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A Study on the Effects of Pulp and Paper Mill Effluents on the Water Quality snd Fish Diversity of Hooghly River for Determination of Its Ecological Health.

Biology

KEYWORDS : Pulp and paper mill effluents, Hooghly River, water quality, fish diversity.

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ABSTRACT

A seasonal study was conducted on water quality and fish diversity of six different stations adjacent to a paper mill along a small stretch of the Hooghly River at Chakdah, Nadia, West Bengal to determine its ecological health. During the study period, the temperature of the six stations varied between 26.6-32.4 °C and the pH was slightly alkaline in nature (7.5-8.4). The free carbon dioxide value at the outfall (station 3) was markedly reduced compared to other stations (0.0-6.0 mg/l). Dissolved Oxygen, alkalinity and hardness ranged from 4.08-6.60 mg/l, 150-228 mg/l and 115-155 mg/l respectively. The lowest diversity of fishes was observed in station 3 and this was due to the entry of pollutants coming from the pulp and paper mill effluents. The present findings also suggest that special care should be taken in the treatment of the effluents before their final discharge to the riverine ecosystem especially during hot summer.

Introduction

Every year approximately 100 million kg of toxic pollutants are released in the environment by the pulp and paper industry (Cheremisinoff & Rosenfeld, 2011). Many rivers have been grossly affected by discharges from pulp and paper mills (Das & Bordoloi, 2013; Malaviya & Rathore, 2007). There has been a sharp fall in the density and diversity of fish communities in various lakes and streams because of alteration in their taxonomic composition (Kelso, 1977). Various wastes like organic chemicals, reducing agents and wood-pulp sediments are responsible for these effects (Harris et al., 1992). Though there are numerous literatures on the role of industrial effluents in altering the water quality and biodiversity (Das & Chakrabarty, 2007; Mukhopadhyay et al., 2007), scanty reports are available on the effects of pulp and paper mill effluents on the physicochemical properties of natural water bodies and their biodiversity (Das & Bordoloi, 2013; Harris et al., 1992). There are scattered reports on the quantity, nature and characteristics of the pulp and paper mill effluents and their impact on plankton along the Hooghly estuary (Ray & Mitra, 1980). The outcome of cage culture experiments conducted around the outfall of a tissue paper mill has been reported by Ray (1981).

In the present study, an attempt has been made to study the impact of paper and pulp mill effluents on the water quality and fish diversity along a small stretch of the Hooghly River at Chakdah, Nadia for determination of its ecological health.

Materials and Methods

Six sampling stations (S1-S6) of the Hooghly River adjoining to the Supreme Paper Mills Limited and Bhagirathi road at Raninagar, Chakdah, Nadia were selected for the study of water quality and fish diversity analysis. Geographical details of the study area are summarized in Table 1 and Figure 1.

Table 1: Geographical details of the sampling stations

Feature	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Latitude/ Longitude	23°04'51"N 88°29'49 "E	23°04'40"N 88°30'09 "E	23°04'29"N 88°29'58"E	23°04'20.1 "N 88°29'47 "E	23°04'10.5 "N 88°29'30 "E	23°03'59.3"N 88°29'13 "E
Location	Channel inlet adjoining to the river at Raninagar Ferry Ghat	Channel inlet adjoining to the junction of approach road at Raninagar Ghat	Main outfall of the mill joining the channel of the river	Channel outlet adjacent to the main river at Sanyal Char	Channel outlet joining the main river at Sanyal Char	Main river at Sanyal Char opposite to Char Jirat
Distance from outfall	3000 m upstream	1000 m upstream	0 m	1000 m downstream	3000 m downstream	4000 m downstream
Water depth	1.80 ± 0.30m	1.00 ± 0.28m	0.75 ± 0.25m	1.00 ± 0.26m	2.00 ± 0.30m	1.90 ± 0.31m
Vegetation density	Absent	Scanty	High	Very high	Scanty	Absent

Sampling stations were selected based on the distance from the outfall to the main river and its channel, their geographical terrain, depth of the channel and density of bank vegetation. It is about 70 km away from Kolkata, West Bengal, India. The paper mill was established in 1974 and is the manufacturer of three types of printing and writing paper which are creamwove, maplitho and azurelaid paper along with converted paper using kraft process. The mill has a single major outlet containing sludge as well as wastewater. The outlet drains into a wide channel that finally joins the Hooghly river ecosystem.

