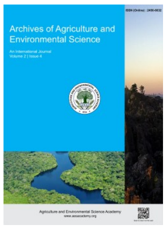
Archives of Agriculture and Environmental Science 3(1): 36-44 (2018)
https://doi.org/10.26832/24566632.2018.030104

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: www.aesacademy.org



ORIGINAL RESEARCH ARTICLE

CrossMark

Impact of jute retting on physicochemical profile of Chhariganga oxbow lake in Nadia district, West Bengal, India

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ARTICLE HISTORY

Received: 16 January 2018
Revised received: 31 January 2018
Accepted: 19 February 2018

Keywords

Gross primary productivity (GPP)
Jute retting
Net primary productivity (NPP)
Oxbow lake
Physico-chemical properties
Water quality

ABSTRACT

The present study was carried out to assess the ecosystem of the Chhariganga, an oxbow lake in eastern India to assess the pollution due to jute retting and trophic status on broader aspects for its sustainable management. The physicochemical analyses of the studied oxbow lake showed the range with annual mean values of surface water temperature in °C (11-37, 27.64±6.56), water transparency in cm (16-106, 45.82±23.39), water pH (7.4-8.8, 8.17±0.34), DO (2.60-7.85, 4.65±1.52 ppm), BOD (1.10-6.40, 2.98±1.59ppm), COD (70-90, 79±7.38ppm), NH_4-N (0.026-0.093, 0.05±0.02ppm), NO_2-N (0.008-0.08, 0.03±0.02ppm), NO_3-N (0-2.459, 0.81±0.69ppm), OP (0.067-0.62, 0.26±0.18ppm), total alkalinity (82-165, 120±24.03ppm), total hardness (70-138, 102.62±19.60ppm), GPP (0.30-1.80, 1.25± 0.47mgC/l/day), NPP (0.15-1.38, 0.95± 0.40mgC/l/day); sediment pH (6.8-7.9, 7.53±0.34) and sediment organic carbon in % (1.87-2.89, 2.17±0.28). The highest mean values of BOD (4.59ppm), COD (86.67ppm), OP (0.50ppm), sediment organic carbon (2.29%) were observed during monsoon whereas the lowest values of oxbow lake water's transparency (27.00cm), pH (7.84), DO (3.63ppm) and NO_2–N(0.01 ppm) contents were found during monsoon when jute retting process intensified in the oxbow lake. Compared to their values in pre-monsoon, mean values in monsoon showed an increase in BOD (182.57%) and OP content (167.64%) unlike reduction in water transparency (62.54%), GPP and NPP (both reduced by about 50%); The highest concentration of NH_4-N and NO_3-N were noticed during post-monsoon and OP during monsoon. The water transparency mean values showed sharp fall during monsoon from pre-monsoon. Physico-chemical analyses revealed that almost all parameters in oxbow lake did not show significant changes throughout the year unlike water transparency, BOD, NO_2 and especially OP content of water which otherwise showed significant changes throughout the year. The present semi-closed oxbow lake water was of poor to moderate quality and it was classified as oligo-mesotrophic in nutrient status with high to moderate organic pollution due to jute retting process which needs to be controlled and regulated for sustainable aquaculture in oxbow lake ecosystem.

Citation of this article: Ghosh, D. and Biswas, J.K. (2018). Impact of jute retting on physicochemical profile of Chhariganga oxbow lake in Nadia district, West Bengal, India. *Archives of Agriculture and Environmental Science*, 3(1): 36-44 DOI: 10.26832/24566632.2018.030104

