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IMPACT OF ANTHROPOGENIC ACTIVITIES ON TROPHIC STATUS OF MIDDLE STRETCH OF THE GANGA RIVER

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Abstract

The Ganga Riveris facing problem of excessive loading of carbon and nutrients because of increasing anthropogenic perturbations. These enrichments cause problem of eutrophication leading to shift in ecosystem structure and functioning. Despite the application of a number of monitoring and assessment programs by the Government of India and other agencies, the problem of nutrient input and eutrophication is still increasing specifically in the middle stretch of the Ganga River. The present study was targeted to estimate the level of trophic status and associated shift in ecosystem responses in the river. This study was conducted from April, 2019 to March, 2020 for all the three seasons at seven sites along 520 km middle segment (from Kannauj upstream and Varanasi downstream) of the Ganga River between. The study shows that the concentration of carbon, nutrients and heavy metals increased downstream cities. The trophic state index (TSI) based on N, P, C, Chl 'a' and transparency categorized the study sites from oligotrophic to hypereutrophic. Similarly, the ecological response index (ERI) categorized the sites from eutrophic to hypereutrophic and low metal polluted to extremely metal polluted. Both the TSI and ERI show that increasing anthropogenic activities along the Ganga River specifically in megacities are affecting the water quality and ecosystem functioning of the river. These results will help understanding the trophic state and associated consequence on the Ganges ecology. The study has relevance in management of eutrophy and regional scale carbon and nutrient budgeting.

Key words: Carbon; Eutrophication; Ganga River; Nutrients; Trophic Status.

Introduction

The cultural eutrophication has dramatically altered the trophic status and carbon (C) biogeochemistry in surface waters including rivers (Pandey, 2011; Pandey *et al*., 2014). Despite being smaller relative to overall surface area of the earth, surface water bodies play significant role in regional and global carbon cycle (Jaiswal and Pandey, 2019a). Inland water bodies receive a large input of carbon and nutrients from point and non-point sources that substantiate the overall C balance of the receiving systems (Yadav and Pandey, 2017; Singh and Pandey, 2019). Thus, the overall carbon budget of surface water is controlled by direct C- sources coupled with a numbers of factors such as nutrients, light, temperature and biogeochemical processes that occur within the system (Argerich *et al*., 2016; Siddiqui *et al*., 2020). Nutrients, light and temperature are key factors that drive photosynthesis (autochthonous C). For the study region, being situated in the mid-Indo-Gangetic plains, light and temperature are not the limiting factors whereas variability in nutrients, especially those in N and P, drives changes in photosynthetic C-capture (Pandey *et al*., 2014). Thus, a heterogeneity in the distribution of nutrients, mainly N and P can be used as a level determinant of variability in the trophic state. In addition, there are a number of point sources creating heterogeneous patches of C-flushing and concordantly the overall carbon-relation in the river.

Although only one–third of C that enters the river is transported to the ocean (Aufdenkampe *et al*., 2011), the sediment controlled C burial in the Bengal fans has been reported to be about 1.1×10^{12} mol C yr^{-1} constituting about 10% of global-C burial flux in the continental margins of the world (France-Lanord *et al*., 1997). The Ganga-Brahmaputra alone contribute about 7 Tg C yr^{-1} (Patra *et al*., 2013) to the global dissolved organic carbon (DOC) export to the ocean. Recent study show that autochthonous-C substantially contribute to overall C production in the Ganga River (Pandey *et al*., 2014). Different indices are used to address the state of eutrophy

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in surface waters. Carlson's index is one of the most commonly used empirical relationships for addressing the state of eutrophy. Carlson, (1977) used three common determinants such as P, chlorophyll 'a' biomass and light penetration for computing trophic state index (TSI) separately from each determinant. Further, Kratzer and Brezonik, (1981) used N and Dunalska, (2011) used C for computing TSI. The N and P reflects nutrients limitation–photosynthesis linkage, Chl 'a' biomass is used as a determinant of autochthonous–C and light penetration represent the role of dissolved and particulate carbon together with other substances opaque to light penetration. Carbon as a determinant is used to represent the cumulative role of auto- and allochthonous-C in determining the overall trophic state of the system. More recent studies consider ecological response index (ERI) to simultaneously address eutrophication and metal pollution. The ERI considers, together with other variables, total organic carbon (TOC) as an important determinant which can be used to classify the system from oligotrophic to hypereutrophic states (Jaiswal and Pandey, 2019b).

Studies on the Ganga River indicate large inputs of carbon and nutrients from a number of point- and non-point sources including treated and untreated sewage, industrial effluents, atmospheric deposition, agricultural runoff and a number of tributaries (CPCB, 2013; Pandey *et al*., 2014; Siddiqui *et al*., 2019). Accordingly, the river, all along its length, experience excessive load of allochthonous-C together with a large production of autochthonous-C. Despite this fact, there is a general lack of systematic data on trophic state of the river particularly for the most polluted middle stretch of the Ganga River. The present study is an effort to relate functional variables such as carbon, nutrients (N and P), microbial biomass (C_{mic}) and FDAase activity with the trophic state of middle stretch of the Ganga River. The study has relevance in management of eutrophy and regional scale carbon and nutrient budgeting.

