Int.J.Curr.Microbiol.App.Sci **(2017)** ***6*****(7): 4323-4334**

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 7 (2017) pp. 4323-4334**
Journal homepage: http://www.ijcmas.com

Original Research Article

https://doi.org/10.20546/ijcmas.2017.607.450

Diatoms as Indicator of Pollution Gradients of the River Ganga, Allahabad, India

Brajesh K. Dwivedi[1*] and Asutosh Kr. Srivastava[2]

[1]Environmental Sciences, Botany Department, University of Allahabad,
Allahabad- 211 002 (India)
[2]Govt. Degree College, Haripur Nihastha, Raebareli, U.P. (India)
**Corresponding author*

ABSTRACT

The impact of liquid wastes from a city sewage/ waste water on the benthic diatoms in flowing waters has been studied for a period a year (May 2015-April 2016). Water and algal samples were analyzed seasonally intervals at five sites along the course of the rivers Ganga, Allahabad. The hydrological strata of river water before the confluence of sewage / waste water were recorded low concentration of NH_3 and other nutrients. At the entry of sewage/ waste water, the water showed considerable decline in dissolved oxygen content, increase in organic matter, hardness, CI, HCO_3 and total dissolved solids. Diatoms constituted 61% by numerical abundance. Multiple regression analysis was employed to discover the relative importance of various physicochemical variables on the abundance and distribution of diatoms at various sampling stations. Mathematical equations were derived involving the physicochemical variables for better prediction of algal number.

Keywords

Indicator,
Pollution,
Gradients and
River Ganga.

Article Info

Accepted:
29 May 2017
Available Online:
10 July 2017

Introduction

Fresh waters are perhaps the most vulnerable habitats and are most likely to be changed by the activities of man. This essential resource is becoming increasingly scarce in many parts of the world due to the severe impairment of water quality. City wastes contribute at least 2/3 of the organic matter entering into our water resources. Within the last decades, limnologists have aimed at describing the structure and function of streams; a short review of concept in river ecology is given a Townsend (1996). The demand was for a more integrated assessment of rivers system that could evaluate the various and wide-reaching impacts of anthropogenic activities on the aquatic environment (Chovanec and Winkler, 1994; Tallberg *et al.*, 1999; Muhur *et al.*, 2000; Muhur and Jungwirth, 1998; Chovanec et. al., 2000; Dwivedi *et al.*, 2012. Dwivedi and Srivastava, 2015; Dwivedi, 2016c). These activities, including wastewater discharge, changes of habitat structure and connectivity aspects, as well as altered flow regimes, are often complex and difficult to describe directly in terms of their ecological repercussions. Phytoplankton encountered in the water body reflects the average ecological condition and therefore, they may be used as indicator of water quality & assessing the degree of pollution (Bhatt *et al.*, 1999; Saha et el., 2000; Dwivedi and Pandey, 2001; Pandey and Dwivedi, 2002; Dwivedi and Pandey, 2002a,b; Dwivedi and Pandey, 2003a,b; Shiddamallayya & Pratima, 2008). Over the years, the water quality of these sacred rivers is fast deteriorating. Organic and inorganic stress on rivers is reflected in active microbial growth and change in Physico-chemical parameters (Dwivedi, *et al.*, 2012; Dwivedi and Srivastava, 2015).

Biological information is of great value and, if considered in combination with chemical data, it can serve as an intelligible guide for the evaluation of degree of pollution (Dwivedi, and Pandey, 2015; Dwivedi 2016abcd and Dwivedi, 2017).). Algae are very suitable organisms for the determination of the impact of toxic substances on the aquatic environment, because any effect on the lowest level of the food chain will also have consequences on higher levels (Manikya Reddy and Venkateswarlu, 1987; Lund and Davis, 2000) attempted to study the influence of sewage wastes on the hydrobiology of the river Ganga, Allahabad. The present paper deals with the analysis of varied effects of on the diatom communities in the river.

