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INCREASING CARBON POLLUTION CONSTRAINS THE GROWTH OF BENTHIC DIATOMS IN GANGA RIVER

Usha Pandey
Department of Botany, Faculty of Science and Technology
M.G. Kashi Vidyapith, Varanasi-221002 (Uttar Pradesh) India.
Email: u_pandey28@rediffmail.com

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ABSTRACT

Carbon pollution of freshwater ecosystems causes predictable decreases in the depth of light penetration. Tests of dissolved organic carbon (DOC) enrichment on the fates of benthic light climate with concurrent effects on periphytic diatoms in the Ganga River is lacking. This study, conducted along a 37 km gradient of the Ganga River, indicated rising concentration of DOC downstream point sources and downstream Varanasi city. High turbidity and concentration of DOC with a concurrent decline in the depth of light penetration (Secchi depth) lead to a significant decline in the abundance of periphytic diatoms. Site with highest DOC showed lowest Secchi depth and poorest dominance of study species. This study shows that increasing concentration of DOC and turbidity over time, which is expected to rise due to tourism-driven increase in the frequency of boating, will alter the light climate and consequently the population of benthic diatoms. Because benthic diatoms oxygenate the bottom, the study has relevance for sediment P-driven eutrophy, waste assimilation capacity, resilience and fisheries in the Ganga River.

***Keywords*:**Carbon pollution; Diatoms; DOC; Eutrophication; Ganga River; Resilience.

Introduction

The Ganges River is the largest river system of India. This trans-boundary perennial river traverses 2525 km in the country from Gangotri in the Himalaya to the Ganga Sagar in the West Bengal. Its basin represents over 26% of the geographical area of the country. The river basin represents over 73% agricultural lands with intensive agricultureas a major share that contributes large amount of carbon, nutrients, pesticides etc., reaching to the river. The river is divisible into three reaches - the upper, middle and the lower, wherein the middle reach, particularly the stretch between Kanpur and Varanasi is the most polluted segment (CPCB, 2013). While traversing its 2525 km long course, the river receives about 2723 MLD of sewage of which over 56% is flushed to the river without treatment (CPCB, 2013). In addition, it receives large amount of effluents released directly and indirectly from large and small industries placed all along its tract. Varanasi region is also a highly polluted belt of the Ganga River. Its two tributaries (now converted into drains) – Assi and Varuna situated up and downstream Varanasi city, respectively, add massive amount of sewage and waste water to the river. Also, atmospheric deposition adds substantial amount of organic carbon to the river in this region (Yadav and Pandey, 2017).

The Ganga-Brahmaputra River system is the largest transporter of carbon and sediment to the Bay of Bengal. This river system transport about 7 Tg of carbon each year reaching to the Bay of Bengal (Aitkenheadand Mc Dowell, 2000). Organic carbon in the river originates from two major sources– nutrient driven eutrophy where autochthonous C is generated through primary productivity; andallochthonous C which is added mainly by point and non-point polluting sources (Pandey *et al.*, 2014;Yadav and Pandey, 2017). Both these forms of organic carbon- measured as total organic carbon (TOC) and dissolved organic carbon (DOC) are balanced by source-sink linkages including CO_2 emission, sediment preservation and transport. Auto- and allochthonous sources of carbon are responsible for C-eutrophy and constitute an important attribute of health of surface waters (Jaiswal and Pandey, 2019). These sources of C force the river to work as C-digester and deplete dissolved oxygen. Both the forms of carbon, especially DOC, imparts turbidity and consequently, reduces the light penetration.