Materials and Methods

Study Area

This one-year (April, 2019 to March, 2020) study was conducted at seven sampling stations of Ganga River along a river segment of about 520 km from upstream of Kannaujcity (27° 17'N; 79° 84'E) to down stream of Varanasi city (25° 32'N; 83° 03'E). The Ganga River Basin is largest in India (1,086,000 km^2) and fourth in the world, covering ~73.4% agricultural area of the country which support ~43% of the Indian population. The Ganga River travels a distance of 2525 km from Gangotri to Gangasagar. Along this stretch, there are 36 Class I and 14 Class II cities generating more than 2723 MLD sewage,

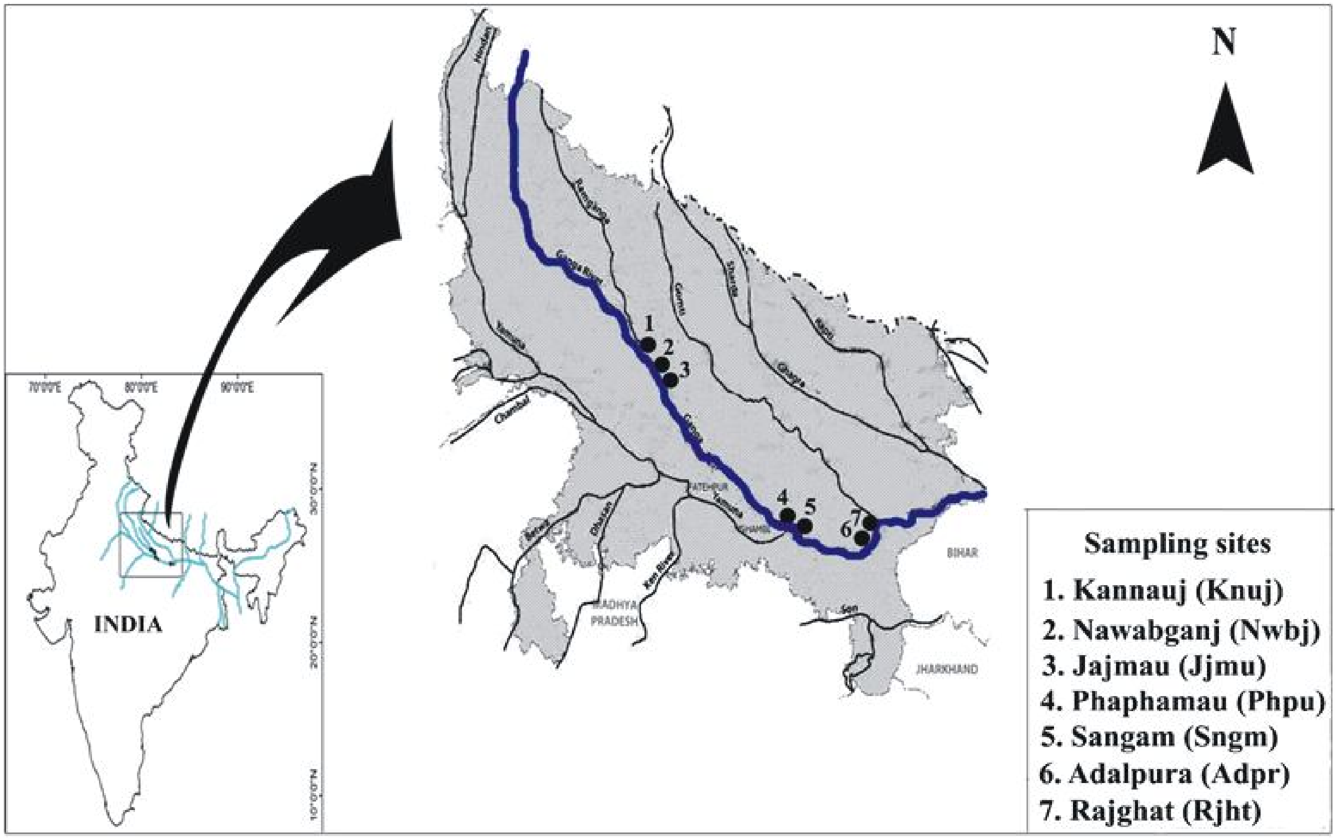

Fig. 1: Map of the study area showing locations of sampling sites.

out of only ~44% is added to river after treatment. The middle stretch of the river is considered to be the most polluted, where four metro polish cities Kannauj, Kanpur, Prayagraj and Varanasi substantially pollute the river water. The Kannaujcity adds massive amount of sewage directly to river without any treatment. Similarly, Kanpur city discharges 50% untreated sewage, Prayagraj contributes ~208 MLD out of which only ~89 MLD is added after treatment. Varanasi city generate ~141 MLD sewage out of which only ~67% is treated (CPCB, 2013). The basin's climate is tropical to sub-tropical monsoonal. The basin has three distinct seasons; summer (April to June), rainy (July to September) and winter (November to February).