Figure 1: Satellite view of the six stations (S1-S6) adjacent to the pulp and paper mill



Temperature (°C), pH, free carbon dioxide (mg/l), dissolved oxygen (mg/l), total alkalinity (mg/l) and total hardness (mg/l) of water were studied between 8 to 10 a.m. in all six stations at premonsoon, monsoon and postmonsoon during the period from August 2011 to October 2013. All the water quality parameters were determined following the method of American Public Health Association (2012).

In addition to the water chemical analysis, the fish were also

sampled during the study period. The sampling was done using various indigenous gears like cast net, hook and baits and other common gears. The collected specimens were preserved in 5% formalin by giving an abdominal incision to the specimen. Fish specimens were brought to the laboratory and identified with the help of standard literatures (Jayaram, 1999; Talwar & Jhingran, 1991; Nelson, 1976).

For the determination of diversity indices, random fish samples were taken from five nettings and pooled together to make a 1kg sample of fish for each station. Total number of individuals, total number of species and total number of individuals of a species were determined during premonsoon, monsoon and postmonsoon. From these data Shannon-Weaver (H') species diversity index (Shannon & Weaver, 1963), Evenness (J') index (Pielou, 1966) and Index of Dominance (ID) (Simpson, 1949) were determined using the following equations:

$H' = -\Sigma\, p_i \ln p_i$

where $p_i = N_i/N$ i.e. fraction of the entire population made up of species i and N is the total number of individual; N_i is the number of specimens in each species.

$J' = (H')/\log_2 S$

where H' is the S.W. Species Diversity Index; S is the total number of species.

$ID = \Sigma\, (N_i/N)^2$

where N is the total number of individual; N_i is the number of individuals in each species.

The data on physicochemical parameters was subjected to analysis of variance using the computer software provided by the R Development Core Team (2011) followed by Duncan's multiple range test to determine significant differences among means (Gomez and Gomez, 1984).

Results and Discussion

The mean (all values are the mean of six observations) seasonal variation in various physicochemical parameters of water from stations 1-6 are summarized in Table 2.

Table 2: Seasonal variation of the physicochemical parameters of six stations at pre monsoon (P), monsoon (M) and post monsoon (PM) during the period from August 2011 to October 2013 (Values within columns indicated by different superscript letter (a,b,c) and values within rows indicated by different superscript letter (m,n,o,p,q) are significantly different at 5% level determined by Duncan's Multiple Range Test).