INTRODUCTION

Oxbow lakes being natural depressions and kidneys of the land-scape have great ecological and socio-economical importance (Ghosh and Biswas, 2015a, d). They are subject to various human activities, pollution, eutrophication, use of agricultural pesticides in catchment areas, jute retting. Excavation and large scale pit extraction disfigure oxbow lakes landscapes and limits their values for other (Ghosh and Biswas, 2015d). The effects of siltation, habitat destruction, and macrophyte infestation, isolation from river flow, flood water, inadequate rainfall and nutrient influx in changed climate have degraded oxbow lake environments as a whole. Habitat loss or modification is often associated with habitat fragmentation. Jute retting during monsoon is a common anthropological activity in the rural Bengal (Ghosh and Biswas, 2015e). Population pressure, urbanization, industrialization and increased agricultural activity including jute retting have significantly contributed to the pollution and toxicity of aquatic ecosystems including oxbow lakes. Pollutants bring about a change not only in the physical and chemical quality of water but also modify the biotic components, resulting in the elimination of some potentially valuable species. The impact of urbanization the urbanization of surrounding areas leads to the discharge of domestic sewage and industrial effluents into lake (Chandrasekhar *et al*., 2003). Varied studies have been conducted on oxbow lake ecosystems across the world in general (Banerjea, 1967; Zutshi *et al*., 1972, 1980; Vass and Zutshi, 1979; Trisal, 1985; Patil and Panda, 1986; Joo and David, 1995; Nandan, 1997; Sugunan *et al*., 2000; Obire *et al*., 2003; Aswathi and Tiwari, 2004; Chindah *et al.* 2005; Hart and Zabbey, 2005; Sikoki and Zabbey, 2006; Koliyar and Rokhare, 2008; Joadder, 2009; Feresin *et al*., 2010; Das *et al*., 2009, 2011, 2011a) and in Nadia district in particular (Dasgupta *et al*., 2006; Biswasroy *et al*., 2011; Bala and Mukherjee, 2011; Ziauddin *et al*., 2013). Despite studied effect of jute retting on the water of an oxbow lake (Dasgupta *et al*., 2006) and assessed impact of jute retting on native fish diversity and aquatic health of roadside transitory water bodies (Ghosh and Biswas, 2015c) considering limited parameters, the present study was specifically conducted to revisit the impact of jute retting on physico-chemical condition of a randomly chosen semi-closed oxbow lake ecosystem (Ghosh and Biswas, 2017b; 2017d) in the northern side of the Nadia district, West Bengal through the analyses of as much as 16 physico-chemical parameters during April 2013-March, 2014 to assess the pollution due to jute retting and trophic status on broader aspects for its sustainable management.

MATERIALS AND METHODS

Study area

The Chhariganga oxbow lake is located in Nakashipara development block of Nadia district, West Bengal, India (23.5779214^{0}N, 88.3471226^{0}E). This lake is situated at about 90 Km away from Kalyani university campus, Nadia and nearly 40 km north of the tropic of cancer line. The Chhariganga oxbow lake was formed as an abandoned meander of the river Ganga and is freshwater, semi-closed oxbow lake that receives water from the Ganga River, during monsoon, through a narrow channel at the north-east corner of a loop of the river. The Chhariganga oxbow lake also stores rain water. This oxbow lake is spread over an area of 58.28 ha with an annual average depth of 2.6 m. The catchment area of the oxbow lake is nearly 600 ha. The oxbow lake was selected at random among a total of 122 similar oxbow lakes in Nadia District, West Bengal (Ghosh and Biswas, 2017b; 2017d). There are three distinct annual seasons in this region: pre-monsoon or dry season, from March to June; monsoon, or rainy season, from July to October (within this period jute retting takes place, generally from August to September); and post-monsoon or winter season, from November to February. There have been occasional inundations of the surrounding banks during monsoon. The Chhariganga Lake is subjected to all forms of human activities including jute retting during monsoon, agriculture and fishing. It is the only source of irrigation water to the immediate agriculture communities. The Chhariganga oxbow lake has taken different names in four different development block locations like "Errerdanga Chhariganga", "New Chhariganga" along its largest (about 88.63 ha) segment in Kaliganj,"Bhagirathi Chhariganga" in Nabadwip, "Chhariganga" in Nakashipara and "Chhariganga Oxbow lake" in Santipur covering a total recorded area of 207.20 ha. This lake is important because it accounts for around 8.69% of the total oxbow lake Government area of water bodies and is probably the sole example of a semi-closed type oxbow lake in the district. This oxbow lake has an estimated average effective water spread area (EWSA) of 33.33 ha, that accounts for about 57% of a recorded water body area (RAW) of 58.28 ha, as registered by the land and land revenue department of West Bengal from April 2013 to March 2014. In this 12-month period, flood water entered the lake enhancing its EWSA and its annual average water depth of 2.55 m. Thus, the volume of the EWSA (in millions of tons) was estimated to be 0.42, 1.50, 0.77, 0.85, and 0.90 for pre-monsoon, monsoon, post-monsoon, annual average, and annual total, respectively. The Chhariganga oxbow lake has on average 600 jute retting units of mean size 30 m2, with each unit covering about 3.6% of the EWSA (3.09% of RAW) and consuming a water volume of more than 5% of the total EWSA annual average during monsoon (Table 1). Ultimately, the present study focused on 28.13% of the whole Chhariganga's recorded area (2.44% and 11th largest of the total oxbow lakes as public water bodies in the district) which is in Nakashipara Block.