Sampling and Analysis

For sampling, each study site was divided into three sub-sites and the samples of water and sediment were collected seasonally in triplicate from each sub-site. Water samples were collected from the depth of about 15-25 cm from mid-stream of each sub-site in pre-washed plastic containers. The sediment samples were collected from the depth of 0-10 cm from each sub-site with the help of corers in a plastic bags and preserved in an ice box. The samples were brought to the laboratory following standard protocols. Secchidisc transparency (SD) was measured using secchi disc. Total organic carbon (TOC) concentration in water and sediment was measured using TOC analyzer (Lotix combustion TOC analyzer). The nitrate concentration was estimated following phenol disulphonic acid (PDSA) method (Nicholas and Nason, 1957) and total nitrogen was measured following Kjeldal method. The phosphate concentration in water samples was estimated using the stannous chloride ammonium molybdatemetod (APHA, 1998). Chlorophyll 'a' (Chl 'a') was extracted in acetone and measured spectrophotometrically (Maiti, 2001). The Gross primary productivity (GPP) was measured following light and dark bottle method (APHA, 1998). Fluoresce in diacetate hydrolytic activity (FDAase) was quantified by following Schnürer and Rosswall, (1982). Microbial biomass carbon (C_{mic}) was estimated by chloroform fumigation- extraction method (Jenkinson and Powlson, 1976). For estimating the heavy metal concentrations, these diment sample were digested in tri-acid mixture using a microwave digestion system (Model: SINEO model MDS-6G). Then, the concentrations were measured using an atomic absorption spectrophotometer (Model: Perkin Elmer model analyst 800, USA).

Trophic state indices

1. Trophic state index (TSI):

The trophic state index (TSI) based on total phosphorus (TP), secchi disctransparency (SD) and chlorophyll a data was calculated following Carlson, (1977):

$$TSI\ (TP) = 4.15 + 14.42 \ln (TP)$$

$$TSI\ (SD) = 60 - 14.41 \ln (SD)$$

$$TSI\ (Chl\ a) = 30.6 + 9.81 \ln (Chl\ a)$$

The TSI based on total nitrogen (TN) data was calculated following Kratzer and Brezonik, (1981):

$$TSI\ (TN) = 54.45 + 14.43 \ln (TN)$$

The TSI based on total organic carbon (TOC) data was calculated following Dunalska, (2011):

$$TSI\ (TOC) = 20.59 + 15.71 \ln (TOC)$$

TSI classifies water bodies as: TSI<40 oligotrophic; 40 to 50 mesotrophic; 50 to 70 eutrophic and >70 a hypereutrophic condition.

2. Ecological response index (ERI):

The ERI was calculated following Jaiswal and Pandey, (2019b):

$$ERI = \frac{FDAase \times C_{mic}}{TOC \times THM}$$

where, TOC = total organic carbon, C_{mic} = microbial biomass-C, ©THM $= \sum_{i=1}^{n} (M_i)$ and M_i = concentration of ith metal. On a scale of 0-320, the ERI between 0-24 represents extreme metal pollution; 25-38 a combination of metal pollution and eutrophy; 39-77 low metal pollution and hypereutrophy; 78-155 eutrophy and 156-320 represents the oligotrophic state.

Statistical analysis

Data in the figures are presented as mean and supported by standard error (SE). Principal component analysis (PCA) was used to ordinate environmental variables. Statistical software, Sigmaplot (version 11.0) and PAST (version 2.17c) were used for statistical analysis.

Results and Discussion

The concentrations of total organic carbon (TOC) and nutrients (TN, NO_3^- and PO_4^{3-}) in river water showed an increasing trend downstream the cities. Their concentrations were highest at Jjmu and lowest at Nwbj Site (Fig. 2). The TOC in riverbed sediment showed synchrony with those in river water. On seasonal scale, the concentrations were highest in summer season whereas lowest in rainy season. The Jjmu site is situated at downstream of Kanpur city which is well known for its leather industries. The river in Jajmau area receives about 168 MLD untreated and about 171 MLD treated sewage. Further, the Wazidpur drain situated close to

Jjmu Site adds over 54 MLD industrial effluent (CPCB, 2013). The Rjht Site was second in position in terms of carbon and nutrients concentration. The site is present at downstream of Varanasi city where the river receives ~141 MLD of treated sewage and ~46 MLD untreated urban sewage (CPCB, 2013). The Assi drain has been estimated to add over 66 MLD urban sewage whereas the Rajghat drain present close to this site adds ~16 MLD sewage. Additionally, the Ramnagar industrial area, which is present ~11 km upstream to the Rjht site, adds ~25