Materials and Methods

Study area

The study covers stretch of river Ganga from Rasoolabad Ghat, Daraganj Ghat, Ram Ghat, Sangam and Chhatnag Ghat location of Allahabad city areas.

Rasoolabad Ghat (Site 1) - This sampling site is situated at upstream where the river enters into the domain of city of Allahabad. The sources of pollution at this site are cremation, disposal of untreated sewage, washing of clothes, agricultural runoff and temple's solid waste disposal etc. Daraganj Ghat (Site 2) - It is situated at downstream of Rasoolabad Ghat, on the left bank of the river. This site is known for having big and glorious temples on its bank. Many drains like Saloridrain, Govindpurdrain, and Mori drain find their way directly near to this site. Other sources of pollution at this site are cattle wallowing, agricultural runoff, mass bathing, dhobi ghat and flower offerings etc. Ram Ghat (Site 3) - This site is situated at downstream of Daraganj Ghat, on the left bank of the river. This site is also known for having many big temples. The main sources of pollutionat this site are open drains carrying untreated domestic sewage from Jhunsi area, religious fairs on its bank, garlands and flower offerings.

Sangam (Site 4) - This site is situated at the confluence point of River Yamuna, Ganga and invisible Saraswati. Because of this rare occurrence, this site is known for the huge fair '*KumbhMela*' organized every year due to its great religious value. People from all over the world come here to have a holy dip. Main source of pollution at this site are mass bathing, flower offerings, cremation activities and religious fairs. Chhatnag Ghat (Site 5) - At this site river leaves the city and carries water of both the rivers Yamuna and Ganga. This site is situated at the downstream of river Ganga after the *Sangam.* This site is also used as the crematorial ground. Cattle wallowing are a common picture here. This site also receives untreated sewage and agricultural run-off.

Site1-Rasoolabad Ghat, Site2- Daraganj Ghat, Site3- Ram Ghat, Site4-Sangam and Site 5-Chhatnag Ghat.

The river Ganga, the largest of the India Rivers, rises from Gomukh Uttarakhand, enters Uttar Pradesh, Bihar, Jharkhand State and joins the Bay of Bengal near Ganaga

Sagar after traversing a distance of 2525 km (Figure 1). The river provides large quantities of fresh water to 30 crore people and different industry for processing, different river canal and in turn receives enormous quantities of liquid wastes and nutrient transport sediments. Water and algal samples were collected from five sampling sites along the course of the rivers Allahabad city at monthly/ seasonally intervals for a period of a year. Samples were collected in the. River before the entry of wastes at the point of entry of wastes and at proper distance after the entry of wastes into the river. Sewage / waste water were also collected just before their discharge into the river. Samples were analysed for selected variables by following the standard procedures (APHA, 2010).

For the collection and analysis of algae, the standard techniques were followed. Four or five uniformly sized pebbles (2 x 2 in) coated with brown or green scum were collected from the habitat in a wide-mouthed bottle containing 250 ml of water. The pebbles were scraped carefully with a. scalpel and a brush. The samples were preserved in 4% formaldehyde solution and the final volume of sample was reduced to 50 ml by sedimentation. The concentrated material was used for frequency measurements and species identification. A record was made of the total number of organism’s present high power fields of the microscope and the number of individual organisms. Finally, the percentages of different groups and species of algae were calculated.

Multiple regression analysis was employed for the evaluation of the relative importance of various physicochemical variables on the growth and development of diatom communities by taking their number as dependent variable and physicochemical factors as independent variables. The percentage variance brought about in algal number is expressed as an R^2 value and its statistical significance is tested with the F value. The proposed models contain the minimum number of variables required to explain the variation in diatom number to the maximum extent in a statistically significant way, along with their regression coefficients (Nageswara Rao, 1983).

