RESEARCH ARTICLE

Algal Blooms and Phosphate Eutrophication of Inland Water Ecosystems with Special Reference to India

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Abstract

Algal blooms lead to hypoxia resulting in the mortality of fish and other aquatic animals in inland as well as marine waters. A number of reports on fish mortality in lakes and river waters due to hypoxia are available in India. The main cause of algal blooms is reported to be the eutrophication of inland and marine waters with plant nutrients, of which phosphate is the most important. Phosphate is added to inland and marine waters from run-offs from agricultural fields receiving phosphate fertilizers. Phosphate is also added to the waters from untreated human solid waste and sewage in the river and lake waters from nearby towns and cities. An N:P ratio of less than 10:1 is reported to encourage bloomer phytoplankton. Causes other than hypoxia, responsible for the mortality of fish and other aquatic animals include the production of neurotoxins and methanol by phytoplankton, heavy metals from industrial effluents and residues of pesticides from agricultural fields.

Keywords: Algae, Algal bloom, Cyanobacteria, Diatoms, Dinoflagellates, Eutrophication, Fish mortality, Inland water, Marine waters.

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Introduction

'Algal bloom' refers to the rapid growth and accumulation of a large mass of phytoplankton (cyanobacteria, algae, diatoms, dinoflagellates) in waters, which results in hypoxia (lack of oxygen) leading to the mortality of fish and other aquatic animals. This subject has received considerable attention from the Oceanographers in sea waters. Such areas in the seas are known as "Dead Zones" and as many as 405 have been recognized in the world (Diaz and Rosenberg, 2008) including coasts of Gulf of Mexico (Malakoff, 1998), Chesapeake Bay (Science Daily, 2015), south China sea (Liu *et al*., 2009), east China sea (Lin *et al*., 2017), Arabian Sea and Bay of Bengal (D'Silva *et al*., 2012). From India, Padmakumar *et al*. (2012) reported that during 1998–2010, eighty algal blooms were recorded, of which 31 were due to dinoflagellates, 27 by cyanobacteria and 18 by diatoms. Recently, algal blooms were blamed for a dip in fish catch from sea coast at Bombay by an Indo-US team of experts (TOI, 2018a).

Algal blooms could be green or red. When red or brown algae accumulate in large proportions, this is known as a 'Red Tide' (Anderson, 1989) as in a recent report from Florida (USA) coast of Gulf of Mexico (Williams, 2018). In China, there is an upward trend in the occurrence of Red Tides. In the 1960s, there used to be one Red Tide once in 5 years, but now there are about 90 Red Tides each year (Zhou *et al*., 2008). The algal blooms use oxygen dissolved in water for the decomposition of organic matter produced after their death, and this leads to hypoxia. It may be mentioned that the life of a phytoplankton cell is short and is of only a few days.

Some of the algal blooms, especially, the "red tides" are known as 'Harmful Algal Blooms' (HAB). Among other phytoplankton, they contain dinoflagellates, which produce neurotoxins that adversely affect the shellfish and other aquatic animals (Hallegraeff, 1992; Landsberg, 2002; Flewelling *et al*., 2005; Starr *et al*., 2017). Some dinoflagellates are mixotrophic, combining photosynthesis with ingestion of prey (phagotrophy) (Stoecker, 1999). Further, when such aquatic foods are consumed by humans, they may lead to several kinds of poisoning, namely, ciguatera poisoning, paralytic shellfish poisoning (PSP), neurotoxin shellfish poisoning, diarrheic shellfish poisoning, and amnesic shellfish poisoning, for which there is no known antidote (Grattan *et al*., 2016).

Inland waters also get algal blooms, and these have been reported from the lakes and rivers in the USA (USEPA, 2017), Europe (Gilbert, 2015), Australia (WRC, 1998), Japan (Iwayama *et al*., 2017) and China (Stone, 2017; Xie, 2018). In China, algal blooms are frequent in the three largest lakes, namely, Taihu, Chaohu, and Dianchi, resulting in heavy ecological and economic damage and even affecting social stability (Jin, 2003). *Microcystis* cyanobacteria dominate HAB plague in Lake Erie (USA) each summer. *Microcystis* can vertically migrate, consume excess P at the sediment-water interface, and then rise to from algal blooms (Paerl and Fulton, 2006). Algal blooms lead to fish mortality, affect drinking water supply and make lakes risk-prone for entertainment. Toxins produced by algal blooms also lead to illness and mortality of cattle (Puschner *et al*., 1998; Hilborn and Beasley, 2015).

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Indian Scenario

Algal blooms in inland waters of India have been reported by a number of researchers in India, for example, in Udaisagar lake in Rajasthan (Vijaivergia, 2008), Dal Lake in Jammu and Kashmir (Solim and Wanganeo, 2008), Upper Lake (*Bhojtal*) in Bhopal in Madhya Pradesh (Kundu *et al*., 2015), Chilika lake in Odisha (Sengupta *et al*., 2017) and in River Ganges at Varanasi (Singh and Choudhary, 2011).

Inland waters (ponds, lakes, drains, and rivers) in India are largely used for domestic use including bathing, washing clothes, wading and drinking by cattle and other animals. During monsoons, human feces, kitchen waste, and surface run-off from the adjoining agricultural fields is added and brings in plenty of nutrients including phosphorus (P). The temperatures in India are generally warm in the plains and there is plenty of sunshine encouraging algal growth. Thus plenty of algae, especially the green ones are always present there in large amounts; about 5000 kg ha^{-1} (Singh, 1953).

Large-Scale fish mortality was reported during June–July 1995 in the *Sankey* Lake, situated in Sadashiva Nagar of Bengaluru city and it was found to be due to hypoxia, caused by sewage let into the lake resulting in algal blooms (Benjamin *et al*., 1996). Again in Karnataka, fish mortality was also reported from *Usuru* lake in 2005 and 2016 and *Kukurhalli* and *Karanji* lakes in 2001 and 2014, and the cause was same, that is hypoxia (TOI, 2016a). Fish mortality was also reported from lakes in Andhra Pradesh, Madhya Pradesh and Kerala (TOI, 2016a). Thousands of fish died in Zoo lake in Kanpur in 2016 (TOI, 2016b) and again in Sher Shah Suri lake in Chakeri area in 2017 (TOI, 2017).

Fish mortality has been quite frequent in the Ganges at Kanpur. Thousands of dead fish were found floating in the Ganga near Ganga Barrage and across various city *ghats* (places used for taking a bath) in June 2014 (TOI, 2014). Again in February 2015, thousands of dead fish were found floating at *Dhabka nullah* and *Dhaneshwar ghat* at Jajmau in Kanpur (TOI, 2015). Then again in May 2018, dead fish was found floating at Kannauj and at Bilhaur's Nanamau *ghat* and at Chaubeypur's Andimata and Pratapgarh *ghats* (TOI, 2018b) (Fig. 1). The main cause in most cases has been ascribed to be hypoxia caused by algal blooms.