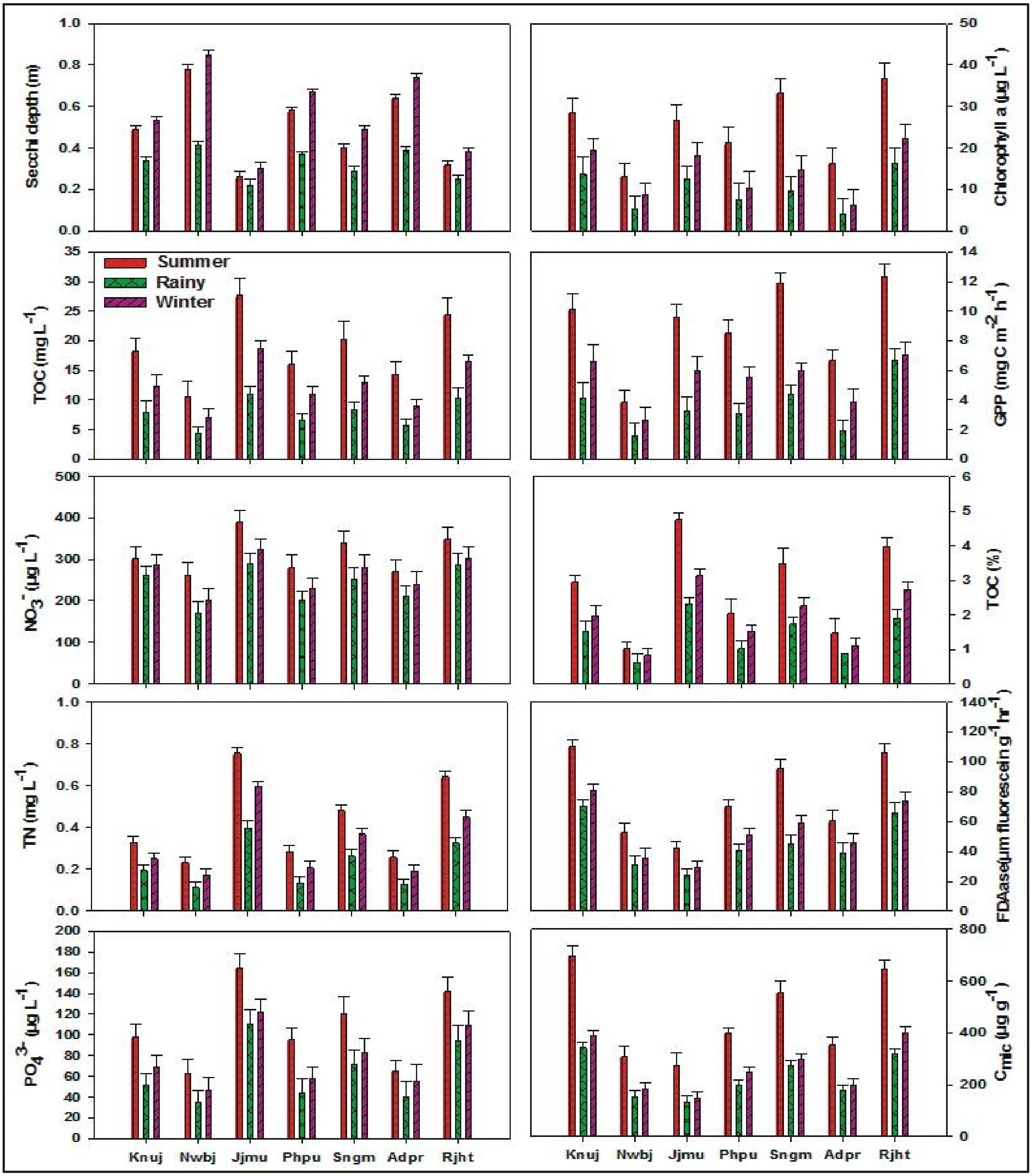

Fig. 2: Seasonal and spatial variations in sechhi depth, total organic carbon (TOC), nutrients (NO_3^-, total nitrogen; TN, PO_4^{3-}), chlorophyll a biomass, gross primary productivity (GPP)in river water and TOC, FDAase and microbial biomass-C (C_{mic}) in riverbed sediment at study sites. Values are mean (n = 12)±1SE.

MLD industrial effluents rich in metals and other chemicals (CPCB, 2013). A number of point- and non-point sources adds large amount of carbon and nutrients to the Ganga River. Studies show that point sources and non-point sources such as atmospheric deposition play more effective role in regulation of nutrients input such as N and P whereas surface runoff significantly add organic carbon to the water bodies (Yadav and Pandey, 2017). Ongley *et al*., (2010) have reported that in China, from the total water pollution, the non-point sources adds ~81% of N and 93% of P. Similarly, the study of three different river catchments of UK showed that at annual scale ~75% of the total phosphorus load comes from diffuse sources (Bowes *et al*., 2008). Further, a study of 86 rivers of US showed that point sources contribute >50% of the N and P whereas, non-point sources are responsible for >90% of N input reaching to the rivers from urban areas (Carpenter *et al*., 1998). The point sources in the Ganges basin have been estimated to add ~13.28 Gg of dissolved inorganic nitrogen (DIN) and about 5.29 Gg of dissolved reactive phosphorus (DRP) to the river each year (Singh and Pandey, 2019). The Assi drain at Varanasi which discharges over 66 MLD of sewage has been estimated to add over 535 tonnes of DIN and 133 tonnes of DRP annually to the river (Yadav and Pandey, 2017). Similarly, the atmospheric deposition has been estimated to add ~2.77 Tg DIN and ~0.13 Tg DRP in the catchment and ~5.31 Gg of DIN and ~0.37 Gg of DRP directly on the river surface annually (Singh and Pandey, 2019). Further, the extensive low flow period

