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The Influence of DOC Trends on Light Climate and Periphyton Biomass in the Ganga River, Varanasi, India

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Abstract Investigations on periphyton along an eutrophication gradient ($NO_3^- = 0.23-0.96$ mg L^{-1}; $PO_4^{-3} = 0.16-0.86$ mg L^{-1}) of Ganga River indicated that benthic algal biomass decreased with increasing concentrations of nutrients and dissolved organic carbon (DOC). Periphyton biomass showed negative relationship ($R^2 = 0.98$; $p < 0.0001$) with DOC and positive relationship ($R^2 = 0.96$; $p < 0.0001$) with Secchi depth. Sites with high DOC showed dominance of cyanophycean *Phormidium uncinatum.* The study shows that the rising concentration of DOC over time may alter the light climate and consequently the fate of benthic primary producers in Ganga River.

Keywords Ganga River · Dissolved organic carbon · Light climate · Nutrients · Periphyton

Increasing anthropogenic activities during the last few decades have dramatically enhanced nutrient and pollutants input to Ganga River along its 2,525 km course from Gangotri in Himalaya to its confluence with Bay of Bengal. As a major effort to clean this important river system, the Government of India initiated the Ganga Action Plan (GAP) in 1984 with a view to maintain biological oxygen demand (BOD) and dissolved oxygen (DO) levels within the acceptable limits. Despite such national level efforts and massive drives, the Ganga River water quality is continuing to decline. Rapidly changing river ecology and associated shift in its capacity to assimilate organic load necessitate long- term management efforts to reduce eutrophication along human dominated urban landscapes.

Oxygen production by primary producers is one of the most important biological attributes for maintaining the capacity of water bodies to assimilate organic loads without appreciable depletion in dissolved oxygen level. Algal periphyton, the submerged micro-floral community living attached to the substrate, are important group of primary producers that helps maintaining river ecology through increased oxygen supply and reduced nutrient release from bottom sediments (Luijn et al. 1995). For phytoplankton community of tropical waters, nutrient limitation is the primary driver of productivity (Yang et al. 2008). For benthic primary producers however, light limitation is the major constrain (Carey et al. 2007). Increasingly high levels of DOC may constrain periphyton growth through reduced light assimilation. DOC attenuates water column light penetration and, in turn, constrains the growth of benthic primary producers (Karlsson et al. 2009). Elimination of periphyton would reduce the capacity of ecosystem to assimilate anthropogenic inputs and, by implication, the restoration of river ecosystems. Despite their significant roles, algal periphyton community has received little attention for this major river of India. There is a general dearth of studies explicitly addressing the relationships in the dynamics of algal periphyton and DOC level in Ganga River. The present study was an effort to investigate algal periphyton in relation to dissolved organic carbon- linked light attenuation in Ganga River at Varanasi, India. To examine possible effects of light driven constrains, attempts were made to test whether benthic algal biomass was positively related to depth of light penetration.

Materials and Methods

The study was conducted during summer of three consecutive years (2009–2011) at 10 selected sites along a 35 km long

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Table 1 Characteristics of sampling sites

S. No.	Site	Code	Substrate	Mean depth (m)	Discharge (ms^{-1})	Input
1.	Adalpura	Adp	Sandy/rocky bottom	21	0.40 ± 0.02	Natural and agricultural runoff
2.	Sultankeshwar Ghat	Stg	Muddy with hard pans	20	0.45 ± 0.02	Agricultural runoff
3.	Bypass downstream	Bds	Sandy	12	0.39 ± 0.02	Dredging runoff
4.	Nagwa discharge	Ngw	Muddy	14	0.26 ± 0.01	Sewage discharge
5.	Assi Ghat	Asg	Muddy/sandy	14	0.26 ± 0.02	Urban surface discharge
6.	Shivala Ghat	Slg	Hard pans and pebbles	16	0.29 ± 0.02	Municipal waste and sewage
7.	Harishchandra Ghat	Hcg	Sandy with pebbles	16	0.36 ± 0.02	Biomass burning
8.	Rana Ghat	Rng	Hard pans and pebbles	20	0.30 ± 0.01	Cloth washing
9.	Raj Ghat	Rjg	Muddy/sandy	20	0.35 ± 0.02	Sewage discharge
10.	Raj Ghat downstream	Rds	Sandy with pebbles	18	0.30 ± 0.01	Downstream influence

eutrophication gradient of Ganga River at Varanasi (25°18′N latitude, 83°1′E longitude and 76.19 m above msl), India. Varanasi city is situated at the west margin of the Ganga River. Climate of the region is tropical with distinct seasonality and dominant westerly winds. A description of different sampling stations is presented in Table 1.