Phytoplanktons and Eutrophication of Waters

Phytoplankton is microplants present in all water bodies (ponds, lakes, rivers, estuaries, and seas) and forms the base of the aquatic food web. They also produce half of the world's oxygen and are a source of dissolved oxygen in water (Roach, 2004). Algae are also proposed as an important feedstock for bioethanol production (Chaudhary *et al*., 2014). Blue-green algal cultures, known as biofertilizers, are recommended for N-fixation in rice paddies (Dhar and Singh, 2007). However, when in bloom they create dissolved oxygen deficiency in waters. Phytoplankton includes Cyanobacteria (popularly known as blue-green algae), algae, diatoms, and dinoflagellates. Cyanobacteria include *Anabena, Microcystis, Nodularia,* etc., while macroalgae could be *Gracilaria, Cefamium, Polysiphonia* (reds), *Cladosphora* (goat weed), *Chaematophora* (rope weed), *Rhizoclonium, Enteromorpha, Ulva* (sea lettuce), *Caulespa* (grens), *Giffordia* (browns), etc. Diatoms include *Synedra, Chaeticeros, Chlamydomonas, Licomphora, Asterionellopsis, Ceratium, Nitzchia, Skeletonema, Pleurosigma*, etc. Dinoflagellates include *Alexandrium*, *Pyrodinium, Scrippsiella trochoidea*, *Cochlodinium* cf. *helix, Gymnodinium* cf. Karenia, *Galatheanum, Gymnodinium mikimotoi* and *Prymnesium parvum (golden brown). In India, a large diversity of* chlorophycean algal flora was reported in the Ganges at Varanasi and included *Pediastrum, Hydrodictyon, Chlorella* and *Scenedesmus, Pandorina, Eudorina, Enteromorpha, Spirogyra, Zygnema, Cosmarium*, *Closterium, Stigeoclonium* and *Cladophora* (Singh and Chaudhari, 2011). These are only a few examples. There are thousands of species in each group of phytoplankton. Recently Dwivedi and Srivastava (2017) reported that diatoms constituted 61% of the phytoplankton in River Ganges waters at Allahabad. As regards phtoplanktons in freshwater lakes in India, Giripunje *et al.* (2013) reported that most lakes contained Cyanobacteria, but diatoms were present in Dal, Waskur, and Anchor lakes (Jammu and Kashmir), Kitham Lake (Uttar Pradesh), Badualake (Bihar) and Ranchi Lake (Jharkhand).

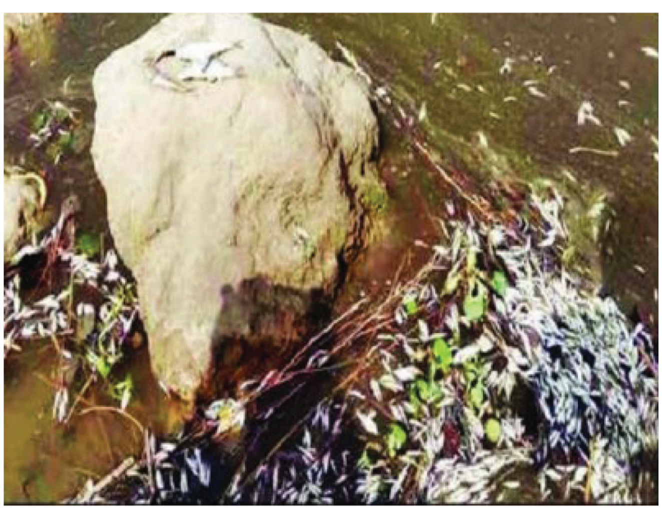

Fig. 1: Dead fish found floating in Ganga on 15 May 2018 at Kanpur
Photo Courtesy: Times of India; reprinted with permission.
(**Editor:** Use this photograph after obtaining permission from Times of India, May 16, 2018)

Algal blooms are most often considered as a consequence of anthropogenic factors, especially phosphorus pollution (Lathrop *et al*., 1998), which is referred to as eutrophication. Carpenter (2008) refers to eutrophication as a syndrome of excessive nutrients, noxious algae, foul smell, and dead zones. The global agricultural P budget indicated that the average annual P accumulation in agricultural areas of the world was 8 Tg yr^{-1} from 1958 to 1998; developed countries contributing about 60% (Benett *et al*., 2001). Part of this P moves to inland waters and Benett *et al*. (2001) suggested P retention of 1.2 Tg yr^{-1} in freshwater ecosystems in the pre-industrial period and about 3.1 Tg yr^{-1} in 1998. The causes of phosphorus pollution of inland and marine waters in addition to agricultural runoff include fossil-fuel burning, wastewater treatment effluents, and detergents in washings (Gilbert and Dejong, 1977). Phosphorus availability is considered critical for algal growth since most algae can fix atmospheric N (Schindler *et al*., 2008). Redfield (1934) had suggested a universal N:P ratio of 16 for good algal growth. However, Klausmeier *et al.* (2004) classified phytoplankton into three groups on the basis of their relative need for N:P ratio in waters: 1. Survivalists- that grow in N:P ratio of 30:1 or more; 2. Bloomers- that can grow in N:P ratio of 10:1 or less, and 3. Generalists-needing an in-between N:P ratio of 16 (close to the ratio suggested by Redfield). Correll (1999), however, pointed out that while P is the limiting nutrient in inland waters, N is the limiting nutrient in marine waters. This is because nitrogen fixation is not observed at salinity levels greater than 10 (g kg^{-1} water), while the mean salinity in marine waters is ~35 (Paerl *et al*., 2004).

Nitrate and Phosphate Concentration in Some Inland Waters in India

Available information on nitrate and phosphate concentration in ponds, lakes, and rivers in India is provided in Tables 1 to 4. Phosphate concentration in Diggi pond in Aligarh in Uttar Pradesh, and lake, groundwater and channel waters in Mysuru district, Karnataka were 1.87 to 6.79 mg L^{-1} (Table 1), which is fairly high and as explained by the authors, this was mainly due to high levels of N and P fertilizers used in the region. High level of N and P fertilizer use could be the main factor responsible for frequent reports of fish kill reported from Karnataka. In the case of Mysuru district, even nitrate concentrations were high enough to damage the fish, which was further accentuated by the presence of urea in the waters. Camargo *et al.* (2005) pointed out that nitrate concentration of 50 mg NO_3-N L^{-1} (WHO safe limit for drinking water by humans) can adversely affect freshwater invertebrates (*E. toletanus, E. echinosetosus, Cheumatopsyche pettiti, Hydropsyche occidentalis),* *fishes (Oncorhynchus mykiss, Oncorhynchus tshawytscha, Salmo clarki)*, and amphibians *(Pseudacris triseriata, Rana pipiens, Rana temporaria, Bufobufo*), at least during long-term exposures.