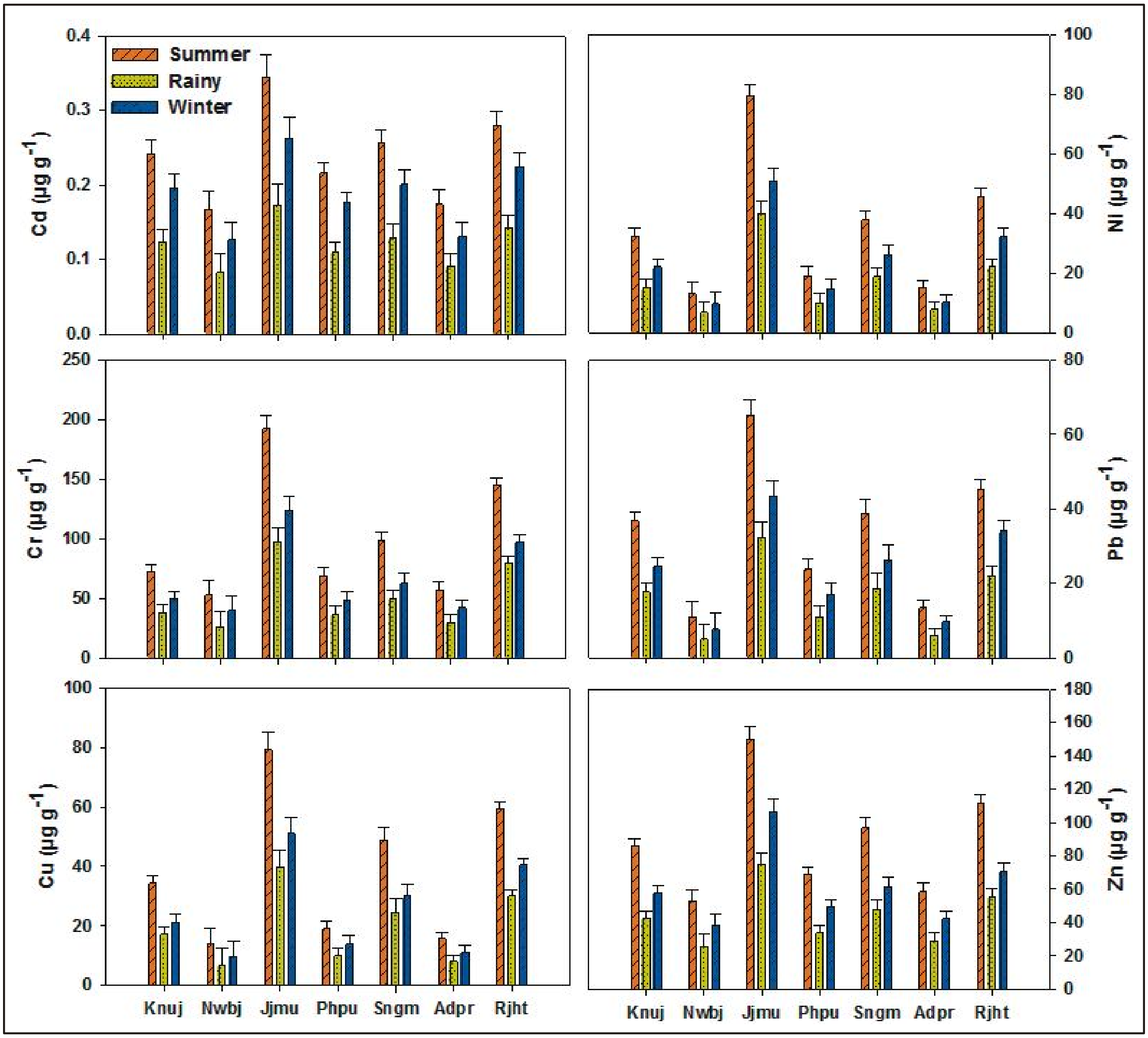

Fig. 3: Seasonal and spatial variations in concentration of heavy metals in riverbed sediment at study sites. Values are mean (n=12)±1SE.

also enhance the concentration of pollutants in the river.

The study area considered in this study also experience massive land use change which has been characterized as one of the main cause of aquatic pollution. These changes cause massive deforestation, aggravated soil erosion, siltation, flash floods and loss of ecological balance (Vergheseet *al*., 1994). The Ganges basin is very extensively cultivated; ~73.4% of the total area of the basin is cultivable as compared to country level of 47.9%. It has been estimated that about 10 million tonnes of chemical fertilizers are applied in the basin (2007-2008), which represent 45% of India's total annual consumption. Uttar Pradesh alone consumes about 38% of the total fertilizer consumption in the basin. The runoff emerging from these agricultural lands carries massive amount of soil, chemicals and nutrients to the river (Pandey *et al*., 2013, 2014). Yadav and Pandey, (2017), in their study at Varanasi region have shown that the agricultural land adds ~403, 186 and 24 Gg yr^{-1}, woodland ~67, 30 and 19 Gg yr^{-1} and built-up area adds ~11, 55 and 34 Gg yr^{-1} of NO_3^-, NH_4^+ and DRP respectively through surface runoff in the Ganga River. The basin scale extrapolation of these data shows that the river receives ~ 193 to 1181 Gg DIN and ~59 to 218 Gg of DRP each year through surface runoff. These high inputs of carbon and nutrients may cause detrimental effects including negative impact on buffering capacity of soil, soil leaching, biodiversity loss and eutrophication of the river.