The experimental design consisted of three tiers of study that include water quality variables, depth of light penetration and algal periphyton. Water pH, total dissolved solids (TDS), dissolved oxygen (DO) and chemical oxygen demand (COD) all were measured following standard methods (APHA 1998). Composite water samples were collected from 15 m reach in the River during summer of three consecutive years. The distance between replicate sampling (n = 3) was about 50 m. Water was collected from each site, directly below the surface (6–10 inch depth), in acid- rinsed 5 L plastic containers for analysis of dissolved organic carbon (DOC), dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). DOC was quantified using a $KMNO_4$ digestion procedure (Michel 1984). Water samples were mixed with acidified N/80 potassium permagnate and incubated at 37°C. Organic carbon was estimated by titrating to quantify oxygen after 4 h of incubation (APHA 1998). Nitrate–N was quantified using a brucine sulphuric acid method (Voghe 1971). Orthophosphate (dissolved reactive phosphorus, DRP) was quantified using Olsen's ammonium molybdate method (Mackereth 1963). Depth of light penetration in the River was measured using Secchi disk and light at depth was calculated using mid- summer surface light intensities following Vadeboncoeur et al. (2003).

Periphyton biomass was measured in terms of chlorophyll *a*. For this purpose, 35 mm plastic slides were laid in triplicate over the experimental rock surface fixed in closed wire cage (basket sampler) of 15 × 15 × 15 cm size at 2 m depth for one month (16th April to 15th May each year). Each replicate represents a composite sample of three independent slides placed at each collection point at a distance of 2 m. The material within the slide area (scrub area = 2.3 cm × 3.5 cm = 8 cm^2) was pulled by vacuum

Table 2 Variation in river water quality along the study gradient

Site	Average Flow (ms^{-1})	pH	TDS ($mg\ L^{-1}$)	NO_3^- ($mg\ L^{-1}$)	PO_4^{3-} ($mg\ L^{-1}$)	DO ($mg\ L^{-1}$)	COD ($mg\ L^{-1}$)	C: N (DOC)
Adp	0.40 ± 0.02	7.50 ± 0.54	475.00 ± 27.50	0.23 ± 0.01	0.16 ± 0.01	9.42 ± 0.46	3.70 ± 0.27	18 ± 2
Stg	0.45 ± 0.02	7.50 ± 0.48	480.20 ± 31.00	0.27 ± 0.01	0.18 ± 0.01	8.55 ± 0.42	4.62 ± 0.32	17 ± 1
Bds	0.39 ± 0.02	7.80 ± 0.55	755.30 ± 56.75	0.40 ± 0.02	0.28 ± 0.02	7.35 ± 0.37	5.80 ± 0.37	18 ± 2
Ngw	0.26 ± 0.01	8.40 ± 0.61	848.20 ± 67.05	0.81 ± 0.03	0.53 ± 0.02	6.70 ± 0.35	6.65 ± 0.48	15 ± 1
Asg	0.26 ± 0.02	8.40 ± 0.58	850.50 ± 69.22	0.86 ± 0.04	0.68 ± 0.03	6.45 ± 0.33	6.80 ± 0.45	17 ± 2
Slg	0.29 ± 0.02	8.50 ± 0.59	860.40 ± 64.80	0.90 ± 0.04	0.72 ± 0.04	6.22 ± 0.31	7.15 ± 0.54	17 ± 2
Hcg	0.36 ± 0.02	8.50 ± 0.62	850.60 ± 62.05	0.91 ± 0.03	0.76 ± 0.04	5.90 ± 0.28	7.80 ± 0.61	18 ± 2
Rng	0.30 ± 0.01	8.80 ± 0.64	826.30 ± 59.88	0.92 ± 0.04	0.81 ± 0.04	5.20 ± 0.28	8.85 ± 0.64	18 ± 2
Rjg	0.35 ± 0.02	8.70 ± 0.63	876.25 ± 70.24	0.96 ± 0.04	0.86 ± 0.03	4.23 ± 0.24	11.90 ± 0.74	19 ± 2
Rds	0.30 ± 0.01	8.60 ± 0.65	850.20 ± 65.18	0.94±0.04	0.84 ± 0.04	4.45 ± 0.27	11.40 ± 0.73	20 ± 2