Parameters	Seasons	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Temperature (°C)	P	$30.6^{an} \pm 1.75$	$31.6^{ao} \pm 0.51$	$32.4^{an} \pm 2.85$	$32.3^{ao} \pm 0.88$	$31.0^{ao} \pm 1.04$	$30.6^{an} \pm 0.69$
	M	$29.5^{an} \pm 1.35$	$29.8^{an} \pm 0.55$	$29.8^{amn} \pm 0.73$	$29.7^{an} \pm 0.94$	$29.6^{an} \pm 0.83$	$29.5^{an} \pm 1.74$
	PM	$26.6^{am} \pm 1.25$	$26.7^{am} \pm 1.12$	$28.4^{bm} \pm 1.08$	$27.2^{abm} \pm 0.32$	$26.7^{am} \pm 0.53$	$26.6^{am} \pm 0.46$
pH	P	$7.9^{am} \pm 0.50$	$8.0^{am} \pm 0.24$	$8.4^{am} \pm 0.73$	$8.1^{am} \pm 0.32$	$7.8^{am} \pm 0.18$	$7.7^{am} \pm 0.55$
	M	$7.5^{am} \pm 0.25$	$7.8^{am} \pm 0.37$	$8.1^{am} \pm 0.24$	$7.9^{am} \pm 0.29$	$7.5^{am} \pm 1.28$	$7.6^{am} \pm 0.44$
	PM	$7.8^{am} \pm 0.18$	$8.1^{am} \pm 0.69$	$8.3^{am} \pm 0.53$	$8.0^{am} \pm 0.24$	$7.8^{am} \pm 0.27$	$7.8^{am} \pm 0.39$
Free CO_2 (mg/l)	P	$28.0^{co} \pm 0.64$	$5.0^{bm} \pm 0.26$	$0.0^{am} \pm 0.04$	$6.0^{bm} \pm 0.40$	$27.0^{cmn} \pm 3.98$	$25.0^{cm} \pm 2.22$
	M	$20.0^{cm} \pm 1.39$	$12.0^{bn} \pm 4.30$	$6.0^{an} \pm 0.76$	$10.0^{abn} \pm 1.16$	$28.0^{dn} \pm 5.54$	$28.0^{dm} \pm 2.14$
	PM	$26.0^{dn} \pm 1.02$	$6.0^{bm} \pm 0.14$	$0.0^{am} \pm 0.04$	$7.0^{bm} \pm 0.62$	$21.0^{cm} \pm 3.18$	$26.0^{dm} \pm 3.63$
DO (mg/l)	P	$5.18^{cm} \pm 0.26$	$5.02^{cm} \pm 0.12$	$4.08^{am} \pm 0.19$	$4.51^{bm} \pm 0.15$	$5.50^{dm} \pm 0.24$	$5.22^{cdm} \pm 0.17$
	M	$5.26^{bcm} \pm 0.09$	$5.08^{bm} \pm 0.10$	$4.42^{am} \pm 0.20$	$5.13^{bo} \pm 0.07$	$5.50^{cm} \pm 0.18$	$5.40^{cm} \pm 0.20$
	PM	$5.90^{bn} \pm 0.22$	$6.60^{cn} \pm 0.37$	$4.61^{am} \pm 0.55$	$4.83^{an} \pm 0.13$	$6.04^{bn} \pm 0.11$	$6.02^{bn} \pm 0.15$
Alkalinity (mg/l)	P	$175^{bn} \pm 4.94$	$195^{cm} \pm 10.16$	$228^{dn} \pm 12.95$	$212^{dn} \pm 14.80$	$175^{bn} \pm 6.81$	$155^{am} \pm 11.28$
	M	$145^{am} \pm 5.62$	$176^{cm} \pm 4.10$	$210^{dm} \pm 5.59$	$183^{cm} \pm 3.22$	$154^{bm} \pm 5.33$	$152^{abm} \pm 6.96$
	PM	$180^{bcn} \pm 9.25$	$190^{bcm} \pm 24.29$	$225^{dmn} \pm 13.24$	$195^{cmn} \pm 12.93$	$170^{bn} \pm 6.36$	$150^{am} \pm 7.72$
Hardness (mg/l)	P	$130^{abm} \pm 16.71$	$132^{abm} \pm 17.61$	$152^{cmn} \pm 6.29$	$140^{bcm} \pm 8.20$	$118^{am} \pm 11.44$	$115^{am} \pm 7.85$
	M	$116^{am} \pm 13.04$	$120^{am} \pm 23.39$	$130^{am} \pm 25.09$	$126^{am} \pm 17.75$	$112^{am} \pm 6.54$	$112^{am} \pm 4.94$
	PM	$125^{abm} \pm 13.39$	$135^{bcm} \pm 5.14$	$155^{dn} \pm 5.22$	$142^{cdm} \pm 10.84$	$118^{am} \pm 7.07$	$120^{am} \pm 2.53$

In the present study, water temperature varied from 30.6-32.4˚C, 29.5-29.8˚C and 26.6-28.4˚C during the pre monsoon, monsoon and post monsoon periods respectively (Table 2). The seasonal fluctuation portrayed higher values of water temperature for all the stations during the pre monsoon period only. A significantly higher ($p<0.05$) water temperature was observed in stations 3 and 4 compared to other stations for the post monsoon period only. Highest temperature was recorded at Station 3 (32.4°C) due to direct mixing of partially treated effluents from the outfall of the mill. Moderately higher water temperature was recorded at Stations 2 and 4 due to dilution of released effluents during high tide and low tide respectively.

The pH values ranged from 7.7-8.4, 7.5-8.1 and 7.8-8.3 during pre monsoon, monsoon and post monsoon periods respectively (Table 2). The pH values were slightly alkaline in nature. Higher pH values were observed in station 3 (8.1-8.4) irrespective of seasons. This is possibly due to impact of the effluents discharged into the river at that point while the similarity in the pH values at upstream (station 1 and 2) and downstream (station 4, 5 and 6) might be due to possible recovery of the river stretch from the impact of the effluents. This corroborates the study of Odoemelam (1999). The reduction in photosynthetic activity, carbon dioxide and bicarbonate assimilation are responsible for the rise in pH (Karanth, 1987).