Among the primary producers, the lotic systems such as rivers and streams support a diversity of periphytic communities constituting mainly Cyanophycean, Chlorophycean and Bacillariophycean algal species. Benthic diversity of primary producers is important because they oxygenate the bottom and water column and help maintaining desired level of dissolved oxygen.Among the periphytic primary producers, diatoms (Bacillariophyceae) are important group of primary producers that effectively utilize silica and nutrient derived from benthic sediment. For this reason, nutrients are generally not a limiting factor for periphytic diatoms in rivers and streams. Instead, the benthic periphytic communities are largely constrained by availability of suitable light climate in the bottom (Pandey, 2013). Light penetration reaching to benthic primary producer is a function of water column turbidity where DOC plays important role (Pandey and Pandey, 2012; Pandey, 2013). Recent researches conducted in the middle segment of the Ganga River have indicated that the DOC in the river is rapidly rising. In addition to direct flushing from urban-industrial sources, atmospheric deposition-driven stimulated carbon has become an important causation of DOC rise in the Ganga River (Pandey *et al*., 2014; Siddique *et al*., 2020). Under such condition, light penetration is expected to decline sharply, causing a large scale erosion of benthic primary producers including diatoms. Despite these concerns, there is no report so far, addressing the state of declining light penetration on benthic diatoms of the Ganga River. This study is an effort to investigate response of diatom diversity to reducing effective light climate in the Ganga River in the Varanasi region. This has relevance for restoration of benthic communities, bottom oxygenation and designing an appropriate action plan for the management of this important river.

Materials and Methods

Study Area

A two consecutive years (2021-2022) of study was conducted at 5 selected sites of the Ganga River at Varanasi (25° 18' N, 83°1' E). The study region is considered one of the most polluted key station of the middle segment of the Ganga River, which receives pollutants and massive amount of the carbon from point and non-point sources. This tropical climatic belt observes distinct seasonality–winter, summer and rainy. During summer season, which also coincides with increased pumping by irrigation canal, the river flow is significantly reduced. Predominant wind is westerly and soil consists of typical fertile Gangetic sandy alluvium. A description of the sampling sites is presented in Table 1.

Experimental Design

It consists of a three tiers of study-water quality, sediment quality and periphytic-diatom diversity. Among the water quality determinants, together with other attributes, the study considers the depth of water column light penetration to address light climate issues. Each site was divided into three sub-sites and samples from all the three sub-domains were collected in triplicates (about 50m distance) during summer low flow. Samples placed in pre-washed plastic containers and finally in ice box were brought to the laboratory for analysis and identification. To optimize standard deviation, the samples were pooled to obtain composite samples.

Methods

Sub-surface (15-25 cm depth) water samples were collected in acid-rinsed plastic containers for analysis of water quality attributes. Water pH, dissolved oxygen and total dissolved solids all were measured as described in standard methods (APHA, 1998). The dissolved organic carbon (DOC) was quantified after digestion in $KMnO_4$ (Michel, 1984). After digestion at 37°C, the organic carbon was quantified in terms oxygen produced after 4 hours of incubation period (APHA, 1998). The concentrations of nitrate and orthophosphate were estimated following Voghe (1971) and Mackereth (1963). The study considers the Secchi disk method to infer the depth of light penetration at sampling sites. Light at depth was quantified using ambient light intensities (summer season) following Vadeboncoeur *et al*. (2013). For diatoms, samples were collected using box corers. Top layer of sediment was used for the analysis of diatoms following Renberg (1990). For sample preparation, 1 gram of dry sediment was transferred into 250 mL flask. This was treated with HCl (10%) to remove carbonates. This was followed by incubation in distilled water (250 mL) for 24 h for removal of clay materials. The supernatant was decanted and the process was repeated 3-4 times. Samples were examined and diatom valves counted under Metzer and Nikon Trinocular microscope following standard protocols (Karthick *et al*., 2010; Pandey *et al*., 2017).

All values presented as mean supported by standard errors (SE). Significant effects were tested using analysis of variance (ANOVA).

