heavy rainfall and floods often play a significant role in transporting invasive, freshwater-evolved HAB species to coastal waters and estuaries.[25] In Bangladesh, several HAB species in freshwater ecosystems were reported, among which cyanobacteria are the most dominating and problematic species. Species that form blooms belong to the genera *Tripos, Anabaena, Aphanizomenon, Nodularia, Cylindrospermopsis, Oscillatoria, Nostoc* and *Microcystis*, predominantly Microcystis aeruginosa. Hence, the occurrence, bloom and toxicity related studies of HAB species were consistently reported from the different freshwaters of Bangladesh, including the findings of Jahan et al.[26] and Sultana et al.[27] These freshwater-evolved harmful species can be introduced from the freshwater bodies in the Bangladesh coast where they compete with other phytoplankton species.

From the coastal waters of Bangladesh, the most frequently occurring HAB species amongst the groups of dinoflagellates, diatoms and cyanobacteria are listed in Table 1, while only a very few studies were conducted in this aspect. Significantly, these all mentioned species in the table are globally marked as severely harmful in varying degrees and frequencies.

Seasonal abundance of bloom-forming harmful algae and their associated environmental factors in the coastal waters of Bangladesh: Marine algal bloom cases from the coasts of Cox's Bazar, Maheshkhali Channel, Bakkhali River Estuary, Laboni Point and Deepsea part along the Bangladesh coast are mostly dominated by dinoflagellate and diatom species during monsoon and autumn. Recent observations added cyanobacterial bloom during winter also. Despite the lack of investigations, several studies suggest that *Tripos* spp., *Dinophysis* spp. and *Pseudo-nitzschia* spp. are the most frequent bloom-forming species along the coastal waters of Bangladesh (Table 2). In particular, monsoon blooms of *Tripos* spp. included seven species (i.e. *Tripos furca*, *T. muelleri*, *T. hircus*, *T. fusus*, *T.*

azoricus, *T. trichoceros*, *T. inflatus*) reaching maximum densities at 40 × 10^5 cells/L in September 2000.[28] In that bloom event, *Tripos furca* (36 × 10^5 cells/L) played the most dominant role.[28] *Dinophysis caudata* was first observed in Maheshkhali Channel in 1998 with an exceptionally heavy red tide showing its maximum abundance at 1.17 × 10^6 cells/L.[29] *Pseudo-nitzschia* spp. was mostly recorded with higher abundance in late autumn. Jewel et al.[35] reported four species of *Pseudo-nitzschia*, namely *P. pungens*, *P. pseudodelicatissima*, *P. delicatissima* and *P. australis* with a very high concentration (105.5 × 10^5 cells/L).

Table 1 Harmful algal species identified in the coastal waters of Bangladesh

Phytoplankton group	Causative species	Source
Dinoflagellates	*Tripos furca*, *T. muelleri*, *T. hircus*, *T. fusus*, *T. azoricus*, *T. trichoceros*, *T. inflatus*, *T. massiliensis*, *T. setaceus*, *T. belone*, *T. lineatus*, *Dinophyis caudata*, *D. homunculus*, *Phalacroma mitra*, *Cucumeridinium coeruleum*, *Lingulodinium polyedra*, *Gonyaulax spinifera*, *G. polygramma*, *Alexandrium catenella*, *Prorocentrum micans*, *P. gracile*, *Protoperidinium divergens*, *P. depressum*, *P. claudicans*, *Pyrophacus steinii*, *Noctiluca scintillans*, *Spatulodinium pseudonoctiluca*, *Scrippsiella acuminata*, *Karenia* sp.	Khan et al.,[28] Haque et al.,[29] Khan et al.,[30]Shaika and Khan,[31] Ahmed,[32] Shaika[33]
Diatoms	*Chaetoceros curvisetus*, *C. aequatorialis*, *C. affinis*, *C. compressus*, *C. diversus*, *C. danicus*, *C. decipiens*, *Pseudo-nitzschia pungens*, *P.pseudodelicatissima*, *P. delicatissima*, *P. australis*, *P. turgidula*, *P. seriata*, *P. cuspidata*, *P. fraudulenta*, *P. lineola*, *Trieres chinensis*, *Asterionellopsis glacialis*, *Coscinodiscus radiates*, *Proboscia alata*, *Skeletonema costatum*, *Thalassionema frauenfeldii*, *Thalassiothrix* sp.	Jewel et al.,[34] Jewel et al.,[35] Khan et al.,[30]Dad Khan[36]
Cyanobacteria	*Anabaena circinalis*, *Anabaenopsis* sp., *Aphanocapsa* sp., *Aphanizomenon flos-aquae*, *Trichodesmium erythraeum*, *Oscillatoria* sp., *Nodularia spumigena*, *Microcystis aeruginosa*	Jewel et al.,[34] Shaikaand Khan,[37] Shaika[33]