The free carbon dioxide values varied from 0.0-28.0 mg/l, 6.0-28.0 mg/l and 0.0-26.0 mg/l during pre monsoon, monsoon and post monsoon periods respectively (Table 2). The free carbon dioxide value at the outfall (station 3) was markedly reduced compared to other stations. During pre monsoon and post monsoon period, free carbon dioxide was completely absent at station 3. There was a significant variation ($p<0.05$) in free carbon dioxide values of station 3 compared to both upstream (stations 1 and 2) and downstream stations (stations 4, 5 and 6). The higher free carbon dioxide concentration at station 1, 2, 4, 5 and 6 was probably due to increase in the decomposition of organic matter and low photosynthetic activities of phytoplankton (Manjare et al., 2010).

DO ranged between 4.08-5.50 mg/l, 4.42-5.50 mg/l, 4.61-6.60 mg/l during pre monsoon, monsoon and post monsoon periods respectively among the studied stations (Table 2). A significantly lower ($p<0.05$) DO value was observed at station 3 when compared to other stations (station 1, 2, 4, 5 and 6). The depleted

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dissolved oxygen level at Station 3 may be due to pollution load and increased microbial activity which have consumed all the oxygen present in the water. Similar trend in dissolved oxygen was observed by earlier workers (Singh & Rai, 1999; Hiware & Jadhav, 2001; Rafeeq & Khan, 2002).

Total alkalinity ranged from 155-228 mg/l, 145-210 mg/l and 150-225 mg/l during the pre monsoon, monsoon and post monsoon periods respectively (Table 2). A significantly higher ($p<0.05$) alkalinity value was evident at station 3 (210-228 mg/l) compared to both upstream (stations 1, 2) and downstream stations (stations 4, 5 and 6). The higher alkalinity was due to the increased organic decomposition thereby liberating carbon dioxide which reacts with water to form bicarbonate and thus increases the total alkalinity. Similar seasonal variations have been recorded by Singh & Rai (1999) in river Ganga at Varanasi.

The hardness of the different stations varied from 115-152 mg/l, 112-130 mg/l and 118-155 mg/l during pre monsoon, monsoon and post monsoon period respectively (Table 2). The maximum values were observed at station 3 for all the seasons. A significant variation ($p<0.05$) in hardness was observed at station 3 compared to other stations during the pre monsoon and post monsoon period. This was probably due to the admixture of different chemicals along with calcium and magnesium salts coming out from the paper and pulp industry.

Various species of fishes were recorded at the different stations located both upstream and downstream to the outfall. Thirty six species of fishes comprising of twenty five genera, fifteen families and eight orders have been observed at the different stations during the study period 2011-12 (Table 3). The highest number of species was recorded in Order Cypriniformes and Order Siluriformes (eleven species each) and the lowest number of species was recorded in Order Beloniformes and Order Mugiliformes (one species each). However, total number of individuals was highest in Cypriniformes and lowest in Mugiliformes.

Table 3: Different fish species observed at the different stations along with their local name, common name and conservation status as per IUCN 2011

Phylum: Vertebrata

Class: Osteichthyes

Systematic position		Scientific name	Common name (English)	Local name (Bengali)	IUCN status
Order	**Family**				
Clupeiformes	Clupeidae	*Gudusia chapra* (Hamilton, 1822)	Indian river shad	Khoira	Lower risk least concern
		Tenualosa ilisha (Hamilton, 1822)	Hilsa shad	Hilsa/ Ilish	Lower risk least concern
	Engraulidae	*Setipinna phasa* (Hamilton, 1822)	Gangetic hairfin anchovy	Phasa	Lower risk least concern
Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	Bronze featherback	Pholui	Lower risk near threatened
		N. chitala (Hamilton, 1822)	Clown knifefish	Chital	Near threatened
Cypriniformes	Cyprinidae	*Salmostoma bacaila* (Hamilton, 1822)	Large razorbelly minnow	Beki chela	Lower risk least concern
		Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	Mourola	Lower risk least concern
		Puntius chola (Hamilton, 1822)	Swamp barb	Punti	Lower risk least concern
		P. sophore (Hamilton, 1822)	Pool barb	Punti	Lower risk near threatened
		P. sarana (Hamilton, 1822)	Olive barb	Saral punti	Vulnerable
		Catla catla (Hamilton, 1822)	Catla	Katla	Vulnerable
		Labeo rohita (Hamilton, 1822)	Rohu	Rui	Lower risk near threatened
		L. bata (Hamilton, 1822)	Bata labeo	Bata	Lower risk near threatened
		L. calbasu (Hamilton, 1822)	Black rohu	Kalbaus	Lower risk near threatened
		Cirrhinus mrigala (Hamilton, 1822)	White carp	Mrigal	Lower risk near threatened
		C. reba (Hamilton, 1822)	Reba carp	Raikhar bata	Vulnerable