Results and Discussion

Rivers are intimately connected with atmosphere and terrestrial domains. These water bodies are ecologically very important as not only they drive carbon cycle but also act as critical intersect between terrestrial and coastal domains. Accordingly, they help transporting carbon of atmospheric to terrestrial origin to coastal ocean. While transporting and accumulating carbon, rivers work as an important heterotrophic digester enhancing CO_2 emission. Middle segment of the Ganga River receives organic pollutants mainly from agricultural runoff, sewage and C rich industrial effluents. Also, this region receives massive amount of organic-C through atmospheric deposition (Yadav and Pandey, 2017). In the process of breakdown, large amount of dissolved organic carbon (DOC) is formed, which together with other sources of turbidity reduces light penetration. Thus, DOC is an important constraint altering the light climate in surface waters (Pandey and Pandey, 2012; Pandey, 2013). The constrained light climate reduces the growth of periphytic producers including diatoms. Here, the study is targeted to address this issue in Varanasi region, an area rich in flushes of organic pollutants.

This study considers two water quality attributes–total dissolved solids (TDS) and dissolved organic carbon (DOC) to address light climate of periphytic diatoms. Both these variables constrain light penetration. The TDS varied with site and the concentration was found to be the highest at Site Ⅲ and lowest at Site Ⅰ. The TDS at study sites ranged from 470.71 mg L^{-1} (Site Ⅰ) to 860.50 mg L^{-1} (Site Ⅲ) (Fig. 1). Site Ⅳ comes next in order from highest to lowest. Site Ⅲ is characterized by massive amount of sewage input and Site Ⅳ is under strong downstream influence at Varanasi city. Water transparency, measured in terms of Secchi depth of light penetration showed an opposite trend. The depth of light penetration was highest at Site Ⅰ and lowest at Site Ⅲ. The highest and lowest values were 65 and 26 cm respectively (Fig. 1). The differences in both attributes–TDS and depth of light penetration, were significant ($p < 0.001$; ANOVA). The relative abundance of periphytic diatoms followed a trend similar to the depth of light penetration (Table 3). With a very few exception, the relative abundance was highest at Site Ⅰ and lowest at Site Ⅲ. With respect to species, *Pinnularia viridis* (relative abundance ranged from 3.25% to 13.20%) was found to be the most abundant species followed by *Navicula lanceolate. Tabellaria flocculosa* did appear the least abundant (relative abundance ranged from 0.0 to 2.62. The differences in relative abundance were found to be significant ($p < 0.001$; ANOVA).

In comparison to light climate in river ecosystem functioning, benthic diatoms have been poorly considered in the Ganga River restoration. Periphytic diatoms trigger sequestering nutrients, oxygenating bottom environment, stabilizing sediments, reducing sediment – P release and help supporting food web and consequently enhancing aquatic ecosystem resilience. Because these primary producers drive sediment based nutrients, their growth is limited generally by light climate and not by nutrient status. Thus, benthic producers including diatoms are susceptible to the factors such as river morphometry, turbidity, total dissolved solids, dissolved organic carbon etc., that constrain light penetration. Dissolved organic carbon (DOC) is an important attribute that constrains light penetration in aquatic bodies. Here, two of the study Sites (Ⅲ and Ⅳ) showed invariably high concentrations of DOC. This not only expected to enhance oxygen demand but also interferes with depth of light penetration. In sediment also, the TOC was highest at Site Ⅲ but silica showed almost an opposite trend to TOC (Table 2). There are two major determinants of rising DOC in most surface waters. These include nutrient driven increase in primary production; and enhanced anthropogenic input of DOC from point- and non-point sources (Pandey *et al*., 2014; Yadav and Pandey, 2017). Because this study was conducted during summer low flow, surface runoff-borne sources are ruled out and the differences in DOC, in a major way, seem to be due to differences in frequency and magnitude of point sources. Sites Ⅲ and Ⅳ, representing Assi drain and Rajghat downstream receive large amount of urban sewage (over 65 MLD) and downstream urban influences respectively. Reduced stream flow due to summer season coupled with effects of damming and pumped extraction by river canals further lead to concentrate the organic and inorganic pollutants. This was reflected also in terms of high concentrations of nutrients and total organic carbon (TOC) in sediments.