Similarly, Kincheloe *et al.* (1979) concluded that a nitrate level as low as 10 mg NO_3-NL^{-1} in surface waters would be expected to limit survival of some salmonid fish populations because of impaired reproductive success. Susceptibility to nitrate toxicity is, in general, higher at the egg and early growth stages of fish. Grown-up fish can tolerate much higher nitrate concentration. In a study in India with *Catlacatla* (Hamilton), median lethal concentration (LC50) values for 24 h acute toxicity of nitrate was found to be 1565 mg NO_3-NL^{-1} in static test and 1484 mg NO_3-NL^{-1} in the continuous flow-through test (Tilak *et al.*, 2002). Similarly, Essien-ibok *et al.* (2014) from Nigeria, showed that *Heterobranchus bidorsalis* fingerlings were susceptible to urea in water and mortality rate increased as the concentration of urea increased from 0 g L^{-1} to 16.25 g L^{-1}. Exposed fish showed initial stress responses such as erratic swimming, restlessness, loss of balance, frequent attempts at jumping out of the tank and quietness. Thus in ponds and lakes, high concentrations of both N and P could be responsible for fish mortality.

As regards river waters, phosphate concentration was much higher in northwestern rivers Ravi, Sutlej, and Beas as compared to that in the eastern, western or southern India (Table 1). Data on nitrate and phosphate concentration at three points in Sutlej River in Punjab (Table 2) showed that concentrations were much higher at Budha Nullah at Wallipur, a point near the industrial area of Ludhiana (Jindal and Sharma, 2011). This shows the role of industrial effluents in increasing the nitrate and phosphate content in the Sutlej River. The role of industrial effluents in increasing phosphate concentration is also brought out by the data on River Ganges at, Haridwar, Kanpur, Prayagraj, Varanasi and Patna (Table 3), which was the highest at Kanpur, the most industrial town on Ganges (Vaas *et al.*, 2015), while at Haridwar, where there is no industry, phosphate content was nil. The data in Table 3 also show that phosphate concentrations increased over a period of 36 years (1960–1996), indicating increased pollution of the river water. In the study by Tiwari *et al.* (2016), both nitrate and phosphate levels were the highest at Varanasi (Table 4).

According to the Minnesota Pollution Control Agency (MPCA, 2007) total phosphorus levels of 100 ppb (0.1 mg L^{-1}) or more categorize lakes as highly eutrophic, with high nutrient and algae levels. Thus inland waters in India are highly eutrophic. It is also worth noting that N:P ratio in most Indian inland waters was less than 10, suggesting the possibility of phytoplankton 'Bloomers' as per classification of Klausmeier *et al.* (2004) leading to fish mortality and this has been confirmed by reports discussed earlier.

Sources of N and P in Inland Waters

The primary source of phosphate in ponds, lakes, and rivers are sediments, the upswellings from which provide phosphate to water. This depends upon climatic factors, such as temperature, sunshine, winds, and rains (in the case of marine waters tectonic shifts also

Table 1: Nitrate and phosphate concentration (mg L^{-1}) in inland waters in India

Inland water kind	*Location/ name*	*Season/Other items*	*NO_3 (mg L^{-1})*	*PO_4 (mg L^{-1})*	*N:P[1] ratio*	*Reference*
Diggi Pond	Aligarh (UP)		9.3-11.2	2.4-3.8	2.9-3.9	Khan *et al*. (2014)
Upper lake	Bhopal (MP)	Pre-monsoon	–	0.28-0.47	–	Kundu *et al*. (2015)
		Post-monsoon	–	0.31-0.59	–	
Udaisagar lake	Udaipur (Rajasthan)	Summer 1986	0.45	0.40	1.1	Vijaivergia (2008)
		Summer 2006	0.50	0.56	0.9	
		Rainy 1986	0.74	0.86	0.9	
		Rainy 2006	0.80	0.90	0.9	
		Winter 1986	0.58	0.58	1.0	
		Winter 2006	0.60	0.60	1.0	
Groundwater	Mysuru district (Karnataka)	–	100–1650	2.20–4.23	45.4–888.3	Divya and Belagali (2012)
Lake			40–280	1.87–3.64	21.3–76.9	
Channel			30–120	2.19–6.79	13.6–17.7	
Rivers	Northwest					Vaas *et al*. (2015)
	Ravi	–	–	0.17–0.20	–	
	Sutlej	–	–	0.12–0.15	–	
	Beas	–	–	0.18–0.29	–	
	East					
	Brahmaputra	–	–	Tr-0.02	–	
	Damodar	–	–-	Tr-0.35	–	
	Brahmani	–	–	Tr-0.03	–	
	Mahanadi	–	–	Tr-0.001	–	
	West					
	Narmada	–	–	Tr-0.10	–	
	South					
	Godavari	–	–	0.06–0.18	–	
	Krishna	–	–	0.04–0.30	–	
	Cauvery	–	–	0.02–0.94	–	

[1]N:P ratio calculated by the authors of this paper

Urea content was also reported in Mysuru study. It was 0.6–4.2 mg L^{-1} in groundwater, 0.6–3.40.6–4.2 mg L^{-1} in lake and 0.1-0.80.6–4.2 mg L^{-1} in channel

Table 2: Nitrate and phosphate content in the Sutlej River at three different sites in Punjab

Location	*Season*	*NO_3 (mg L^{-1})*	*PO_4 (mg L^{-1})*	*N:P ratio[1]*
Ropar head works	Winter	0.32–0.43	0.10–0.02	3.2
	Summer	0.40–0.62	0.22–0.27	–2.1
	Monsoon and post	0.53–0.82	0.20–0.32	1.8–2.3
	Monsoon			2.6
Budha Nullah at Phillaour	Winter	0.38–0.62	0.21–0.31	1.8
	Summer	0.80–1.05	0.33–0.50	–2.0
	Monsoon and post	0.82–1.26	0.33–0.57	2.1–2.4
	Monsoon			2.2–2.5
Budha Nullah at Wallipur (Industrial area of Ludhiana)	Winter	0.80–1.30	0.52-0.70	1.5-1.8
	Summer	1.10–1.35	0.67-0.98	1.4-1.6
	Monsoon and post Monsoon	1.16–1.62	0.76-1.10	1.5

[1]Calculated by the authors of this paper Source: Jindal and Sharma (2011)