Table 2 Important HAB incidents in the coastal waters of Bangladesh

Bloom-forming species	Month and year of maximum abundance and cell density	Source
Tripos spp.	September 2000 (40 × 10^5 cells/L)	Khan et al.[28]
	August 2001 (11.07 ± 1.89 × 10^5 cells/L in upstream & 9.92 ± 1.26 × 10^5 cells/L in downstream)	Ahmed[32]
Tripos furca	Early October 1998 (3.0 × 10^4 cells/L)	Haque et al.[29]
	September 2000 (36 × 10^5 cells/L)	Khan et al.[28]
	September 2000 (27.9 × 10^5 cells/L)	Jewel[38]
	August 2001 (10.56 ± 1.89 × 10^5 cells/L in upstream & 9.11 ± 1.65 × 10^5 cells/L in downstream)	Ahmed[32]
Tripos trichoceros	September 2001 (74.67 ± 0.14 × 10^3 cells/L in upstream & 83 ± 0.16 × 10^3 cells/L in downstream)	Ahmed[32]
Tripos massiliensis	September 2001 (42.9 × 10^3 cells/L in upstream & 31.15 × 10^3 cells/L in downstream)	Ahmed[32]
Chaetoceros spp.	November 2001 (5.30 × 10^5 cells/L in upstream & 4.20 × 10^5 cells/L in downstream)	Dad Khan[36]
Chaetoceros curvisetus	November 2000 (31.6 × 10^6 cells/L)	Jewel[38]
	November 2001 (4.79 × 10^5 cells/L in upstream & 3.26 × 10^5 cells/L in downstream)	Dad Khan[36]
Dinophysis caudata	September 2001 (65.57 × 10^3 cells/L in upstream & 57.6 × 10^3 cells/L in downstream)	Ahmed[32]
	Early August 1998 (1.17 × 10^6 cells/L) & Mid-August 1998 (1.10 × 10^6 cells/L)	Haque et al.[29]
Microcystis aeruginosa	January 2021 (26.43 ± 1.62 ×10^4 colonies/L)	Shaika[33]
Oscillatoria spp.	February 2021 (30.13 ± 14.10 ×10^3 filaments/L)	Shaika and Khan[37]

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Table Continued..

Bloom-forming species	Month and year of maximum abundance and cell density	Source
Protoperidinium divergens	November 2001 (86.1 × 10^3 cells/L in upstream & 61.75 × 10^3 cells/L in downstream)	Ahmed[32]
	November 2002 (66.14 ± 26.65 × 10^3 cells/L)	Khan et al.[39]
Pseudo-nitzschia spp.	November 2000 (105.5 × 10^5 cells/L)	Jewel et al.[35]
	November 2001 (14.40 × 10^5 cells/L in upstream & 11.66 × 10^5 cells/L in downstream)	Dad Khan[36]
Pseudonitzschia delicatissima	November 2001 (13.25 × 10^5 cells/L)	Dad Khan[36]
Skeletonema costatum	August 2001 (1.66 × 10^5 cells/L in upstream & 1.44 × 10^5 cells/L in downstream)	Dad Khan[36]
Trichodesmium erythraeum	February 2021 (91.47 ± 52.94 ×10^3 colonies/L)	Shaika[33]

The geo-climatic environment of the Bangladesh coast is dominated mainly by wind direction, precipitation and river discharge that all have a very strong influence on the marine environmental factors, with physical (temperature and light intensity) and chemical factors (dissolved oxygen, pH, salinity, total hardness, electrical conductivity and nutrient level) which in turn influence the seasonal growth, abundance and diversity of phytoplankton in the area. The relationships between the most common bloom-forming dinoflagellate and diatom species and the corresponding environmental factors, such as temperature, salinity, pH and nutrients along the coastal waters of Bangladesh are graphically represented in Figure 2.