Collection of water and sediment samples

For well mixed waters (i.e. water free from any aquatic weed and not isolated by any fishing enclosure), a sample was taken within 1 m below the surface and away from the edge. To collect a sample of the surface layer, a 500 ml polypropylene bottle was held horizontally and half submerged. All samples for chemical analysis were taken between 8 and 9 am of the sampling day. Sediment was collected from different locations and depths of the Chhariganga oxbow lake ecosystem and mixed thoroughly. All collected samples were pooled into one to make a composite sample for chemical analyses (Ghosh and Biswas, 2017d).

Analyses of physico-chemical parameters

Water physicochemical parameter analyses were carried out during the pre-monsoon, monsoon and post-monsoon seasons (from April 2013 to March 2014). Analyzed parameters for all water samples included (Ghosh and Biswas, 2017d): (i) temperature, recorded on the spot with a WTW Multi-parameter portable meter MultiLine"R (F/SET-3, Weilheim, Germany); (ii) transparency, assessed with a metallic Secchi disc of 20 cm in diameter with four quadrants of alternate black and white colours on the upper surface. The disc was ballasted on the ower surface and suspended with a graduated cord at its center. (iii) Water pH, measured using a WTW Multi-parameter portable meter MultiLine"R (F/SET-3, Weilheim, Germany). For pH, the averaging across samples procedure described by Boyd (1992) was used, pH readings were converted to hydrogen ion concentrations and these were then averaged. (iv) Dissolved oxygen in the lake water was measured with a specific probe of a WTW Multi-parameter portable meter MultiLine"R (F/SET-3, Weilheim, Germany). (v) Biochemical oxygen demand (BOD) was obtained following Selvaraj (2005) and Ghosh & Biswas (2015c). This is an in situ method that consisted of filling an 250 ml, airtight bottle and incubating it at in situ temperature for 1 day. Dissolved oxygen (DO) was measured, by the Winkler method, before and after incubation, and the BOD was computed from the difference between initial and final DO. (vi) Chemical oxygen demand (COD) was determined using a digestion mixture of 0.25 N potassium dichromate and concentrated H_2SO_4 (5:1) with 1 g of AgSO4 and titrating against ferrous ammonium sulphate taking phenanthroline as indicator (Golterman and Ohnstad, 1978). (vii) Ammonium nitrogen (NH4 –N) was measured at 654 nm, following the modified phenate method (Wetzel & Likens, 1991) with a Shimadzu UV-visible spectrophotometer Model UV-1601 (Kyoto, Japan). (viii) The concentration of nitrite nitrogen (NO2–N) was measured at 543nm in a spectrophotometer (Shimadzu, Model UV-1601, Kyoto, Japan) using α-naphthylamine and sulphanilic acid (Wetzel & Likens, 1991). (ix) The concentration of nitrate nitrogen (NO3–N) was determined by UV-spectrophotometric method (APHA, 1998) using aluminum hydroxide suspension and 1 N HCL at 220 nm and 275 nm in a spectrophotometer (Shimadzu, Model UV-1601, Kyoto, Japan). The measurement of the ultraviolet absorption at 220 nm enabled rapid determination of nitrate nitrogen, and because dissolved organic matter may also absorb at 220 nm, a second measurement was made at 275 nm to correct the nitrate nitrogen value. (x) Orthophosphate (OP) content of the lake water was determined calorimetrically at 690 nm in a spectrophotometer (Shimadzu, ModelUV-1601, Kyoto, Japan) following the stannous chloride method (APHA, 1998). (xi) Total alkalinity was determined by titration of a lake water sample with sulphuric acid (0.02 N). Alkalinity due to hydroxide and carbonate was determined to the first end point (pH 8.3) using phenolphthalein as indicator, and bicarbonate alkalinity was determined to the second end point (pH 4.5) using methyl orange (APHA, 1998). Finally, (xii) water total hardness was determined in alkaline medium with 2-3 drops of eriochrome black-T indicator, by titration against standard 0.01 Methylene diamine tetra acetic acid (EDTA) until the red wine colour of the solution turns pale blue at the end point (APHA,1998).