Results and Discussion

The average values of various physicochernical factors and the percentage increase and decrease of concentration of various factors of the river water/ sewage waste water incorporated from one station to other were shown in Figures 2 -11. The water was slightly alkaline in nature at all sampling sites. Bicarbonates at Station 2 were 46.8% higher than at Station 1. Chlorides at Station 2 showed a 165% increase over Station 1. Dissolved oxygen declined by 55.5% from Station 1 to 4 and increased by 78% from Station 2 to 3. Oxidizable organic matter increased 13 times from Station 1 to Station 2. Calcium values doubled from Station 1 to 2, Ammonia is very high more at Station 2 and 4 than at Station 1. Nitrates were elevated by 296% and 164% from Station 1 to Stations 2 and 3, respectively. Sulfates increased by 159% from Station I to 5 and declined by 41 % from Station 2 to 3. Total dissolved solids increased by 127% from Station 1 to 2 and decreased by 18% from Station 2 to Station 4. Suspended solids increased by 239% from Station I to 5 and declined by 29% from Station 1 to 4.

In the city sewage, temperature varied between 24°C and 35.4°C. pH fluctuated around 6.9. Bicarbonates and chlorides were observed in very high quantities, their average values being 333.4 mg/l and 192.0 mg/I, respectively. Free CO_2 fluctuated widely between 0.0 131.2 mg/1. The sewage / waste water were characterized by very low dissolved oxygen and very high organic matter. Nitrates were the dominant forum of nitrogen (3.4 mg/l). While free ammonia had an average. Of 1.05 mg/1, nitrates fluctuated between 0.64 to 3.21 mg/l. whereas phosphates reached a maximum of 2.0 mg/l. The effluents were characterized by the presence of higher total dissolved solids (362.5 mg/1) than suspended solids 393.3 mg/1).

Bacillariophyccae was the predominant group in benthic algae and constituted about 61 and 51% of total algae at. Station 4 and 5, respectively.I. At Station 3 they became subdominant to Cyanobacteria and represented only 45% of total algae. Again Bacitlariophyceae became dominant at Station 3, 4 and 5, constituting about 49.3% of algae. Bacillariophyccae are more diversified at Station 3 than at other stations. (Figure 12).

At station 3 and 4 all physicochemical variables together account for 86% of diatom variance. However, the F value is not statistically significant. With the elimination of dissolved oxygen and magnesium in the step-down regression analysis the contribution of other variables becomes statistically significant, and together they account for 83% of the variation in the algal number. Except for pH, temperature, suspended solids, nitrates, carbonates, chlorides and dissolved solids, the contribution of rest of the chemical factors is found to be negligible in the distribution of diatoms.

The effects of pH on diatom communities are both direct and indirect. In the present study, pH, fluctuated within a. narrow range (8.4-8.8) and showed a positive influence on the growth of diatoms. In the presence of other factors, pH accounts for 4% of algal variance. Some diatoms seem to be able to withstand fairly wide temperature ranges and maintain fairly good growth rates, whereas other diatoms seem to have small ranges of temperature. However, most diatoms prefer temperatures less than 30°C (Dwivedi, 2016c). Temperature may have varied effects upon diatom communities. It is well known that those diatoms living in warm water often have less silica in their cell wall than those living in cold waters. Temperature effects the diffusion rates of chemicals and decreases the amount of dissolved oxygen. These changes affect the reproductive rates and metabolism of diatoms. Manikya Reddy and Venkateswarlu (1987) observed an inverse relationship between temperature and diatom number. Such a relationship is also evident in the present study and temperature accounts for 5% of algal variation.

In most fresh waters there is sufficient carbon present in the form of CO_2 or carbonates or bicarbonates for diatom growth. In the present study, carbonates were recorded in low concentrations as pH ranged between 8.4 and 8.8. Diatoms appear to prefer carbonates as carbon source at that pH range and carbonates account for 5% in R^2 of variation in algal number.

One of the most important density independent factors affecting diatom growth is turbidity caused by suspended solids (SS). SS correlated negatively with diatom growth and account for 6% algal variance. This negative, effect could be the result of inhibition of growth of diatoms due to logging up habitats and homogenizing sediments or to the cut down of light penetration. This is in conformity with the findings of Dwivedi and Srivastava, Dwivedi, 2016bc. The importance of nitrates and their positively influx for diatoms has been well documented (Manikya Reddy and Venkateswarlu (1987). In the present investigation a negative relationship was recorded between these two and nitrates alone explained the variation in algal number to the extent of 9%.