Table 3: Phosphate content (PO4 mg L^{-1}) in the Ganges at different locations during 1960–1996

Location	1960	1980	1996
Haridwar	–	Tr	0.04
Kanpur	0.07–0.21	0.01-2.10	Tr-2.50
Allahabad	0.09–2.00	0.11–0.32	Tr-0.8
Varanasi	0.08–0.12	0.12–0.73	Tr-1.0
Patna	0.07–0.11	–	Tr-0.01

Source: Vaas *et al*. (2015)

Table 4: Nitrate and phosphate concentration in Ganges river water at three locations

Location	*Quality parameter*	*Summer*	*Monsoon season*	*Winter*
Kanpur	Temperature (°C)	28	20	17
	pH	8.8	8.2	8.5
	Nitrate (mg L^{-1})	1.70	0.45	0.94
	Phosphate (mg L^{-1})	1.58	0.66	0.82
	Nitrate:Phosphate ratio[1]	1.07	0.68	1.14
Allahabad	Temperature (°C)	27	22	17
	pH	8.2	7.6	7.9
	Nitrate (mg L^{-1})	1.5	1.4	0.23
	Phosphate (mg L^{-1})	1.50	0.63	0.78
	Nitrate: Phosphate ratio	1.0	2.2222w	0.29
Varanasi	Temperature (°C)	27	25	20
	pH	8.2	7.7	8.0
	Nitrate (mg L^{-1})	2.6	2.4	2.1
	Phosphate (mg L^{-1})	1.42	1.11	1.37
	Nitrate: Phosphate ratio	1.83	2.16	1.53

[1]Calculated by the authors of this paper Source: Tiwari *et al*. (2016)

play an important role). Banerji *et al*. (2009) reported a critical level of 200 mg N kg^{-1} soil, 13 mg P kg^{-1}soil and 80 mg K kg^{-1}soil for fish ponds in red and lateritic soils for fish production.

In addition to native soil and sediment nitrate and phosphate, most researchers have pointed out that heavy application of N and P fertilizers is a major cause of eutrophication of inland and marine water (Kaur and Singh, 2012). Nitrates leach down the profile and have been a cause of concern in groundwater in several parts in India (Bijai-Singh *et al*., 1995; Prakasa Rao and Puttanna, 2000; Prasad, 2013). Similarly in China, over half of the groundwater samples in Northern China were found to contain higher than 50 mg NO_3-NL^{-1}, the WHO safe limit for drinking water by humans; some contained even higher than 300 mg NO_3-NL^{-1} (Gao and Zhang, 2010). Although some leaching of phosphates is likely (Rashmi *et al*., 2018), most P generally gets fixed by reacting with Ca, Fe and Al ions or gets sorbed on the surfaces of clay mineral particles and oxides and hydroxides of Al and Fe (Sumner and Farina, 1986; Prasad *et al*., 2016). Thus most fertilizer P remains in surface soil near the place, where it is applied and reaches the inland and marine waters by surface run-offs during rains and floods. The amount of P loss depends on amounts applied, soil erodibility, land cover, and cultivation practices (Sharpley *et al*., 2000). In a study in China, an application of 0, 25, 60, 120, and 240 kg P/ha in rice resulted in a loss of 0.13, 0.50, 0.94, 3.02, and 5.97 kg P ha^{-1} to runoff water (Xia *et al*., 2008). The period of most risks of P loss from rice field was within 1-2 months after the application (Zhang *et al*., 2007). Surface runoffs would also include some nitrates and ammonium N, especially when high rates are applied. Freshwater animals appear to be more sensitive to nitrate than marine animals.

Both lake and river waters also get a lot of untreated sewage sludge. Phosphorus concentration in the municipal solid waste can vary from 0.18 to 0.94% P (~0.54-2.82% PO_4) (Rose *et al*., 2015), while in wastewater it is 0.5 mg L^{-1} (~1.5 mg PO_4L^{-1}) (Strom, 2006). Thus sewage sludge could be a major contributor of phosphate to lake and river waters near big towns.

Detergent washings could be another important source of P. About 2.88 million tonnes per year of detergent (containing 8-35 % of sodium triphosphate) is used in India, resulting in an outflow of 146 thousand tonnes per year of detergent (40,000 tonnes per year of P) (Kundu *et al*., 2015).

Morse *et al*. (1993) reported that the contribution of different sources towards phosphorus eutrophication of European waters was as follows: fertilizer 16%, livestock 34%, detergents 10%, human and household waste 24%, industry 7% and background sources 9%. Similarly, a pollution study found that the livestock is the largest contributor to run-off from the land into waterways and through manure is responsible for 56% of P discharge, while cropland contributed only 11.4% (Qiu, 2010).

Algal Blooms and Hypoxia

Hypoxia (lack of adequate oxygen) due to algal blooms has been ascribed to be the most common cause of fish mortality. The desired level of dissolved oxygen in waters for fish would vary depending upon the species and several other factors, such as temperature, salt content, alkalinity, pH, etc. Dissolved oxygen is high at low temperatures and declines as the temperatures rise. At 20°C and one atmosphere of pressure a maximum of 9 mg L^{-1}oxygen can dissolve in fresh water, and it decreases by 1 mg L^{-1} for each 10°C increase in water temperature above 20°C. This would partly explain why oxygen concentrations in Ganges waters are lower in summer and monsoon season than in winter (Table 5). According to USEPA (1986), the desired level of oxygen for fish is 4–8 mg L^{-1}, while a level of 3 mg L^{-1} or less could lead to mortality. Franklin (2014) from New Zealand also recommended the desired level of dissolved oxygen for fish survival to be 3.5–8 mg L^{-1}. Dean and Richardson (1999) from New Zealand reported that freshwater fish were most sensitive to depletion of dissolved oxygen and 50% mortality occurred due to exposure to an oxygen level of 1 mg L^{-1} for 0.6 to 1 hour. The available data (Table 5) from India suggest that levels of dissolved oxygen are reasonably good for the survival of fish; the oxygen levels are slightly lower during monsoon season. Water temperatures of 17–25°C are also good and pH is alkaline (Table 4). All of these factors are good for fish survival.

Causes of Fish Mortality Other Than Hypoxia

Neurotoxins and Methanol

Red tides, as reported from Florida coast in the USA, had high concentrations of the harmful dinoflagell*ate Karenia brevis,* which produced neurotoxins brevetoxins, that caused massive fish kills and marine mammal, sea turtle and sea bird mortalities (Pierce and Henry, 2008). The primary mode of action of brevetoxins is binding to voltage-gated sodium channels causing depolarization of nerve cells, thus interfering with nerve transmission. Other effects include immune depression, bronchial constriction, and hemolysis.