Analysis of physic-chemical parameters of sediment

Sediment pH of the Chhariganga oxbow lake was measured with a potentiometer upon direct reading using a glass electrode with a saturated KCl-calomel reference electrode (Water Resources Department, 2009). For estimation of sediment organic carbon, a 500-mg, dried, and powdered sediment sample was taken and digested with 20 ml (1 N) $K_2Cr_2O_7$ and 20 ml H_2SO_4 (concentrated) then kept for 30 minutes in a dark place. The sample was then diluted with 150 ml distilled water and 10 ml phosphoric acid, and 1 ml diphenylamine indicator was added to it. The sample was then titrated against 0.5 N ferrous ammonium sulphate (Mohr's salt) until a brilliant green colour appeared (Ghosh and Biswas, 2017d).

Statistical analyses of data

Mean, standard deviation and the degree of relationships among different physicochemical factors of water and sediment were determined using linear regression with the help of MS-Excel. The level of statistical significance was accepted at $P<0.05$.

RESULTS AND DISCUSSION

The physicochemical analyses of the studied oxbow lake showed the following range with annual mean values for the selected parameters: surface water temperature in °C (11-37, 27.64±6.56), water transparency in cm (16-106, 45.82±23.39), water pH (7.4-8.8, 8.17±0.34), dissolved oxygen content (DO) in ppm (2.60-7.85, 4.65±1.52), biochemical oxygen demand (BOD) in ppm (1.10-6.40, 2.98±1.59), chemical oxygen demand (COD) in ppm (70-90, 79±7.38), ammonium nitrogen content (NH_4-N) in ppm (0.026-0.093, 0.05±0.02), nitrite nitrogen content (NO_2-N)in ppm (0.008-0.08, 0.03±0.02), nitrate nitrogen concentration (NO_3-N) in ppm (0-2.459, 0.81±0.69), orthophosphate concentration (OP) in ppm (0.067-0.62, 0.26±0.18), total alkalinity in ppm (82-165, 120±24.03), total hardness in ppm (70-138, 102.62±19.60), gross primary productivity (GPP) in mgC/l/day (0.30-1.80, 1.25± 0.47), net primary productivity (NPP) in mgC/l/day (0.15-1.38, 0.95± 0.40); sediment pH (6.8-7.9, 7.53±0.34) and sediment organic carbon in % (1.87-2.89, 2.17±0.28).