Such an inverse relationship might have been due to imbalances in the utilization and regeneration of nitrates.

The utilization of nitrates as the nitrogen source also coincided with high pH of water at Station 3 and 4. Similar observations were made by Patrick (Dwivedi, 2016c).

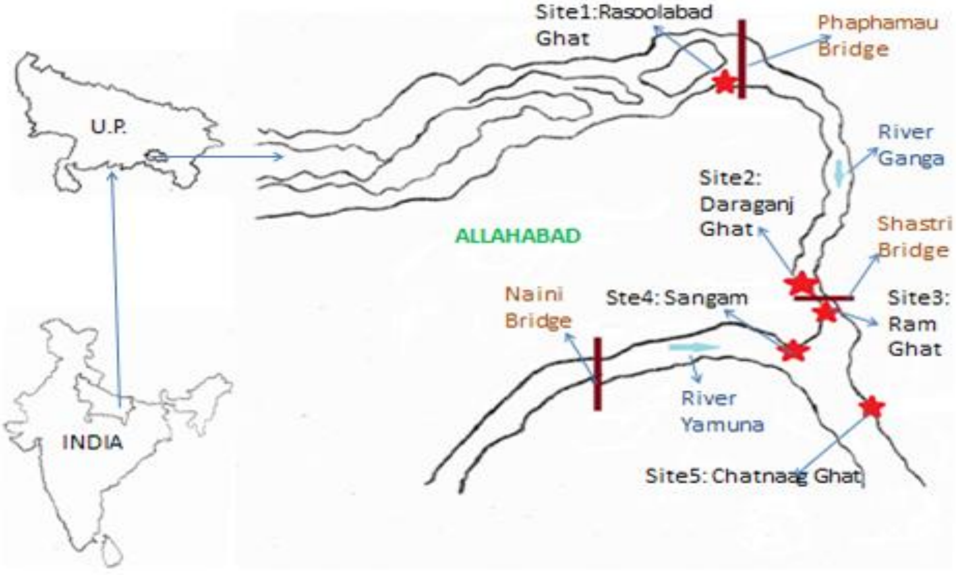
Total dissolved solids are another important factor for the distribution and development of diatom communities.

TDS account for 34% of diatom variation and thus considered to be more important 'than any other individual factor in explaining the algal variance. The model derived for prediction of diatom number in an unknown sample is as follows:

Diatom number = 2161.8 + 36.9 x CO_3 - 13.9 x Cl - 553.3 x NO_3 - 609.7 x NH_3 - 3.8 x dissolved solids
(R^2 = 0.55, F = 4_45, df = 18.5, n. = 24).

At Station 4, pH, temperature, carbonates, carbondioxide; chlorides, dissolved oxygen, organic matter, hardness, calcium, magnesium, nitrates, nitrites, ammonia, sulfates, and suspended and dissolved solids could explain the variation in diatom number significantly to the extent of 93%. However, except pH, temperature, magnesium, nitrites, ammonia, sulfates and suspended solids, the remaining factors could not contribute considerably to diatom growth as evident from the negligible drop in R^2 value with their elimination. In station 5. At this station, pH is related negatively with diatom number and is significant at 5% level of probability. Within a pH range of 7.2-8.0, high pH does not seem to favor the diatoms characteristic of Station 2. Temperature is another minimum variable required to explain the diatom variation to the maximum extent. A change in growth to the extent of 293 organisms is recorded for a change in temperature (Figure 12).