The heavy metal concentrations in riverbed sediment followed trend similar to TOC in the sediment with values recorded to be highest at Jjmu Site while lowest at Nwbj Site (Fig. 3). The microbial biomass-C (C_{mic}) and fluorescein diacetate hydrolytic activity (FDAase) showed toxic impacts as the sites with high concentration of heavy metals i.e. Jjmu and Rjht had low values of C_{mic} and FDAase despite the presence of high amount of carbon and nutrients (Fig. 2). At spatial scale, the sechhi disk transparency (SD) showed a trend opposite to carbon and nutrients and the values varied between 0.22 m and 0.85 m. Seasonally, the transparency was maximum in winter and minimum in rainy season. Low transparency corresponded with high concentration of organic carbon. The concentration of chlorophyll a (Chl a) and gross primary productivity (GPP) followed a variable trend at both spatial and seasonal scale however, a close correspondence with nutrients were observed. Contrary to nutrients, the values were maximum at Rjht Site and minimum at Nwbj Site (Fig. 2). The respective values of Chl 'a' and GPP ranged from 3.91 to 36.65 µg L^{-1} and from 1.61 to 12.35 mg C m^{-2} h^{-1}. The disproportionate loading of N and P from point sources are major cause of this trend as the point sources contribute significantly in productivity specifically during low flow period which persist for longer period in the Ganges basin. Further, the contribution of point sources are more as compared to non-point sources as the runoff driven inputs does not get converted to productivity in proportion to the nutrients added because of unstable and turbulent water during the rainy season. However, the AD-driven inputs may significantly alter the productivity variables and trophic state of water bodies. Jarvie *et al*. (2006) showed that point source driven input of P contribute more significantly in causing eutrophy compared to the agricultural runoff containing high amount of phosphorus however, contrasting results have also been reported for a number of water bodies (Beman *et al*., 2005; Bergström *et al*., 2008; Pandey and Pandey, 2013). For Ganga River, the AD-driven N and P inputs have been reported to contribute 11.6-33.3% and 3.4-10.2% of the GPP respectively (Pandey *et al*., 2014).

The trophic state index (TSI) of the river ranged from 22.86 to 50.39, 43.58 to 72.71, 55.67 to 77.79, 43.97 to 65.93 and 62.34 to 81.81 based TN, TOC, TP, Chl 'a' and SD data respectively (Fig. 4). A variable trend of TSI based on different parameters was observed at both spatial and seasonal scale. The TSI (TN), TSI (TOC), TSI (TP) and TSI (SD), all were highest at Jjmu and lowest at Nwbj Site indicating combined inputs from various anthropogenic sources. The TSI (Chl a) was highest at Rjht and lowest at Nwbj Site indicating that high concentration at Jjmu Site is hampering the growth of phytoplankton. Recent studies have also reported metal induces toxicity to microbial biomass and activity at this site (Jaiswal and Pandey, 2018, 2019c). At seasonal scale, the TSI based on all the variables except those of SD were maximum in summer season and minimum in rainy season indicating low flow and high temperature induced increase in biomass production. Further, the high runoff coming to river during rainy season cause nutrient dilution and the DOC decreases the light penetration leading to reduced biomass production. The trophic status of an ecosystem is used for understanding the food web linkages, water quality (Dodds and Cole, 2007). The Carlson's TSI is one of the easiest and most commonly used index for identifying the trophic level and health status of aquatic ecosystems all over the world. The TSI (TN) classified Jjmu, Sngm and Rjht Site in mesotrophic state while the Knuj, Nwbj, Phpu and Adpr were in Oligotrophic range (Table 1). The TSI (TP) categorized Knuj, Nwbj, Phpu and Adpr in eutrophic range but Jjmu, Sngm and Rjht were in hypereutrophic state. Based on TSI (TOC), all the sites except Nwbj and Jjmu were in eutrophic state. The Jjmu Site was in maximum trophy level (hypereutrophic) while Nwbj was in least trophic level i.e. mesotrophic. The classification of sites based on TSI (Chl a) also showed some deviation where the Nwbj and Adpr were in mesotrophic range and all other sites were in eutrophic range. The TSI (SD) divided the site in two category; hypereutrophic (Knuj, Jjmu, Sngm and Rjht) and eutrophic (Nwbj, Phpu and Adpr) (Table 1). However, there was variations in trophic level based on different parameters but all the sites with high trophic level corresponded with high level of carbon and nutrients indicating that the nutrient concentrations in the river are sufficient to support a reasonably high productivity in terms of Chl 'a' biomass along the study stretch.

The ecological response index (ERI) based on sediment parameters ranged between 3.72 and 120.67 and was minimum at Jjmu Site (Fig. 4). Based on ERI, the Knuj, Nwbj and Adpr sites were in eutrophic range while the Phpu, Sngm and Rjht were in low metal polluted