Even green algal blooms due to Cyanobacteria also produce toxins. Mass fish mortality due to toxin-producing cyanobacterial blooms was registered during December 2003 in Marechal Dutra Reservoir Acari/RN in Northeast Brazil (Chellappa *et al.*, 2008). The toxic blooms of *Cylindrospermopsis raciborskii* and *Microcystis aeruginosa* produced neurotoxin microcystin, which lethally affected fishes *Oreochromis niloticus, Plagioscion squamosissimus, Cichla monoculus, Prochilodus brevis, Hoplias malabaricus* and *Leporinus friderici*.

Phytoplankton is also a major source of methanol (Mincer and Aicher, 2016); in their studies all phytoplankton tested (Cyanobacteria: *Synechococcus spp*. 8102 and 8103, *Trichodesmium erythraeum, and Prochlorococcus marinus*), and Eukarya (heterokont diatom: *Phaeodactylum tricornutum*, coccolithophore: *Emiliania huxleyi*, cryptophyte: *Rhodomonas salina*, and non-diatom heterokont: *Nannochloropsis oculata*) produced methanol, ranging from 0.8–13.7 µM micromoles in culture and methanol per total cellular carbon were measured in the ranges of 0.09–0.3%.Methanol is toxic to aquatic and non-aquatic animals. Ninety-six-hour acute toxicity tests by Kaviraj *et al*. (2004) revealed that water fleas *Cladoceran crustacea* and *Moina micrura* were the most sensitive to methanol toxicity (LC50, 4.82 g L^{-1}), followed by freshwater teleost fish *Oreochromis mossambicus* (LC50, 15.32 g L^{-1}) and oligochaete worm *Branchiura sowerbyi* (LC50, 54.89 g L^{-1}). The fish, when exposed to lethal concentrations of methanol, showed difficulties in respiration and swimming. The oligochaete's bodies wrinkled and fragmented under lethal exposure of methanol. Chronic toxicity bioassays (90 days) in outdoor enclosures showed a reduction in growth, maturity index and fecundity of fish at 47.49 mg L^{-1} or higher concentrations of methanol. Chronic exposure to

Table 5: Dissolved oxygen (mg L^{-1}) in the Ganges River at three locations

Location	*Summer*	*Monsoon*	*Winter*
Kanpur	4	3	4.8
Allahabad	5	4	6
Varanasi	4	3.3	5

Source: Tiwari *et al*. (2016)

1527.6 mg L^{-1} methanol resulted in damages of the epithelium of primary and secondary gill lamellae of the fish. The results revealed 23.75 mg L^{-1} as the no-observed-effect concentration (NOEC) of methanol to the freshwater aquatic ecosystem.

Neurotoxins and methanol produced by algal blooms can be also toxic to cattle drinking water from ponds and lakes, especially during summer months.

Heavy Metals

Industrial effluents from the industries located at Kanpur, Varanasi, and Kolkata include heavy metals, such as cadmium, lead, and mercury, copper, cobalt, and zinc in River Ganges (Kannan *et al*., 1993; Sinha, 2004; Paul, 2017). Similarly, Pal *et al*. (2017) reported heavy metal pollution of Yamuna water at Mathura. Shah *et al*. (2017) from Gujarat reported heavy metals affected the reticuloendothelial system and hematopoiesis, changing osmotic resistance of erythrocytes and the red and white blood cells at different stages of the pathological process were subjected to quantitative and qualitative deformation in fish Labeo rohita. Cadmium, lead, and mercury is reported to be significant contributors to central nervous system morbidity in fish (Green and Planchart, 2018). Copper sulfate is generally employed to control algal growth (Raman and Cook, 1986), however, at higher rates, it could be toxic to fish (Richey and Roseboom, 1978; Oaifa *et al*., 2004).

Pesticide Residues

About 2,573 tonnes pesticides, mainly DDT and BHC-Y have applied annually for pest control in India (Sinha, 2007) and their residues would find a way into inland waters. Toxic effects of pesticides on aquatic life are well known (Larson *et al*., 1997). Organochlorine pesticides and polychlorinated biphenyls (PCBs) (Kannan *et al*., 1994), and butyltin compounds in Ganges river are a threat to dolphins. Thus the continued use of organochlorine pesticides and PCBs in India is of concern for fish production (Kannan *et al*., 1994, 1995; Kole and Bagchi, 1995).

Conclusion

Increasing concentration of phosphorus in inland waters is the main cause for the formation of algal blooms leading to hypoxia and the mortality of fish and other aquatic animals. Although most researchers suggest that phosphorus in runoffs from agricultural fields is the major cause for the addition of P to inland waters, the European study by Morse *et al*. (1993) suggests that other sources such as livestock excreta, detergents, human and household waste and industrial effluents also contribute considerably towards phosphate addition to inland and marine waters. Thus the preventive measures to reduce phosphate addition to inland waters is needed not only at reducing phosphate fertilizer addition to agricultural fields but also in reducing the flow of industrial effluents and household wastes including washings involving detergents to inland waters. Addition of pesticide residues in runoffs from agricultural fields and heavy metals through industrial effluents also needs to be reduced.