Under suitable light condition, the concentrations of nutrients favour the growth of periphytic diatoms. Here, the hypothesis was that increased TDS and DOC will constrain the growth and abundance of periphytic diatoms by reducing the depth of light penetration. This was clearly observed here as expected through other studies (Carey *et al*., 2007). Abundance of benthic diatoms (sediment diatoms) was found to be lowest at Site Ⅲ characterized by high DOC, TDS and reduced depth of light penetration indicating the role of these attributes in light attenuation. Low light climate is likely to constrain the growth of sensitive species and favour those having ability to withstand diffused light availability and high level of nutrients (Pandey and Pandey, 2012; Pandey 2013). When DOC concentrations remained still higher most species show low abundance. The significant effects of TDS and DOC on light attenuation observed here showed concurrence with the results of previous studies. The study showed that about 5mg L^{-1} rise in DOC showed concentration dependent effects. These results are consistent with those observed by Bergstrom *et al.* (2001) and Pandey (2013) wherein about 7 mg L^{-1} rise in DOC corresponds to over 37 % decrease in light penetration. Similar was the case reported by McEachern *et al.* (2003). This study indicates DOC and TDS as factors constraining light penetration and causing significant loss of periphytic diatoms. Furthermore, major share of DOC in the Ganga River is of allochthonous origin (high C:N ratio > 15; Elser *et al*., 2000), which are optically dense and more effectively reduce the depth of the light penetration. This has concern because allochthonous DOC is continuously rising. If the rising trend of DOC and turbidity continued, it will lead to remove benthic flora where diatoms assumes predominance. This will result poor oxygenation and altered functioning of the Ganga River ecosystem.

Conclusions

This study concludes that the rising state of turbidity, as expected to be continued in near future, will alter the light climate and concurrently the fate of the benthic diatoms in the Ganga River. This has particular concern because the tourism-driven increases in the frequency of boating between Assi and Rajghat has enhanced the turbidity of water in this stretch. Benthic diatoms are important group of primary producers that regulate bottom oxygen supply. Loss of these producer organisms would make long-term ecosystem level effects including sediment P-release, waste assimilation capacity, resilience and fisheries. This will reduce the natural capacity of the river to recover and question the action plans and strategies of river management. Furthermore, because no systematic data is available on such issue of this major river system, initiatives should be taken to generate large scale data base that can be accurately translated into the action plans.

Table 1: Characteristics of study sites along the Ganga River at Varanasi.

Site name	Site number	Mean depth	Input source
Adalpura	Ⅰ	21	Non-point source - natural and agricultural runoff
SamneGhat	Ⅱ	20	Minor sewage/ Agricultural runoff
AssiGhat	Ⅲ	14	Waste water/ Sewage discharge
Raj Ghat	Ⅳ	20	Downstream city influence
Varuna confluence	Ⅴ	18	Downstream urban-industrial influence

Table 2: Chemistry of bottom sediments at study sites in the Ganga River. Values as mean ± SE.

Variable	Site				
	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
NH_4^+(mg g^{-1})	1.10±0.07	1.25±0.10	3.65±0.15	2.80±0.12	2.95±0.14
NO_3^-(mg g^{-1})	2.81±0.13	2.52±0.12	2.21±0.16	2.65±0.15	2.50±0.14
PO_4^{3-}(mg g^{-1})	1.20±0.07	1.75±0.07	7.20±0.40	6.55±0.31	5.80±0.28
SiO_2 (mg g^{-1})	3.70±0.22	2.80±0.18	1.57±0.09	2.50±0.12	2.62±0.13
TOC (%)	1.82±0.09	2.40±0.11	4.50±0.20	3.55±0.16	3.30±0.15

Table 3: Relative abundance of periphytic diatoms at study sites in the Ganga River.