Siluriformes	Bagridae	*Mystus vittatus* (Bloch, 1794)	Striped dwarf catfish	Tengra	Lower risk least concern
		M. cavasius (Hamilton, 1822)	Gangetic mystus	Kabashi-tengra	Lower risk near threatened
		M. gulio (Hamilton, 1822)	Long whiskered catfish	Nuna-tengra	Lower risk least concern
		Aorichthys aor (Sykes, 1839)	Long whiskered catfish	Aar tengra	Lower risk least concern
		Rita rita (Hamilton, 1822)	Rita	Ritha	Lower risk least concern
	Siluridae	*Ompok bimaculatus* (Bloch, 1794)	Butter catfish	Pabda	Endangered
		Ompok pabda (Hamilton, 1822)	Butter catfish	Pabda	Near Threatened
		Wallago attu (Bloch & Schneider, 1801)	Giant sheatfish	Boal	Lower risk near threatened
	Schilbeidae	*Eutropiichthys vacha* (Hamilton, 1822)	Batchwa vacha	Vacha	Endangered
	Clariidae	*Clarias batrachus* (Linnaeus, 1758)	Walking catfish	Magur	Vulnerable
	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	Stinging catfish	Singhi	Vulnerable
Beloniformes	Belonidae	*Xenentodon cancila* (Hamilton, 1822)	Freshwater garfish	Kankle	Lower risk near threatened
Perciformes	Channidae	*Channa marulius* (Hamilton, 1822)	Great snakehead	Shal/ Gajal	Lower risk near threatened
		Channa striatus (Bloch, 1793)	Striped snakehead	Shol	Lower risk least concern
		Channa orientalis (Bloch & Schneider, 1801)	Dwarf snakehead	Cheng	Not assessed
	Gobiidae	*Glossogobius giuris* (Hamilton, 1822)	Tank goby	Bele	Lower risk least concern
		Pseudapocryptes lanceolatus (Bloch & Schneider, 1801)	Pointed tailed goby	Gule	Lower risk least concern
	Anabantidae	*Anabas testudineus* (Bloch, 1792)	Climbing perch	Koi	Data deficient
Mugiliformes	Mugilidae	*Rhinomugil corsula* (Hamilton, 1822)	Corsula mullet	Khorsula	Lower risk least concern
Mastacembeliformes	Mastacembel-idae	*Mastacembelus pancalus* (Hamilton, 1822)	Striped spiny eel	Pankal	Not evaluated
		Mastacembelus armatus (Lacepède, 1800)	Tire track eel	Bami	Not evaluated

But tank goby, *Glossogobius giuris* was omnipresent and showed dominance at station 3 (main outfall). The clown knife-fish, *Notopterus chitala* was present in station 1 only (Table 4).

Table 4: Variation of different fish orders in respect of their availability among the six stations (-: Absent; +: Rarely found; ++: Moderately found; +++: Frequently found)

Order	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Clupeiformes	+	+	-	-	+	+
Osteoglossiformes	+	+	+	+	+	+
Cypriniformes	+++	++	+	+	++	+++
Siluriformes	+++	+	+	+	+	+++
Beloniformes	+	+	-	+	+	+
Perciformes	++	+	++	++	++	++
Mugiliformes	+	-	-	-	+	+
Mastacembeliformes	+	+	-	+	+	+