Secchi disk transparency showed negative correlation ($R^2 = 0.93$; $p < 0.0001$) with DOC (Fig. 2). Site-wise differences in COD, DO, DOC, Secchi depth and other water quality variables were significant (Table 3)

Values are mean (n = 12) ± I SE

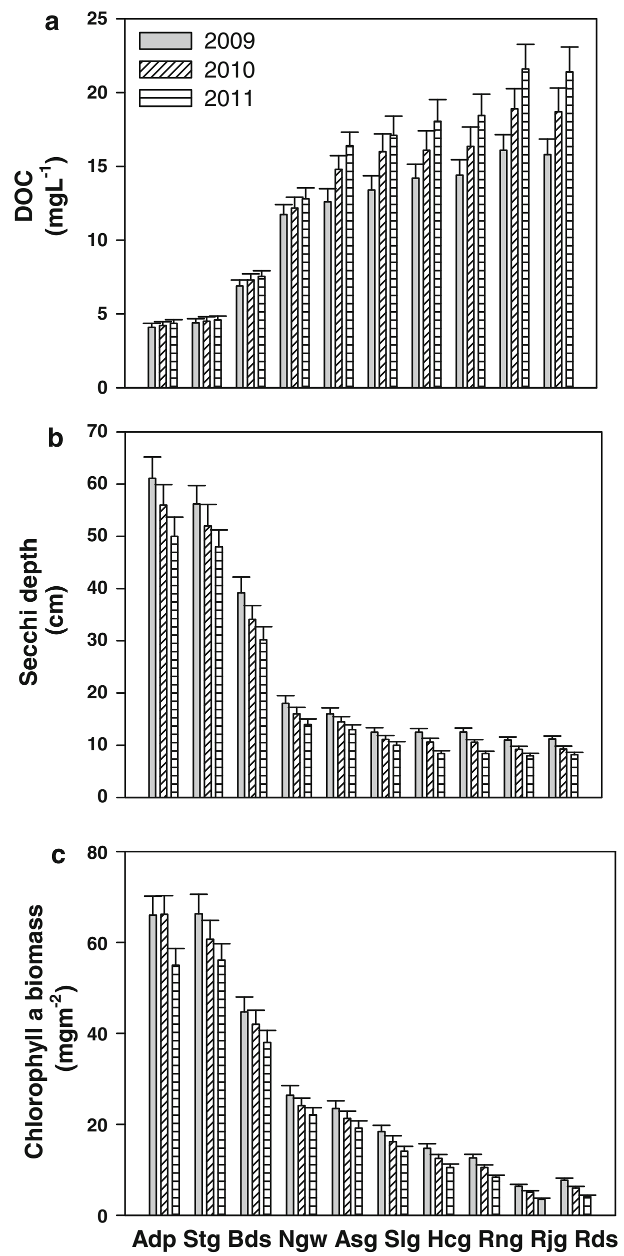

Fig. 1 Variations in dissolved organic carbon (DOC; **a**), Secchi depth (**b**) and periphyton chlorophyll *a* biomass (**c**) along the study gradient. Values are mean (n = 12) ± 1 SE

onto a pre-ashed (free of organic matter) glass fiber filter (Whatman GF/A) for wet and dry weights. Enough care was taken to ensure complete recovery of algal assemblages attached to the surface. Chlorophyll *a* biomass was determined in fresh material following acetone extraction procedure (Maiti 2001) and expressed as mg m^{-2} by relating to exposed surface area. Individual filament/cells per unit area were counted following Biggs and Kilroy (2000).

Significant effects of site and time were tested using analysis of variance (ANOVA). Values were log transformed when needed and interaction terms were included in the analysis. Correlation coefficient (R^2) and regression analysis was used to test significant linearity between variables. SPSS package was used for statistical analysis.