Fig.1 Map showing five sites along the Ganga River at Allahabad city



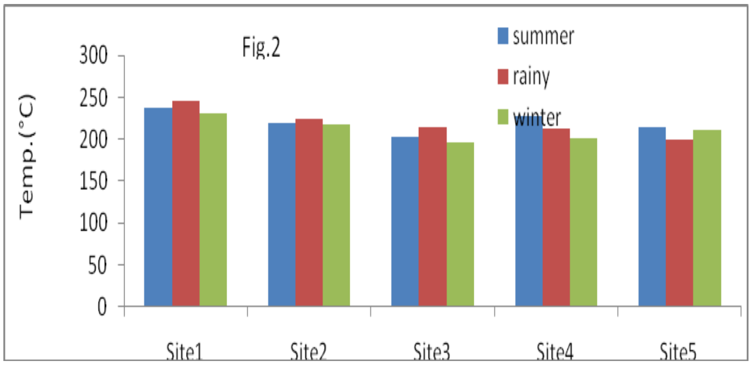


Fig.2
Temp.(°C)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

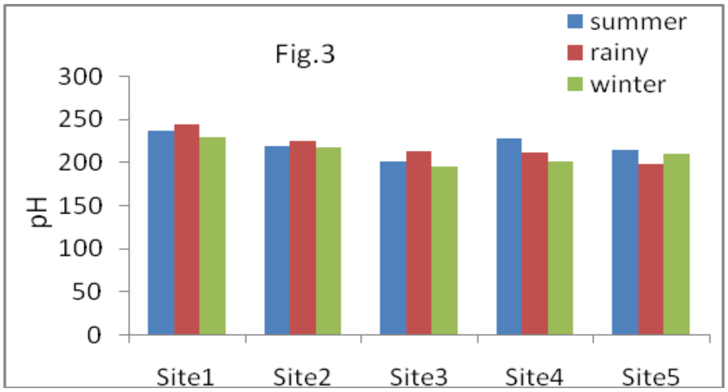


Fig.3
pH
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

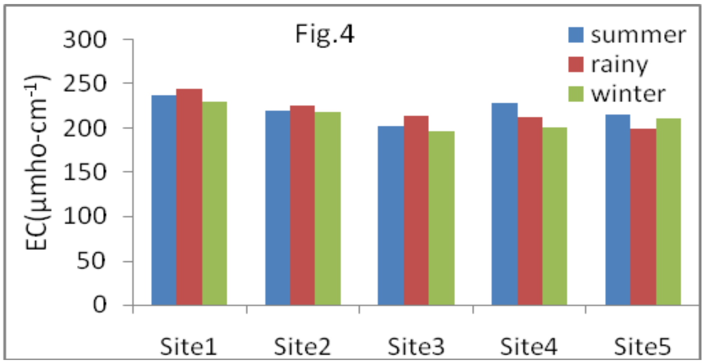


Fig.4
EC(µmho-cm-1)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

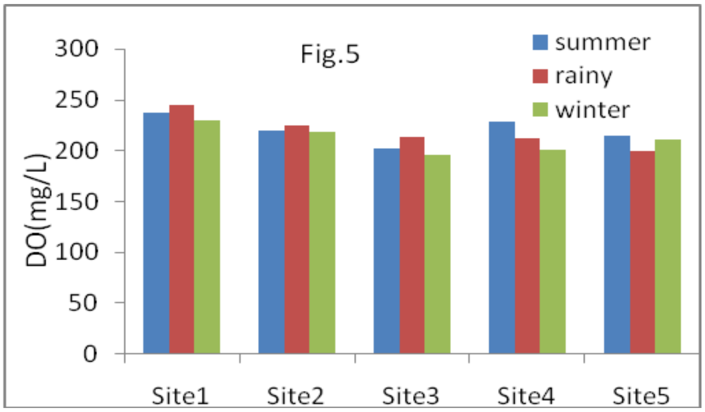


Fig.5