Significantly lower ($p<0.05$) species diversity was recorded in station 3 compared to other stations irrespective of all seasons. Lowest species diversity was recorded during premonsoon in station 3 and highest species diversity was recorded in station 1 during premonsoon and monsoon. Among Clupeiformes, *Gudusia chapra*, *Tenualosa ilisha* and *Setipinna phasa* were observed in all the stations except station 3 and 4 (Table 3 & 4). They were observed in maximum number during the monsoon period and minimum in postmonsoon period. Among Osteoglossiformes, *Notopterus notopterus* and *N. chitala* were observed (Table 3). *N. notopterus* was dominant among them. Among Cypriniformes, *Labeo rohita* was the most dominant group found in all the stations. *Cirrhinus reba* was absent from station 3. Members of Cypriniformes were dominant either during premonsoon and monsoon and were minimum in the postmonsoon period. Among Siluriformes, *Mystus vittatus* was dominant and recorded from all the stations studied. *Rita rita* was absent from station 3. Members of Siluriformes were dominant during premonsoon and monsoon and were minimum in the postmonsoon period except that of *Aorichthyes aor*. Among Perciformes, *Glossogobius giuris* was the most dominant group in all the stations at premonsoon and monsoon. *Anabas testudineus* was absent from station 3. Among Mastacembeliformes, *Mastacembelus armatus* was the dominant group.

The overall diversity of the fishes was highest in station-1 and 5. This was because of lower intensity of organic pollution, suitable water quality parameters and water depth. The lowest diversity of fish was observed in station-3 due to the heavy load of pollution coming from the pulp and paper mill effluents. Significantly lower ($p<0.05$) dissolved oxygen level of station-3 resulted in lower biodiversity of fish. *G. giuris* was dominant at station 3 and this reflects the pollution resistant nature of the species. Similar results were obtained by Das & Bordoloi (2013) while studying the effects of Nagaon paper mill effluents on fish fauna. The Shannon-Weaver species diversity index (H') was signifi-

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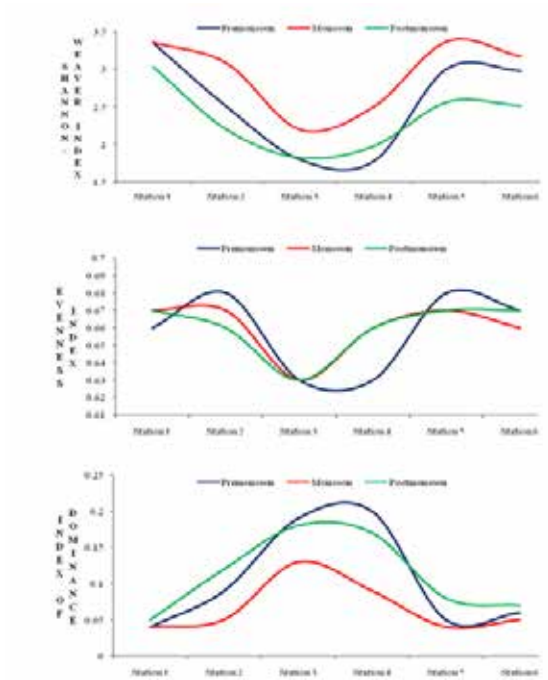
cantly lower at stations 3 and 4 irrespective of seasons (1.77-2.5) which indicates moderate level of pollution (Figure 2). Evenness Index and Index of Dominance of fish ranged between 0.63-0.66 and 0.09-0.20 respectively at station 3 and 4 also lend support for higher to moderate level of pollution. This was because of absence of interspecific competition from the other groups of fishes due to the increased pollutant load at station 3.

Figure 2: Different diversity indices (Shannon-Weaver species diversity index, Evenness Index and Index of Dominance) of fish at the six stations in premonsoon, monsoon and postmonsoon during the period from August 2011 to October 2013 adjacent to Supreme paper mill (all values are the mean of six observations).



The results of the present investigation in water quality and fish diversity can be used as an effective indicator of pollution of the river by pulp and paper mill effluents. Fluctuation of various diversity indices should be taken into account while forecasting diversity and planning for policies necessary to maintain long term sustainability of the water body (Mondal et al., 2010). The present findings also suggest that special care should be taken in the treatment of pulp and paper mill effluents before their final discharge to the riverine ecosystem especially during hot summer.

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