Table 3 F-ratios obtained from analysis of variance (ANOVA) for water quality variables and chlorophyll *a* biomass of periphyton along the study gradient of Ganga River

Variable	Y	S	y × s
TDS	ns	726.10***	3.42*
pH	ns	156.16***	Ns
PO_4^{-3}	ns	596.32***	12.07**
NO_3^-	ns	435.18***	9.26**
DOC	3.22*	735.02***	18.75***
COD	4.70*	394.51***	37.05***
DO	ns	78.42***	11.05**
Secchi depth	46.20***	319.83***	67.33***
Periphyton Chl *a*	57.30***	635.08***	78.35***

TDS total dissolved solids, *DOC* dissolved organic carbon, *COD* chemical oxygen demand

Values significant at * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: not significant

Results and Discussion

Concentrations of nutrients and TDS increased along the study gradient (Table 2) and the values were highest at Site 9 characterized by direct sewage input and downstream influence. Water pH and COD showed a similar trend. Dissolved oxygen however, showed an opposite trend (Table 2). DOC increased along the study gradient and, compared to Site 1, water at Site 9 contained over four- folds higher DOC (Fig. 1). Secchi disk transparency on the other hand, showed a decreasing trend and declined by over 83 % at Site 9 compared to Site 1. Periphyton chlorophyll *a* biomass declined along the study gradient spanning almost 2–10 orders of magnitude and was lowest at Site 9 (Fig. 1). Periphyton biomass showed significant positive correlation ($R^2 = 0.96$; $p < 0.0001$) with Secchi disk transparency (measured as Secchi depth) and negative correlation ($R^2 = 0.98$; $p < 0.0001$) with DOC.

In comparison to other attributes of river ecosystem function, periphyton has been poorly considered in river restoration. Benthic algae support aquatic food web and help sequestering nutrients, stabilizing sediments and reducing sediment P release which, in turn, enhances ecosystem resilience. Benthic primary producers generally derive nutrients from the substrate and hence their growth is limited more by light availability than by nutrient status. In deeper zones of the river, benthic algal growth is constrained by