The highest mean values of BOD (4.59ppm), COD (86.67ppm), OP (0.50ppm), sediment organic carbon (2.29%) were observed during monsoon whereas the lowest values of oxbow lake water's transparency (27.00cm), pH (7.84), DO (3.63ppm) and NO_2–N (0.01ppm) contents were found during monsoon when jute retting process gets intensified in the oxbow lake (Tables 2 and 3). Compared to their values in pre-monsoon, mean values in monsoon showed an increase in BOD (182.57%), COD (18.18%), NH_4-N (7.87%), NO_3-N (17.73%) and OP content (167.64%) while reduction in water transparency (62.54%), pH (5.74%), DO (22.16%), NO_2-N (65.68%), total hardness (21.63%), total alkalinity (24.27%), GPP and NPP (both reduced by about 50%); sediment organic carbon content (10.11%) and pH values (7.36%). The highest mean values of water pH (8.42, increased by 7.30%), DO (5.96 ppm, increased by 64.52%), NH_4-N (0.07 ppm, increased by 88.21%), NO_3-N (1.15 ppm, increased by 83.12%) and sediment pH (7.80) were observed with the lowest mean values of oxbow lake water's temperature (19.56°C), OP (0.13 ppm, decreased by 73.53%), total hardness (85.25 ppm, decreased by 12.17%) and total alkalinity (98.67 ppm, decreased by 11.76%) whereas changes also observed in NO_2-N content (115.34% increase), COD (10.58% decrease), BOD_1 (47.70% decrease), transparency (increased by 49.23%) and sediment's organic carbon content (5.54% decrease) during post -monsoon compared to previous season. During pre-monsoon highest mean values were observed for water transparency (72.07cm, further increased by 78.87%), water temperature (31.5°C, about 61% increase), total hardness (123.86 ppm, 45.29% increase) and total alkalinity (147.64 ppm, 49.64% up) and lowest values observed for sediment pH (7.14, decreased by 8.42%), sediment organic carbon (2.08%, decreased by 3.86%), BOD_1 (1.63 ppm, 32.33% fall), COD (73.33 ppm, 5.38% decrease), NO_3-N (0.53 ppm, 53.62% decrease) with changes in DO (21.91% fall), NH_4-N (50.75% fall) and NO_2-N (35.31% up), OP (41.17% up) if compared to post-monsoon of the study period. The highest concentration of NH_4-N and NO_3-N were noticed during post-monsoon and OP during monsoon. The water transparency mean values showed sharp fall during monsoon from pre-monsoon. Physico-chemical analyses revealed that almost all parameters in oxbow lake did not show significant changes throughout the year unlike water transparency, $BOD_{1,}$ NO_2 and especially OP content of water which have otherwise shown significant changes throughout the year (Figure 1).

Present observed temperature data are concurrent with the several other studies which have demonstrated narrow amplitude of variation showing the characteristic of tropical environment (Obire *et al*., 2003; Chindah *et al.* 2005; Hart and Zabbey, 2005; Sikoki and Zabbey, 2006). Present results are also in full or partial agreement with others studies (Joadder, 2009; Joo and David, 1995, Das *et al*., 2011a; Ziauddin *et al*., 2013; Feresin *et al*., 2010; Biswasroy *et al*., 2011; Das *et al*., 2009). However, the annual average range of water temperature of the studied oxbow lake indicates its suitability for fish habitat and breeding.

The mean values of water transparency showed sharp fall during monsoon compared to pre-monsoon indicating high total solid concentrations due to loading of heavy organic matter restricting light penetration into oxbow lake water. This resulted in decrease in oxygen production owing to reduced rate of photosynthesis. This is accentuated by huge jute retting processes in the lake during monsoon. Present results showed quite similarity with other studies (Joadder, 2009; Feresin *et al*., 2010; Das *et al*., 2011a). Just contrary to the study (Ziauddin *et al*., 2013) present findings on Secchi disc transparency showed peak in pre-monsoon and fall during monsoon. Jute retting and inflowing water during monsoon make all the differences in present case. The higher annual average range of water transparency rendered fish habitat and growth in the studied oxbow lake not conducive as the transparency of productive water bodies should be 40 cm or less to be considered as suitable for aquatic life when the maximum values of the Secchi depth are usually associated with the lowest mean hydrometric levels (Banerjea, 1967).

The pH of the present lake varied (7.4 to 8.8) a great deal during the year, though always falling on the alkaline side. The seasonal variation is attributed to photosynthetic activity as was seen larger during post-monsoon and pre-monsoon resulting in a better utility of carbon sources and an associated decrease in hydrogen-ion concentration (Zutshi *et al*., 1972). Present results showed similarity with other studies (Zutshi *et al*., 1980; Trisal, 1985; Joo and David, 1995; Joadder, 2009; Das *et al*., 2009; Feresin *et al*., 2010; Biswasroy *et al*., 2011; Das *et al*., 2011a; Ziauddin *et al*., 2013). We observed highest water pH during jute retting season on monsoon in contrast to the study (Das *et al*., 2011). The pH range of the present oxbow lake throughout the year may attribute low to medium trophic status of the studied water body that supported moderate number of species.