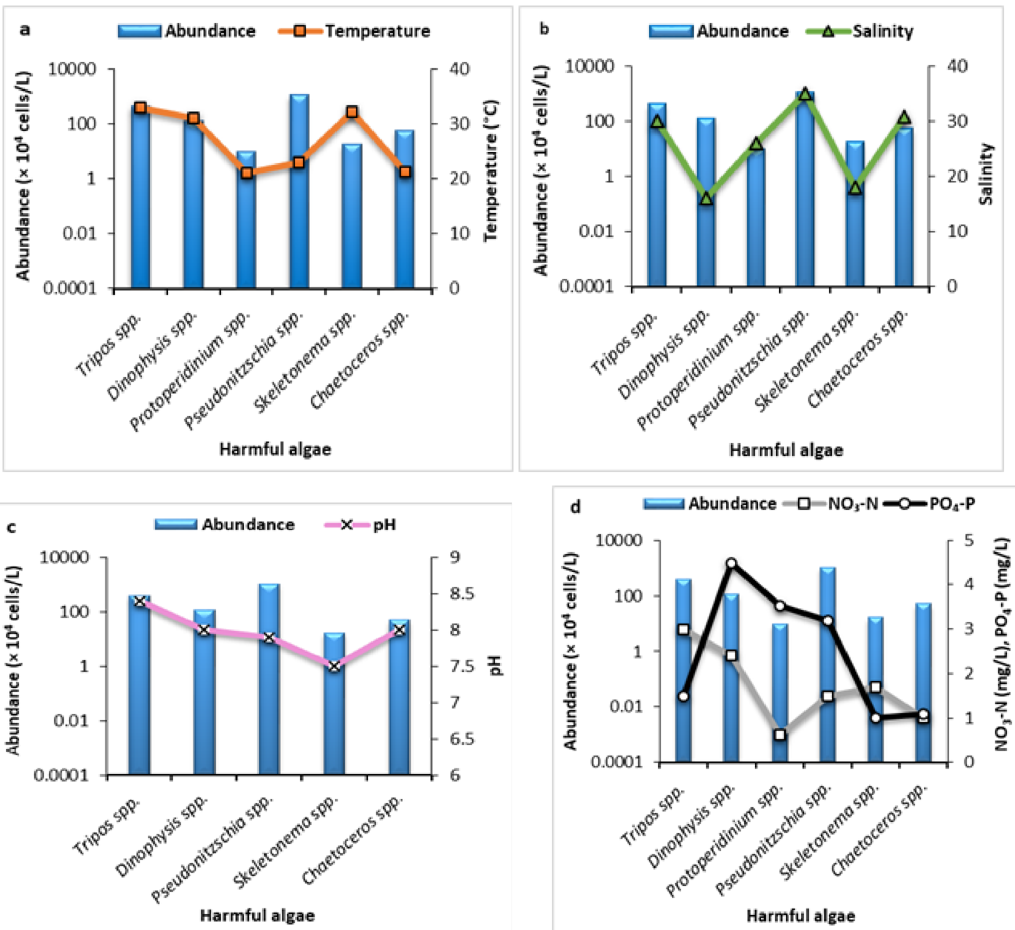

Figure 2 Maximum abundances of harmful algae during bloom incidences and their associated environmental factors, i.e., temperature (a), salinity (b), pH (c) and NO3-N and PO4-P (d) recorded along the coastal waters of Bangladesh (Data taken from different findings).[28,29,35,36,39]

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Phytoplankton diversity and species succession are largely dependent on the seasonality, associated with changes in temperature, salinity and nutrient concentration. The seasonal variation in relation to environmental factors along the coastal region suggests that phytoplankton bloom may occur from July to November when nutrients accumulate from freshwater run-off due to monsoon rainfall and more sewage pollution.[34] Accordingly, it was demonstrated that the higher concentration of NO3-N and PO4-P from the Bakkhali river discharge and precipitation enhance phytoplankton blooms ($33 \times 10^5 \pm 16 \times 10^5$ cells/L) in the Maheshkhali Channel during early post-monsoon (October).[30] In contrast, the lowest abundance was detected during early monsoon (June) which may be due to the lowest concentration of NO3-N and PO4-P. Besides, higher values of NO3-N (3 mg/L) and PO4-P (3.2 mg/L) were observed with the heavy bloom of *Tripos* spp. and *Pseudo-nitzschia* spp., respectively.[28,35] The concentration of PO4-P was also quite high (4.5 mg/L) along with the peak bloom of *D. caudata*.[29]

It is widely known that temperature and salinity are directly related to the bloom development and distribution of harmful algae and this relationship varies among species. For instance, high temperatures (31˚C) and low salinity (16) values were observed in the bloom formation of *D. caudata* in the coastal belts of Bangladesh.[29] Before the time of peak bloom of the species in early August, rainfall began in July and salinity decreased for 2-3 weeks. Contrariwise, high salinity (35) and low temperature (23˚C) were recorded with the maximum abundance of *Pseudo-nitzschia* spp. in late autumn.[35] The maximum cell densities of *Protoperidinium* spp. and *Chaetoceros* spp. also coincided with temperatures near to 21˚C.[36,39] Again, pH showed high (8.4) and comparatively low (7.5) values during high cell density of *Tripos* spp. and *Skeletonema* spp., respectively.[28,36]

Adverse effects of HABs in the coastal waters of Bangladesh: HABs have become one of the most distinguished marine ecological disasters in the world's coastal waters.[40] Negative effects of the diverse group of microscopic plankton that comprise HAB species increasingly threaten the economic viability of fisheries and aquaculture, and the health and diversity of the ecosystem, and recreational activities.[41,42] Van Dolah[43] figured that the recent increase in harmful algal blooms in aquatic systems has begun to unravel the far-reaching effects on species interactions, aquatic animal health, and ecosystem integrity, as well as on major industries and economies. Suitably, the occurrence of blooms and toxic effects of HABs in the waters of Bangladesh is a matter of concern as these effects from harmful algae have been anthropocentric nowadays. Research can make tremendous advances in the understanding of HAB events in coastal and marine waters of Bangladesh, yet their effects remain poorly understood.