DO(mg/L)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

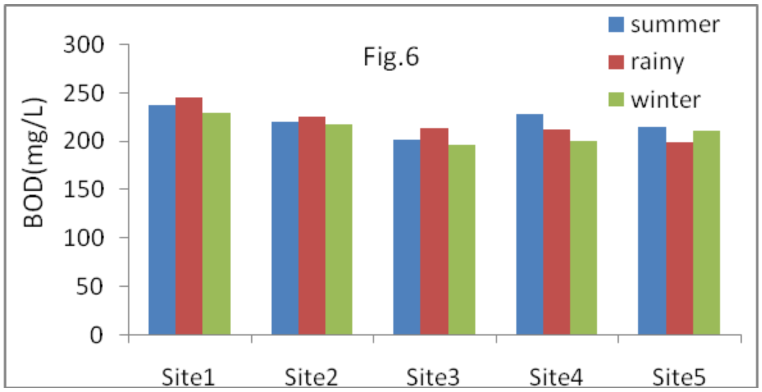


Fig.6
BOD(mg/L)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

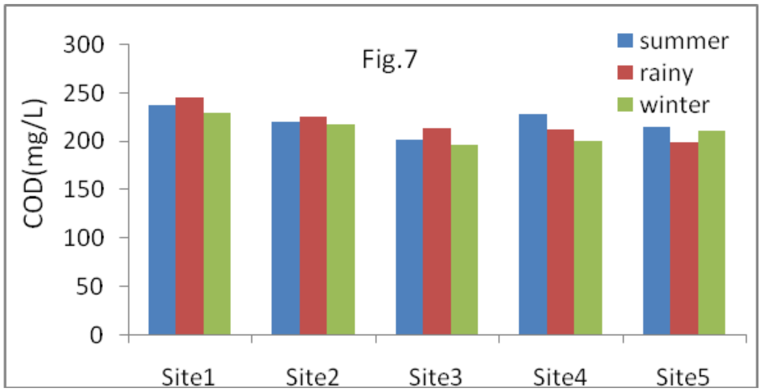


Fig.7
COD(mg/L)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

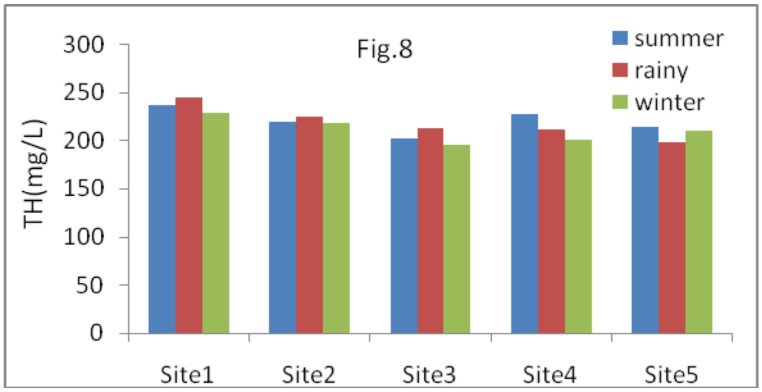


Fig.8
TH(mg/L)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

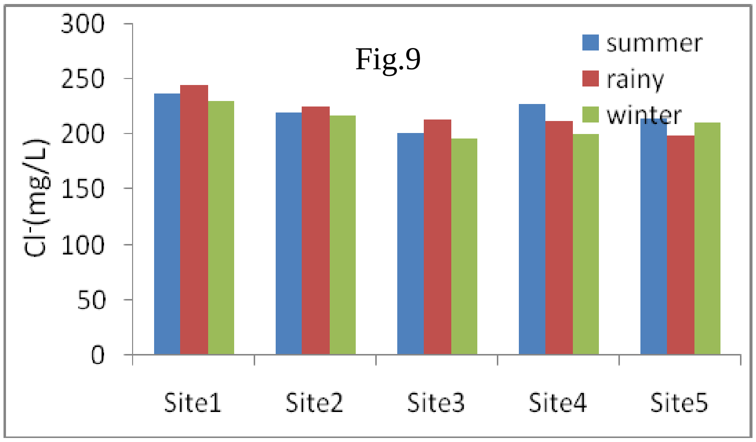
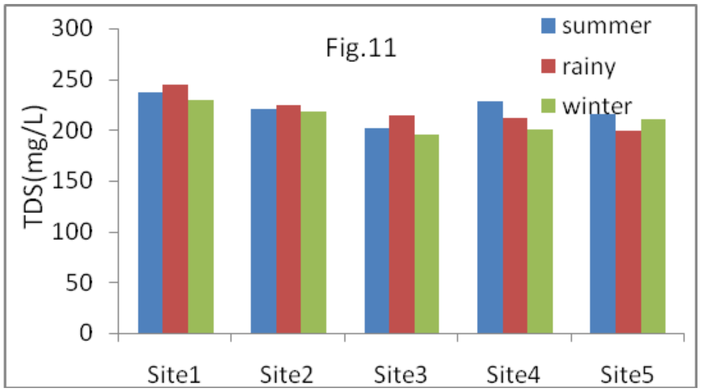