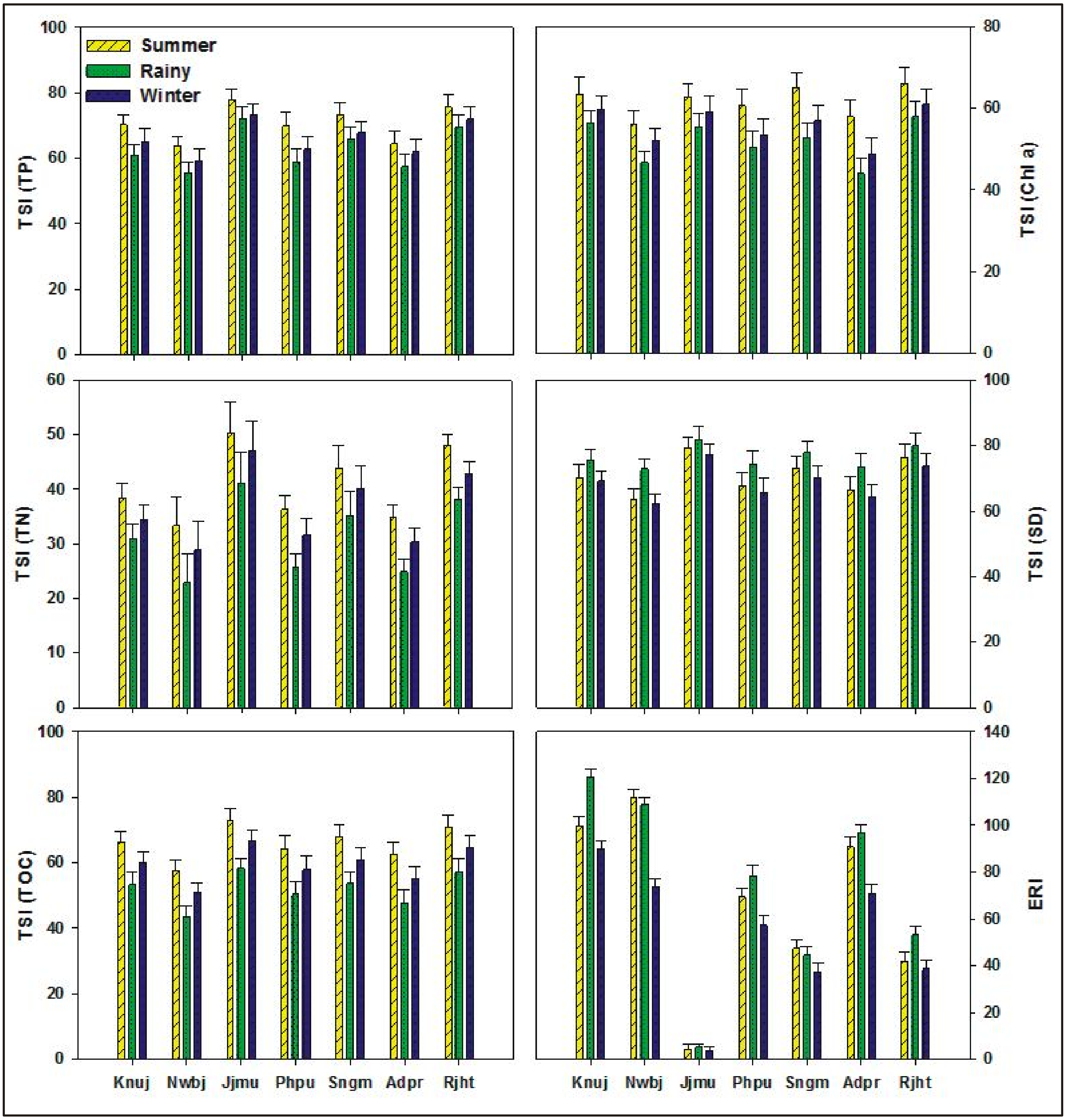

Fig. 4: Seasonal and spatial variationsof trophic state index (TSI) and ecological response index (ERI) at study sites. Values are mean (n = 12)±1SE.

Table 1: Level of eutrophy and metal pollution based on trophic state index (TSI) and ecological response index (ERI) at study sites.

Site	TSI (TN)	TSI (TP)	TSI (TOC)	TSI (Chl a)	TSI (SD)	ERI
Knuj	Oligotrophic	Eutrophic	Eutrophic	Eutrophic	Hypereutrophic	Eutrophy
Nwbj	Oligotrophic	Eutrophic	Mesotrophic	Mesotrophic	Eutrophic	Eutrophy
Jjmu	Mesotrophic	Hypereutrophic	Hypereutrophic	Eutrophic	Hypereutrophic	Extreme metal pollution
Phpu	Oligotrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Low metal pollution + Hypereutrophy
Sngm	Mesotrophic	Hypereutrophic	Eutrophic	Eutrophic	Hypereutrophic	Low metal pollution + Hypereutrophy
Adpr	Oligotrophic	Eutrophic	Eutrophic	Mesotrophic	Eutrophic	Eutrophy
Rjht	Mesotrophic	Hypereutrophic	Eutrophic	Eutrophic	Hypereutrophic	Low metal pollution + Hypereutrophy

and hypereutrophic range and the Jjmu Site was extremely polluted with metals (Table 1). A deviation of these results from those of TSI suggested the need to consider and develop new indices using which the eutrophy and metal pollution both can be assessed simultaneously as these occur together in almost all the anthropogenically-impacted water bodies. The principal component analysis (PCA) also divided the study site in two groups (Fig. 5); (1) Knuj, Jjmu, Sngm and Rjht Sites were in one group having comparatively high concentration of carbon and nutrients and were high in trophic state and (2) Phpu, Adpr and Nwbj were in second group. These sites were in low trophic state and had low carbon and nutrient concentrations. These results clearly indicated the