References

1. Anderson, D.M. 1989. Toxic algal blooms and red tides: A global perspective. In: Okaichi, T. *et al*. (Eds.), Red Tides: Biology, Environmental Science, and Toxicology, Elsevier, New York, pp. 11-16.
2. Banerjee, A., Chattopadhyay, G.N. and Boyd, C.E. 2009. Determination of critical limit of soil nutrients for use in optimizing fertilizer rate for fish ponds in red, lateritic soil zones. Aquaculture Engineering 40(3):144-148.
3. Benette, E.M., Carpenter, S.R. and Caracao, N, F. 2001. Human impact on erodible phosphorus and eutrophication: A global perspective. BioScience 15:227-234.
4. Benjamin, R., Chakrapani, B.K., Devashish, K., Nagarathna, A.V. and Ramachandra T.V. 1996. Fish Mortality in Bangalore Lakes, India. UCLA Electronic Green Journal, published 1996-12-01, ISSN1076-7975 (https://escholarship.org/uc/item/00d1m13p)
5. Camargo, J.A., Alonso, A. and Salamanca. A. 2005. Nitrate toxicity to aquatic animals: A review with new data for freshwater invertebrates. Chemosphere 58:1255-1267.
6. Carpenter, S.R. 2008. Phosphorus control is critical to mitigating eutrophication. Proceedings National Academy of Sciences, USA 106(32):11039-11040.
7. Chaudhary, L., Pradhan1, P., Nishant Soni, N., Singh, P. and Tiwari, A. 2014. Algae as a feedstock for bioethanol production: New entrance in biofuel world. International Journal of ChemTech Research 6(2):1381-1389.
8. Chellappa, N.T., Chellappa, S.L. and Chellappa, S. 2008. Harmful phytoplankton blooms and fish mortality in a eutrophicated reservoir of northeast Brazil. Brazilian Archives of Biology and Technology 51(4):833-841.
9. Correll, D.L. 1999. Phosphorus: A rate limiting nutrient in surface waters. Poultry Science 78:674-682.
10. D'Silva, M.S., Anil, A.C., Naik, R.K. and D'Costa, P.M. 2012. Algal blooms: A perspective from the coasts of India. Natural Hazards 63:1225-1253.
11. Dean, T.L. and Richardson, J. 1999. Response of seven species of native fresh water fish and a shrimp to low levels of dissolved oxygen. New Zealand Journal of Marine and Freshwater Research 33(1):99-106.
12. Dhar, D.W. and Singh, B.V. 2007. Comparative performance of three carrier based blue green algal biofertilizers for sustainable rice cultivation. Journal of Sustainable Agriculture 30(2):41-50.
13. Diaz, R. J. and Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321(5891):926-929.
14. Divya, J. and Belagali, S.L. 2012. Impact of chemical fertilizers on water quality in selected agricultural areas of Mysuru district, Karnataka, India. International Journal of Environmental Sciences 2(3):1449-1458.
15. Dwivedi1, B.K. and Srivastava, A.K. 2017. Diatoms as Indicator of Pollution Gradients of the River Ganga, Allahabad, India. International Journal of Current Microbiology and Applied Sciences 6(7):4323-4334.
16. Essien-ibok M. A, Asuquo I. E and Ekpo I. E. 2014. The assessment of acute toxicity of urea fertilizer against Heterobranchus bidorsalis fingerlings. Global Journal of Fisheries and Aquaculture 2(5):169-176.
17. Flewelling, L.J., Naar, J.P., Abbott, J.P., Baden, D.G., Barros, N.B., Bossart, G.D., Bottein, M.Y., Hammond, D.G., Haubold, E.M., Heil, C.A., Henry, M.S., Jacocks, H.M., Leighfield, T.A., Pierce, R.H., Pitchford, T.D., Rommel, S.A., Scott, P.S., Steidinger, K.A., Truby, E.W., Van Dolah, F.M. and Landsberg, J.H. 2005. Brevetoxicosis: Red tides and marine mammal mortalities. Nature 435(7043):755-756.
18. Franklin, P.A. 2014. Dissolved oxygen for fresh water fish in New Zealand: A revised approach. New Zealand Journal of Marine and Freshwater Research 48(1):112-126.
19. Gao, C. and Zhang, T. 2010. Eutrophication in a Chinese context: Understanding various physical and socio-economic aspects. Ambio 39(5-8):385-393.
20. Gilbert, N. 2015. Europe sends alarm on fresh water pollution. Nature News March 2, 2015.
21. Gilbert, P. A. and Dejong, A. L. 1977. The use of phosphate in detergents and possible replacements for phosphate. Ciba Foundation Symposium 57:253-268.
22. Giripunje, M.D., Fulke, A.B., Khairnar, K., Meshram, P.U., Waman N. Paunikar, W.N. 2013. A review of phytoplankton ecology in freshwater lakes in India. Lakes, Reservoirs and Ponds 7(2):127-141.
23. Grattan, L.M., Holobaugh, S. and J. Glenn Morris, Jr. 2016. Harmful Algal Blooms and Public Health. Harmful Algae 57(B):2-8.
24. Green, A.J. and Planchart, A. 2018. The neurological toxicity of heavy metals: A fish perspective. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 208:12-19.
25. Hallegraeff, G.M. 1992. Harmful algal blooms in the Australian region. Marine Pollution Bulletin 25(5-8):186-190.
26. Hilborn, E.D. and Beasley, V.R. 2015.On health and Cyanobacteria in freshwater systems: animal illnesses and deaths are sentinel events for human health risks. Toxins (Basel) 7(4):1374-1395.
27. Iwayama, A., Ogura, H., Hirama, Y., Chang, C-W., Hsieh, C-H and Kagami, M. 2017. Phytoplankton species abundance in Lake Inba (Japan) from 1986 to 2016. Ecological Research 32(6):783-783.
28. Jin, X.C. 2003. Analysis of eutrophication state and trend of lakes in China. Journal of Limnology 62(2):60-66.
29. Jindal, R. and Sharma, C. 2011. Studies on water quality of Sutlej River around Ludhiana with reference to physico-chemical properties. Environmental Monitoring and Assessment 174:417-425.
30. Kannan, K., Sinha, R.K., Tanabe, S., Ichihashi, H. and Tatsukawa, R. 1993. Heavy metals and organochlorine residues in Ganges river dolphins from India. Marine Pollution Bulletin 26:159-162.
31. Kannan, K., Tanabe, S., Tatsukawa, R and Sinha, R.K. 1994. Biodegradation capacity and residue pattern of organochlorines in Ganges river dolphins from India. Toxicological and Environmental Chemistry 42:249-261.
32. Kannan, K., Tanabe, S. and Tatsukawa, R. 1995. Geographical distribution and accumulation features of organochlorine residues in fish in tropical Asia and Oceania. Environmental Science and Technology 29:2673-2683.
33. Kannan, K., Senthilkumar, K. and Sinha, R.K. 1997. Sources and accumulation of butyltin compounds in Ganges river dolphin, Platanista gangetica. Applied Organmetallic Chemistry 11:223-230.
34. Kaur, S. and Singh, I. 2012. Accelerated phosphate and nitrate level: factors to blame for eutrphication in Yamuna River, Delhi. International Journal of Plant, Animal and Environmental Sciences 2(3):183-187.
35. Kaviraj, A., Bhunia, F. and Saha, N.C. 2004. Toxicity of methanol to fish, crustacean, oligochaete worm, and aquatic ecosystem. International Journal of Toxicology 23:55-63.
36. Khan, F.A., Naushin, F., Masoodi, A., Ifran, M., Hashmi, F. and Ansari, A.A. 2014. Eutrophication: global scenario and local threat to dynamics of aquatic system. In: Ansari, A.A. and Gill, S.S. Eds.), Eutrophication: Causes, Consequences and Control, Vol. 2. Springer (http://www.springer.com/978-94-007-7813-9).
37. Kincheloe, J.W., Wedemeyer, G.A. and Koch, D.L. 1979. Tolerance of developing salmonid eggs and fry to nitrate exposure. Bulletin Environmental Contaminant Toxicology 23:575-578.
38. Klausmeier, C.A., Litchman, E., Daufresne, T. and Levin, S.A. 2004. Optimal nitrogen to phosphorus stoichiometry of phytoplankton. Nature 429(6988):171-174.
39. Kole, R.K. and Bagchi, M.M. 1995. Pesticide residues in the aquatic environment and their possible ecological hazards. Journal of Inland Fisheries Societies of India 27(2):79-89.
40. Kundu, S., Coumar, V., Rajendiran, S., Kumar, A. and Subba Rao, A. 2015. Phosphate from detergents and eutrophication of water ecosystems of India. Current Science 108(7):1320-1325.
41. Landsberg, J.H. (2002). The effects of harmful algal blooms on aquatic organisms. Reviews in Fisheries Science 10(2):113-390.
42. Larson, S.J., Capel, P.D. and Majewski, M.S. 1997. Pesticides in Surface Waters: Distribution, Trends and Governing Factors, CRC Press, Boca Raton, FL, USA.
43. Lathrop, R.C., Carpenter, S.R., Stow, C.A., Soranno, P.A. and Panuska, J.C. 1998. Phosphorus loading reductions needed to control blue-green algal blooms in Lake Mendota. Canadian Journal of Fisheries and Aquatic Sciences 55(5):1169-1178.
44. Lin, Q., Hu, C., Wang, M., Shang, S. and Wilson, C. 2017. Floating algae blooms in theeast China Sea Geophysical Research Letters First published: 26 October 2017 (https://doi.org/10.1002/2017GL075525)
45. Liu, C.L., Tang, D. L. and Nguyen-Ngoc, L. 2009. Variations in the dominant algal bloom-forming species in the western South China Sea from 1993 to 2007. African Journal of Marine Science 31(3):373-380.