Fig.9
Cl^-(mg/L)
300
250
200
150
100
50
0
Site1
Site2
Site3
Site4
Site5
summer
rainy
winter

Table.1 Diatom abundance at different station

Name of species	Station 1	Station 2	Station 3	Station 4	Station 5
Synedra ulna	998	200	1110	1260	2000
Cymbella aspera	970		190	320	790
Achnanthes minutissima	960		700	870	1000
Synedra tabulate	890	200	800	1200	1600
Gomphonema montanum	500		760	870	1200
Navicula rhynchocephala	490	250	780	810	1210
Navicula bacillum	430			720	710
Anamoeneis spheaerophora	220	310	200	310	420
Caloneis bacillum	230	230		320	420
Nitzschia amphibian	240		390	340	510
Gyrosigma acuminatum	230	240	600	580	710
Cymbella affinis	245	270	430	510	810
Pleurosigma angulalum	200	290	450	510	890
Nitzschia denticula	180		70	200	570
Navicula cryptocephala	170	110	210	300	420
Caloneis silicula	130	230	185	310	430
Nitzschia obtuse	130	1220	170	230	340
Nitzschia acicularis	120	610	80	210	360
Achnanthes exigua	58	570	210		
Nitzschia hungarica	47	524		410	680
Nitzschia palea	48	410	190		510
Gomphonema parvulum		400	210	320	400
Navicula pupula	62	120	200	210	310
Cyclotella meneghiniana	20	120		120	430
Gomphonema sphaerophorum	45	70	160	210	320



Sulfates arc one of the important factors that influence the growth of diatoms which is evident in the present study. This could he due, to the decomposition of proteinaccons sulfur eon organic matter which creates altered conditions and in turn mat kindly affect, the cycling of other nutrients (Wetzel, 1983).

Ammonia and nitrates. Which are referred to as nutrient parameters, are utilised by diatoms in varying amounts. The preference of varying amounts of these nutrients by various species of diatoms has led to the development of the saprobic system. In the present study, diatoms prefer NH3 to NO3 as nitrogen source at Station 3 and 4. This could be attributed to higher concentrations of ammonia maintained and formed by rapid decomposition of organic wastes and also due to low pH. The model derived is as follows.

Diatom number = 33.1 - 293.7 x pH - 13.3 x temperature - 4.7 x Mg + 62617.6 x NO_2 - 85.4 x NH_3 – 4 x SO_4 - 0.2 x Suspended solids

(R^2-0.79, F = 8.8, df = 18.5, n 24).

At Station 3, SO, PO_4 CO_3 and temperature are relatively more significant in bringing about a change in diatom number. A positive relationship recorded between them at Station 4 and 5 were statistically significant. However, in association with temperature, sulfates, carbonates and phosphates were able to bring about 2070 units change for one unit change in its own concentration. At this station, SO_4 and CO_3 respectively account for 6% and 9% of algal variance. Phosphates represent the most important nutrient factor to explain the variation in algal number to the extent of 4%. Orthophosphate is the form of phosphorus which is preferred by algae and its uptake is influenced by light, pH and other nutrients (Dwivedi 2016 c, d and Dwivedi, 2017).