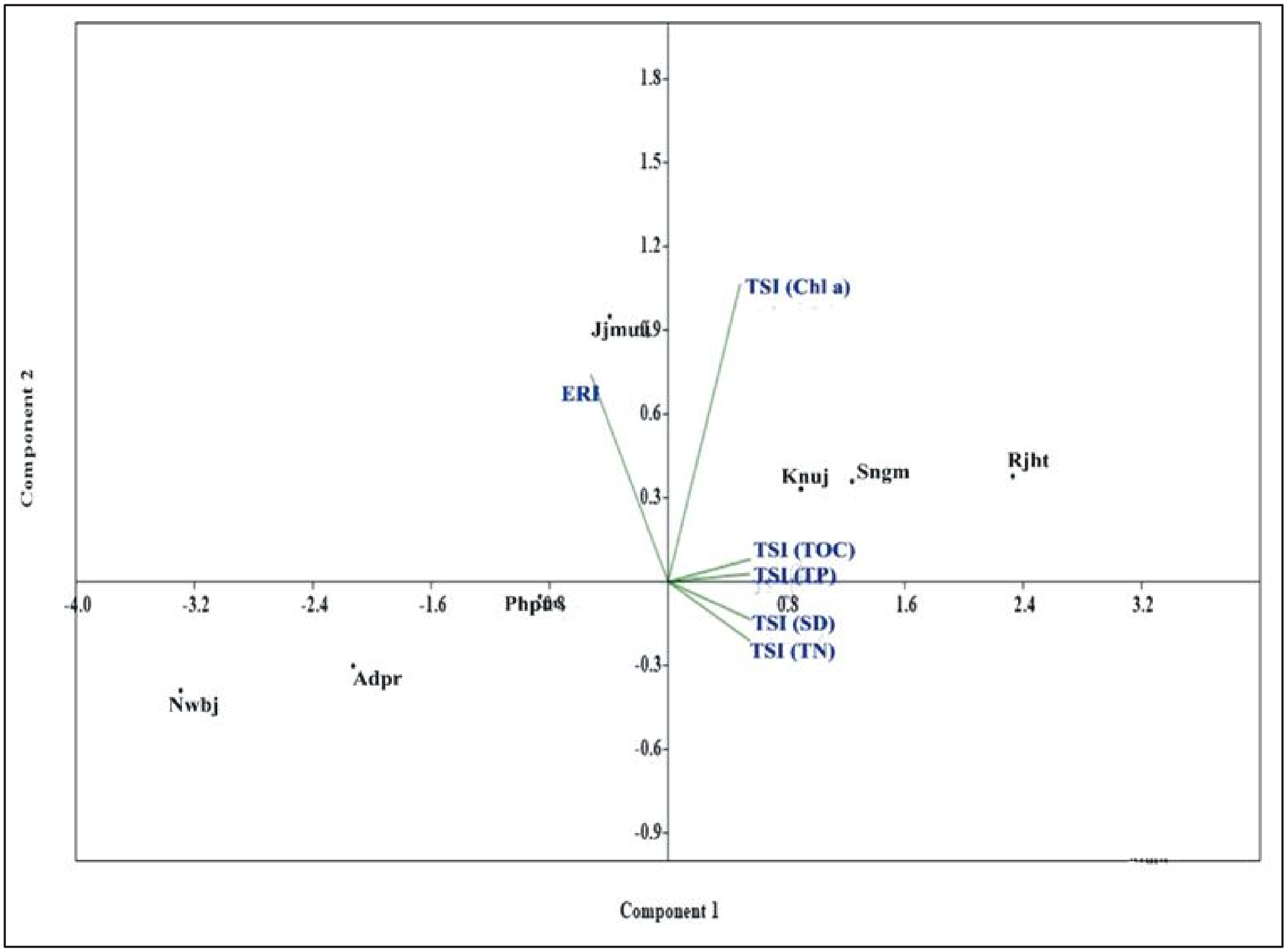

Fig. 5: Principal component analysis (PCA) considering trophic state index (TSI) and ecological response index (ERI) calculated at seven study sites of the Ganga River.

significant role of human-driven inputs on trophic status of the Ganga River. The study also show that allochthonous as well as autochthonous C contribute significantly to the cultural eutrophy of large rivers. The increasing allochthonous input and autochthonous C production would enhance secondary production or heterotrophy which will ultimately alter the food web dynamics of the river (Yadav and Pandey, 2017). Further, the C-eutrophy will significantly alter the magnitude of natural processes and lower the life expectancy of the affected water bodies as the increasing trophic level will cause benthic hypoxia/anoxia which will enhance the ecosystem feedbacks further deteriorating the system and making the recovery even more difficult (Jaiswal and Pandey, 2019d; 2020). These eutrophy-induced hypoxic/anoxic zones will also cause development of dead zones in the water bodies (Diaz and Rosenberg, 2008) leading to deterioration of water quality, loss of biodiversity, fisheries and ecosystem functioning and services.

Conclusions

The results of this study clearly showed marked spatiotemporal variations in carbon and nutrients leading to variable level of trophic status in middle stretch of the Ganga River. The anthropogenic factors appeared to be the principal drivers of enhanced nutrient concentration and consequently high trophic status. The data generated here revealed clearly that most of the sites of middle stretch of the Ganga River specifically those situated downstream of cities such as Jjmu, Sngm and Rjht are facing the problem of C-eutrophy and associated consequences. Both the TSI and ERI have categorized these sites in eutrophic to hypereutrophic category. Also these sites are facing problem of high level of metal pollution having negative impact on microbial biomass and activity. The results also suggest the need of more new indices for assessing the trophic level of human-impacted riverine ecosystems facing simultaneous problem of nutrient and metal enrichment. The study generates a systematic data on trophic state of the most polluted middle stretch of the Ganga River and has relevance in management of eutrophy and regional scale carbon and nutrient budgeting.

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