46. Malakoff, D. 1998. Death by suffocation in the gulf of Mexico. Science 281:190-192.
47. Mincer, J.J. and Aicher, A.C. 2016. Methanol production by a broad phylogenetic array of phytoplankton. PLoS One 11(3):e0150820.
48. Morse, G.K., Lester, G.N. and Perry, R.T. 1993. The Economic and Environmental Impact of Phosphorus Removal from Waste Water in the European Community. Selper Ltd., London, U.K. pp. 92.
49. MPCA. 2007.Phosphorus: Sources, Forms, Impact on Water Quality - A General OverviewMinnesota Pollution Control Agency, St. Paul, MN, USA Water Quality #Impaired Waters #3.12 July 2007 (www.pca.state.mn.us)
50. Oaifa, F.E., Oaifa A.K and Onwude, T.E. 2004. Lethal and sub-lethal effects of copper on the African catfish (Clarias gariepinus) juveniles. African Journal of Biomedical Research 7:65-70
51. Padmakumar, K.B., Menon, R. and Sanjeevan, V.N. 2012. Is occurrence of harmful algae blooms in the exclusive economic zones of India on the rise? International Journal of Oceanography Vol 2012 Article ID 263946, 7 pages (htt://dx.doi.org/10.1155/2012/263946).
52. Paerl, H.W. and Fulton III, R.S. 2006. In Ecology of Harmful Marine Algae (E Graneli and J Turner Eds.), Springer, Berlin, pp. 95-107.
53. Paerl, H.W.,Valdes, L.M., Joyner, A.R., Piehler, M.F. and Lebo, M.F. 2004.Solving problems resulting from solutions: evolution of a dual nutrient management strategy for the eutrophying Neuse River estuary, North Carolina. Environmental Science and Technology 38:3068-3073.
54. Pal, R., Dubey, R.K., Dubey, S.K., Singh, A.K. and Sharma, T.C. 2017. Assessment of heavy metal pollution of Yamuna water in Mathura region through index analysis approach. International Journal of Chemical Studies 5(6):1286-1289.
55. Paul, D. 2017. Research on heavy metal pollution of river Ganga: A review. Annals of Agrarian Science 15(2):278-286.
56. Pierce, R.H. and Henry, M.S. 2008. Harmful algal toxins of the Florida red tide (Karenia brevis): natural chemical stressors in South Florida coastal ecosystems. Ecotoxicology 17(7):623-631.
57. Prakasa Rao, E.V.S. and Puttanna, K. 2000. Nitrates, agriculture and environment. Current Science 79(9):1163-1168.
58. Prasad, R. 2013. Fertilizer nitrogen, food security, health and the environment. Proceedings Indian National Science Academy 79B(4):997-1010.
59. Prasad, R., Shivay, Y.S., Majumdar, K. and Prasad, S. 2016. Phosphorus Management. In: Lal, R. and Stewart, B.A. (Eds.) Soil Phosphorus, CRC Press, Boca Raton, FL, USA, pp. 81-113.
60. Puschner, B., Galey, F.D., Johnson, B., Dickie, C.W., Vondy, M., Francis, T. andHolstege D.M.1998. Blue-green algae toxicosis in cattle. Journal of American Veterinary Medical Association 213(11):1605-1607, 1571.
61. Qiu, J. 2010. Phosphate fertilizer warning for China, Nature, published online September 2010 (doi: 10.1038/news.2010.498)
62. Raman, R.K. and Cook, B.K. 1986. Optimal chelant/copper ratios for maximizing copper solubility in natural waters using citric acid and triethanolamine. Illinois State Water Survey Contract Report 392:52.
63. Rashmi, I., Biswas, A.K., Parama, V.R.R., Athifa, M. and Ramteke, L. 2018. Soil test indices for phosphorus leaching in selected Vertisols and Inceptisols of India. Proceedings National Academy of Sciences, India Section B: Biological Sciences 88(3):867-874.
64. Redfield, A.C. 1934. On the proportion of organic derivatives in sea water in relation to the composition of phytoplankton. In: James, J. and Jellicoe, D.R. (Eds.) James Johnston Memorial Volume, University of Liverpool, Liverpool, U.K.
65. Richey, D. and Roseboom, D. 1978. Acute toxicity of copper to some fishes in high alkalinity water. Illinois State Water Survey Circular 131:24.
66. Roach, J. 2004. Source of Half Earth's Oxygen Gets Little Credit. National Geographic News. June 7, 2004.
67. Rose, C., Parker, A., Jefferson, B. and Cantrell, E. 2015. The characterization of feces and urine: A review. Critical Reviews in Environmental Science and Technology 45(17):1827-1879.
68. Schindler, D.W., Hecky, R.E., Findlay, D.L., Stainton, M.P., Parker, B.R., Patterson, M.J., Beaty, K.G. and Kasian, S.E. 2008. Eutrophication of lakescannot be controlled by reducing nitrogen inputs: Results of a 37 year whole ecosystem experiment.Proceedings National Academy of Sciences, USA 105:11254-11258.
69. Science Daily 2015. Harmful algal blooms in the Chesapeake Bay are becoming more frequent. University of Maryland Center for Environmental Science, (USA), Science Daily May 11, 2015.
70. Sengupta, M., Anandurai, R., Nanda, S. and Datti, A.A. 2017. Geospatial identification of algal blooms in inland waters: A post cyclone case study of Chilka Lake, Odisha, India. RASAYAN Journal of Chemistry 10(1):234-239.
71. Shah, A.I. 2017. Heavy metal impact on aquatic life and human health-An overview. Paper presented at 37th Annual Conference of the International Association for Impact Assessment of Climate Change, 4-7 April 2017, Le Centre Sheraton, Montréal , Canada (www.iaia.org).
72. Sharpley, A.N., Foy, R. and Withers, P. 2000. Practical and innovative measures for control of agricultural phosphorus losses to water: An overview. Journal of Environmental Quality 21:30-35.
73. Singh Benares, India, R.N. 1953. Limnological relations of Indian inland waters with special reference to waterblooms. Internationale Vereinigungfür Theoretische und Angewandte Limnologie: Verhandlungen 12(1):831-836.
74. Singh, A.P. and Choudhary, B.R. 2011. Phenological diversity of Chlorophycean algae for River Ganges at Varanasi, Uttar Pradesh. Journal of Algal Biomass Utilization 2(1):21-29.
75. Singh, B. Singh, Y. and Sekhon, G.S. 1995. Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countries. Journal of Contaminant Hydrology 20(3):167-185.
76. Sinha, R.K. 2004. Monitoring of heavy metal load in the River Ganga at Varanasi. Final Technical Report Submitted to National River Conservation Directorate, Ministry of Environment and Forests, Government of India, New Delhi.
77. Sinha, R.K. 2007. Impact of man-made and natural hazards on fisheries of the river Ganga in India. In: Goswami, U.C. (Ed.) Natural and Anthropogenic Hazards on Fish and Fisheries. Inland Fisheries Society of India, Barrackpore, West Bengal. pp. 245-261.
78. Solim, S.U. and Wanganeo, A. 2008. Excessive phosphorus loading to Dal lake India: Implications of managing shallow eutrophic lakes in submerged watersheds. Internationale Revue Gesamten Hydrologie und Hydrographie 93(2):148-166.
79. Starr, M., Lair, S., Michaud, S., Scarratt, M., Quilliam, M., Lefaivre, D., Robert, M., Wotherspoon, A., Michaud, R., Ménard, N., Sauvé, G., Lessard, S., Béland, P and Measures, L. 2017. Multispecies mass mortality of marine fauna linked to a toxic dinoflagellate bloom. PLoS ONE 12(5):e0176299. https://doi.org/10.1371/journal.pone.0176299.
80. Stoecker, D.K. 1999. Mixotrophy among Dinoflagellates. The Journal of Eukaryotic Microbiology 46(4):397-401.
81. Stone, R. 2017. On lake Taihu-China moves to battle massive algae blooms. Yale Environment 360, July 21, 2011.
82. Strom, P.F. 2006. Introduction to phosphorus removal. Paper presented at Waste Water Treatment Operators Workshop, 91st Annual Meeting, New Jersey Water Environment Association, Atlantic City, NJ, USA, 1-5 May, 2006.
83. Sumner, M.E. and Farina, M.P.W. 1986. Phosphorus interactions ith other nutrients and lime in field cropping systems. Advances in Soil science 5:201-236.
84. Tilak, K.S., Lakshmi, S.J. and Susan, T.A. 2002. The toxicity of ammonia, nitrite and nitrate to the fish, Catlacatla (Hamilton). Journal of Environmental Biology 23(2):147-149.
85. Tiwari, A., Dwivedi, A.C. and Mayank, P. 2016. Time scale changes in the water quality of the Ganges River, India and estimates of sustainability for exotic and hardy fishes. Hydrology Current Research 7:254.
86. TOI 2014. Thousands of fish die in Ganga. Times of India, Kanpur, June 27, 2014.
87. TOI 2015. Dead fish found floating in Ganga. Times of India, Kanpur, February, 22, 2015.
88. TOI 2016a. Bengaluru lakes have seen most fish kill incidents in a decade-IISC study. Times of India, Bengaluru, May 12, 2016.
89. TOI 2016b. Thousands of fishes found dead in the lake of Kanpur Zoo. Times of India, Kanpur, July 17, 2016.
90. TOI 2018a. Algae blooms leading to fish death of Mumbai. Times of India, Mumbai, May 4, 2018.