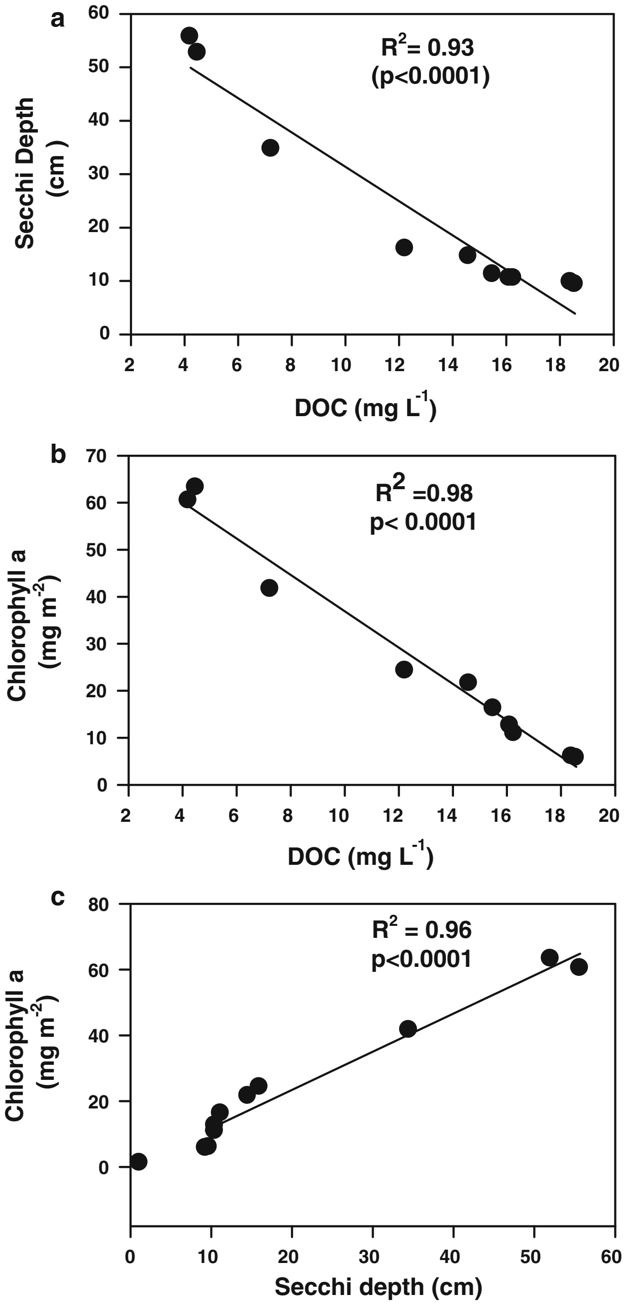

Fig. 2 Significant relationship between DOC and Secchi depth (**a**), DOC and periphyton chlorophyll *a* biomass (**b**) and Secchi depth and chlorophyll a biomass (**c**)

morphometry. However, in shallow regions, that constitute major part of total water spread, benthic producers are highly susceptible to factors which inhibit light penetration.

From the last two decades, there has been a substantial rise in DOC in surface water bodies. The present study showed a marked increase in concentration of DOC along the study gradient. A consistent increase in COD and corresponding decrease in DO along the study gradient indicate the rising influence of oxygen demanding substances. Oxygen dissolved in water is rapidly utilized in the process of microbial decomposition of organic matter. Two possible mechanisms are generally considered to explain DOC rise in surface waters; enhanced pelagic production (autochthonous C-pool) in response to nutrient enrichment (Pandey and Pandey 2009); and, enhanced surface input (allochthonous C-export) driven by climate and hydrological variable (Evans et al. 2006; Pandey and Pandey 2012). Here, surface input of DOC was massively high due to sewage discharge from Varanasi city. Reduced stream flow due to damming of the River could further enhance the overall DOC level due to reduced dilution effect. This effect was also reflected in concentrations of NO_3^- and PO_4^{-3} along the study gradient.

Depth of light penetration and concentration of nutrients regulate the growth of periphyton. In the present study, it was hypothesized that an increase in DOC would have pronounced effect on benthic algal production by reducing the light assimilation. Here, the decrease in periphyton biomass along the study gradient could be related to DOC-linked light limitation (Carey et al. 2007). Benthic algal biomass was positively correlated to depth of light penetration and the latter was negatively correlated to DOC suggesting that DOC could reduce benthic algal production through light attenuation. Increasing dominance of cyanophycean alga *Phormidium uncinatum* along the gradient indicate gradual replacement of sensitive species by more opportunistic invasive species to exploit high available nutrients (Pandey and Pandey 2012). However, on further increase in DOC, light driven constraints did offset the influence of nutrient enrichment causing overall biomass to decline. The results indicate, although the effect of DOC and other factors did not rule out one from the other, the former could be crucial in causing significant loss of benthic periphyton. DOC concentration increased over time from 2009 to 2011as well as along the study gradient while light penetration and periphyton biomass showed opposite trends. DOC of allochthonous origin is usually very optic dense and reduces light penetration more effectively. The C: N ratio of DOC, although did not show a definite trend, was >15 indicating allochthonous influences (Elser et al. 2000). The ratios however, were <20 due probably to the influence of sewage input.

The strong influence of DOC on light interception observed in this study was similar to the results from previous studies. In the present study, a 7 mg L^{-1} increase in DOC caused light penetration to decline by 41 %. Further increase in DOC showed a consistently increasing light attenuation. These observations are in accordance with those recorded by Bergstrom et al. (2001), where a 7 mg L^{-1} increase in DOC had been shown to correspond to an approximately 37 % decrease in light climate. McEachern et al. (2000) observed that a 9 % rise in DOC led Secchi disk transparency to decline by 46 %. Interception of light by DOC could reduce periphyton development across the study gradient. Luijn et al. (1995) have reported that even 15 %–20 % attenuation in Secchi depth can significantly alter the growth of benthic diatoms. It is obvious that the rising organic loading will likely decrease benthic primary production by attenuating light penetration in Ganga River. The study concludes that the rising concentrations of DOC over time may alter the light climate and consequently the fate of benthic algal periphyton in Ganga River. Algal periphyton are important group of primary producers that helps maintaining river ecology through increased oxygen supply and reduced nutrient release from bottom sediments. Loss of benthic primary production may lead to long-term changes in river ecosystem functioning including waste assimilation capacity and ecosystem resilience. Data on these issues may help establishing integrated river basin management strategies.

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