From the foregoing account it is clear that different diatom communities favor specific set of environmental hydrological conditions (Dwivedi and Srivastva 2015; Dwivedi 2016 b, c). Diatoms prefer carbon in the form of carbonates at Stations 4 and 5 (contributed 5% and 9% of variance) and CO_2 at station 2. This could be the reason for their preference of NO3 at higher pH range and of NH3 at lower pH levels. Further, the diatom populations that utilize ammonia are quite distinct from those utilizing nitrates as evident from their distribution at different stations.

At different pH ranges the nitrogen and TDS/SS content seem to favor distinct diatom flora. Constant changes in the physicochemical environment would bring about changes in the percentage composition but not in the flora as it whole (Chovanec *et al.*, 2000). According to this author, a dominant organism at one. Site may become a co-dominant or even a minor member in another sample. This is true in case of *Svnedra ulna*, *Navicula rhynchocephala* and *Synedra tabulaia* which are dominant at Station 3, become minor members at Station 2, and again become dominant at Station 4 and 5, thus showing various degrees of development. However, some of the *Nitzschia* species like *Nitzschia obtusa, N. palea, N. hungarica. N. thermalis, acicularis and Gomphonema parvulum*, which are completely absent at station I, become dominant at Station 4 and co-dominant at Station 5. The high percentage of *Nitzschia* species indicates strong pollution as most of its species require dissolved organic and inorganic compounds for their metabolism and thus adapt to life in a wide variety of ecological conditions. These views more or less fit in with the present data as the percentage. Of most of the *Nitzschia* species is high at Station 4 and 5 and also to low DO tensions and high concentrations of several physicochemical factors. Similar observations were also made by Manikya Reddy and Venkateswarlu (1987).

The occurrence of *Gomphonerna parvuhim Achnanthes exigua*, *Cyclotella rneneghiniana* could be due to their ability to utilise Organic matter and also to their withstanding capacity to low DO tensions. However *Synedra ulna*, *Synedra tabulate* could adapt to the environment with reduced capacity as they exhibit more luxuriant growths at Stations 4 and 5.

The river water at Station 1 exhibits a pH range which is quite distinct from that of Station the influence of pH on diatoms in different ranges is not on diatom group as a whole but it is on individual populations. This is evident from the study, where different sampling stations are characterized by distinct species. Thus different pH ranges appear to favour different diatom communities.

Total dissolved solids found to have more influence on diatom growth. The relatively greater importance of TDS as a factor However, at Station 1 and 2 suspended solids have more influence on their growth because they are discharged in enormous quantities through sewage waste water.

However, from the study, it is possible to assign a role for the diatoms as indicators of pollution. The proliferation of *Cymbella aspera*, *Navicula bacillum*, *Caloneis silicula* and *Achnanthes minutissinza* indicate the uncontaminated and well oxygenated nature of the habitat as at Station 2 and 3 of the present study. The abundance of *Niteschia obtuse var. scalpelliformis*, *N. palea*, *thermalis hungarica*, *N acicularis*, *Achnanthes exigua* and *Cyclotella meneghiniana* shows the heavily polluted nature of the habitat as at Station 5.

The occurrence of *Gyrosigma acminatum*, *Pleurosigrna angulaturn Surirella robusta*, *Pinnularia biceps*, *Achnanthes lanceolatum*, *Gomphonema sphaerophorum* and *G. parvulum.* Reveals the mixed conditions prevailing in the habitat as at Station 4 of the present study.

As such, the presence or absence of the above diatoms in the habitat indicate the pollution gradients in flowing waters and useful in assigning them roles as biological indicators. Instead, the abundance of these organisms in relation to others would greatly help in detecting the degree of contamination.

Acknowledgement

The authors are extremely grateful to the Co-ordinator, Environmental Science, Botany Department, University of Allahabad, for the support and encouragement during the course of this work.

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How to cite this article:

Brajesh K. Dwivedi and Asutosh Kr. Srivastava. 2017. Diatoms as Indicator of Pollution Gradients of the River Ganga, Allahabad. *Int.J.Curr.Microbiol.App.Sci.* 6(7): 4323-4334.
doi: https://doi.org/10.20546/ijcmas.2017.607.450