In the coastal zone of Bangladesh, over 35 million people live for their livelihood[44] which is in jeopardy of marine pollution, mostly derived from land-based exercises due to the discharge of diversified pollutants through the drains, canals and rivers.[45] Pollution could stimulate algal toxin production, and toxicity can oftentimes cause acute illness and mortality of aquatic and terrestrial animals.[46] So far, there are several algal species recorded along the Bay, such as *Protoperidinium divergens*, *Noctiluca scintillans*, *Trichodesmium erythraeum*, *Cucumeridinium* sp., *Dinophysis* sp., *Tripos* sp., *Thalassiosira* sp., *Skeletonema costatum*, *Chaetoceros* sp., *Pseudo-nitzschia* sp., etc. These are commonly responsible for massive fish mortality broadly reported in many parts of the world.[47–53] Haque et al.[29] claimed large-scale mortality of sea fish in September 1998 due to the bloom of *D. caudata*. They also discussed the occurrence and bloom of dinoflagellate with extensive fish mortality and the presence of potentially harmful species, such as *Cucumeridinium coeruleum*, *Lingulodinium polyedra* and *Alexandrium catenella*. Very recently, the mortality of marine mammals in the Bay's water has become a major topic of discussion.[54–58] Several assumptions have been playing for the reasons behind the suspicious mortality cases of such marine mammals year after year along the Bangladesh coasts. The fact is, however, similar mortality cases of marine mammals are reported worldwide just because of the toxic and harmful algal blooms.[59,60] Effects of harmful algal bloom toxins on marine mammals include lethal and sub-lethal impacts. In severe cases, die-offs or mass strandings have been viewed, some affecting multiple species (Figure 3).

Figure 3 Two dead whales were washed up on Bangladesh shore consecutively on April 9 and 10, 2021.

(https://www.dailysabah.com/life/environment/2-dead-whales-wash-up-on-bangladesh-shore-in-two-days)

However, the noxious and toxic algal species have obvious shreds of evidence of alarming impacts on human health worldwide. Humans can be exposed to various types of biotoxins with an onset of symptoms like nausea, diarrhea, chills, gastroenteritis and several neurological problems. Additionally, vision disturbances, unstable blood pressure, dizziness, headache, seizures, unusual heart rhythms, profuse respiratory secretions, and particularly memory loss were viewed.[61] The consumption of raw or cooked contaminated shellfish with algal toxins is the common route for humans to be affected by these syndromes. As the Bay of Bengal is not duopolies under sufficient investigation in terms of HAB events, the wide-ranging cases associated with human intoxication remain sparsely understood to date. But, the coastal waters of Bangladesh are the habitat of several causative organisms primarily accountable for paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP). In some cases, bad odor comes from fish muscle after cooking fish collected from the coastal beach having algal blooms. Poor people in this coastal area suffer from various diseases, such as nausea, malaise, vomiting, diarrhea, abdominal pain, fever, asthma, conjunctivitis, eye and ear irritation, etc. because of regular use of contaminated water for bathing, drinking, cleaning and other domestic and aquaculture purposes. Again, the impacts of toxic algae on shellfish aquaculture are of great concern that may lead to huge economic losses for local shellfish industries. Blooms of toxic algal species and their potential threat to public health are the most hazardous risk to shellfish and finfish industries causing different types of poisonings that subsequently may become more problematic for the fisheries sector.

Conclusions and future directions

In tune with the countless earth's reports, HABs have already knocked a severe alarming impendence to the Bay of Bengal, along the Bangladesh coast, in modern times. The coastal and marine water toxicity issue is underestimated due to less research and publication on the outbreak of harmful algae and diversified biotoxins. HABs of toxin-producing microalgae cause severe illnesses referred to as shellfish poisonings and also cause serious effects on the fisheries resources, socio-economy, maritime trade, tourism, public health and coastal commodities in general. Unpreparedness for substantial propagation of HABs in poorly monitored areas like Bangladesh will be one of the utmost problems for human society. Therefore, updated knowledge and efficient monitoring systems in terms of occurrence, distribution, causes and impacts of harmful algae along the dynamic marine ecosystem of Bangladesh must be inaugurated to diminish all exaggerated effects associated with harmful algal blooms.

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Conflict of interests

The authors declare that they have no direct or indirect conflicts.

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