S. No.	Species	Code	Relative abundance				
			I	Ⅱ	Ⅲ	Ⅳ	V
1	*Achnanthes lanceolata*	Alan	9.50	8.56	5.20	6.25	8.50
2	*Achnanthidium minutissimum*	Amin	8.20	8.00	2.10	3.25	8.20
3	*Amphora ovalis*	Aova	10.25	9.26	6.20	5.25	10.20
4	*Aulacosira granulosa*	Agra	8.10	7.25	2.50	3.36	8.25
5	*Bacillaria paradoxa*	Bpar	7.82	7.82	1.25	0.00	7.80
6	*Caloneissilicula*	Csil	4.62	3.65	2.60	0.00	4.50
7	*Cocconeisplacentala*	Cpla	10.20	8.20	2.55	3.25	9.20
8	*Craticulacuspidata*	Ccus	5.25	4.25	1.20	1.20	4.10
9	*Cymbellaoffinis*	Coff	6.28	4.26	1.20	1.00	5.25
10	*Diatoma vulgaris*	Dvul	8.25	8.20	2.56	1.50	7.10
11	*Eunotiaexigua*	Eexi	6.28	5.25	2.10	1.25	5.28
12	*Fragilaria intermedia*	Fint	9.25	9.20	6.25	7.26	8.20
13	*Gomphonema parvulum*	Gpar	8.25	6.20	2.50	2.50	7.25
14	*Gyrosigma acuminatum*	Gacu	9.26	5.25	1.50	1.20	10.26
15	*Melosira varians*	Mvar	7.28	7.20	1.25	1.20	7.20
16	*Navicula lanceolata*	Nlan	12.28	10.28	3.85	4.20	10.20
17	*Nitzschia palea*	Npal	10.20	9.25	4.86	6.25	9.50
18	*Pinnularia viridis*	Pvir	13.20	13.00	3.25	3.26	12.10
19	*Sellaphora nigri*	Snig	4.26	2.10	0.00	0.00	3.26
20	*Surirella elegans*	Sele	6.28	1.20	0.00	0.00	5.20
21	*Synedra ulna*	Suln	2.50	1.00	0.00	0.00	1.20
22	*Tabellaria flocculosa*	Tflo	2.62	1.25	0.00	0.00	1.00

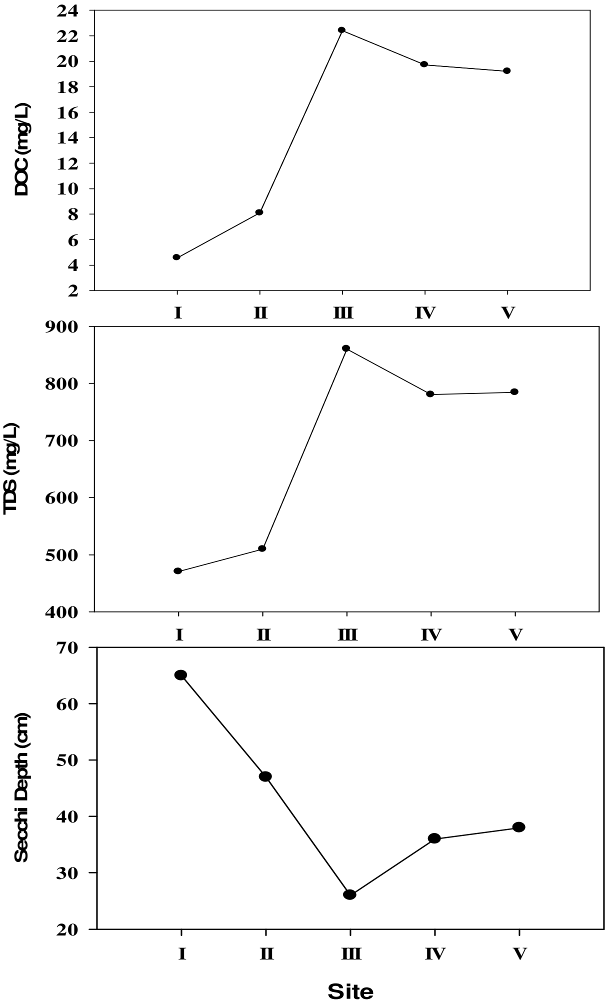

Fig. 1: Site-wise variation in water quality and light penetration in the Ganga River.

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