91. TOI 2018b. Dead fish found floating as oxygen levels dip in Ganges. Times of India, Kanpur, May 16, 2018.
92. TOI 2017. Kanpur administration acts after fish die in historical Sher Shah Suri lake in Chakeri's Lal Bagh area. Times of India, Kanpur, June 13, 2017.
93. USEPA 1986. Ambient Water Quality Criteria for Dissolved Oxygen. United States Environmental Protection Agency, pp. 46.
94. USEPA 2017. Harmful algal blooms are a major environmental problem in all fifty states of USA. Web Snapshot January 19, 2017.
95. Vaas, K.K., Wangeneo, A., Samanta, S., Adhikari, S. and Muralidharan, M. 2015. Phosphate dynamics, eutrophication and fisheries in the aquatic ecosystems in India. Current Science 108(7):1306-1314.
96. Vijaivergia, R.P. 2008. Eutrophication: A case study of highly eutrophicated Lake Udaisagar, Udaipur (Rajasthan), India with regard to its nutrient enrichment and emerging consequences. In: Sengupta, M. and Dalwani, R. (Eds.) Proceedings of Taal 2007: The 12th World lake Conference, pp. 1557-1560.
97 Williams, A.B. 2018. Florida alga crisis. USA Today, August 16, 2018.
98. WRC 1998. Algal blooms. Water and River Commission, Government of Western Australia, Water Facts No. 6.
99. Xia, T.X., Li, W.C. and Pan, J.Z. 2008. Risk assessment on soil environment quality and losses of nitrogen and phosphorus for the gravel soils under different farming practices in the watershed of Lake Fuxian. Journal of Lake Science 20:110-116.
100. Xie, Q. 2018. Green invasion in surreal images show a neon Chinese fresh water lake infested with monstrous algae bloom that suffocates all living creatures in water. Daily Mail Online August 13, 2018.
101. Zhang, Z.J., Zhang, J.Y. He, R. Wang, Z.D. and Zhu, Y.M. 2007. Phosphorus interception in floodwater of paddy field during the rice growing season in Tai Lake Basin. Environmental Pollution145:425-433.
102. Zhou, M.J., Shen, Z.L. and Yu, R.C. 2008. Responses of a coastal phytoplankton community to increased nutrient from Changjiang (Yangtze) River. Continental Shelf Research 28:1483-1489.