One of the most important abiotic factors influencing life in aquatic ecosystem is the dissolved oxygen. Its depletion perhaps is the most critical manifestation of pollution. The overall variation in dissolved oxygen (2.6-7.85) in present study indicate very low levels of dissolved oxygen during extreme monsoon but DO value increased in subsequent period to attain satisfactory saturation in post-monsoon. The observed dissolved oxygen values were somewhat below the range of the other studies (Patil and Panda, 1986; Koliyar and Rokhare, 2008). But like present findings higher DO concentrations in post-monsoon were also observed (McNeely *et al*., 1979, Joo and David, 1995; Joadder, 2009; Das *et al*., 2009, 2011a; Ziauddin *et al*., 2013). Quite similar DO range like present findings was also in an oxbow lake in Nadia district (Biswasroy *et al*., 2011). The annual average DO value indicates unproductiveness and poor ecosystem heath of the studied oxbow lake and was always slightly on lower side throughout the year. This indicates immediate threat of pollution especially due to jute retting during monsoon when compared to the rest of the year.

The values of the biochemical oxygen demand (BOD) in the present study ranged from 1.10 to 6.40 ppm with the annual mean of 2.98±1.59 ppm. Like present findings BOD values were observed quite similar (Das *et al.* 2009; Srinivasan, 1967; Biswasroy *et al*., 2011) and BOD was seen increased during jute retting during monsoon (Dasgupta *et al*., 2006; Ghosh and Biswas, 2015c). High BOD values are generally associated with anoxic conditions and low community diversity of fish and shell fish in coconut husk retting zones (Nandan, 1997). By contrast, it was also reported (Dasgupta *et al*., 2006) that jute retting has dual effects also as it creates anaerobic condition for fish mortality for a short period and releases nutrients with the passage of time to help the growth of the aquatic life. But jute retting impacted significantly on native fish diversity and aquatic health parameter including BOD_1 and transparency (Ghosh and Biswas, 2015c) like the present study. However, higher BOD values in the present study indicate moderate pollution especially during monsoon compared to other seasons. The significantly higher increase in BOD values during monsoon is attributed to organic loading from jute retting and surface run off from neighbouring agricultural areas. The COD concentra-

Table 1. Data synopsis of the Chhariganga oxbow lake ecosystem.

Oxbow lake's Attributes	PRM	MON	POM	YR Average	YR Total
RAW (ha)	58.28	58.28	58.28	58.28	58.28
RAW (sqm)	582800	582800	582800	582800	582800
Average Length (m)	2500	2500	2500	2500	2500
Average Width (m)	80	200	120	133	133
EWSA (sqm)	200000	500000	300000	333333	333333
EWSA (ha)	20	50	30	33.33	33.33
Average Depth (ft)	7	10	8.5	8.50	8.50
Average Depth (m)	2.1	3.0	2.55	2.55	2.55
Volume of EWSA (m^3)	420000	1500000	765000	850000	895000
Volume of RAW (m^3)	1223880	1748400	1486140	1486140	1486140
Volume of EWSA (million ton)	0.42	1.50	0.77	0.85	0.90
Jute retting units	-	600	-	600	600
Jute retting area per unit (sqm)	-	30	-	30	30
Jute retting Total area (sqm)	-	18000	-	18000	18000
Jute retting area (ha)	-	1.80	-	1.80	1.80
Jute retting area % EWSA	-	3.60	-	5.40	5.40
Jute retting area % RAW	-	3.09	-	3.09	3.09
volume of water for jute retting (m^3)	-	54000	-	45900	45900
Water required (%) of EWSA for jute retting	-	3.60	-	5.40	5.13
Water required (%) of RAW for jute retting	-	3.09	-	3.09	3.09

EWSA=Effective water spread area, RAW=Recorded area of water body, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-) = No jute retting seen.

Table 2. Seasonal variations in water parameters and changes compared to previous season.

Season	PRM		MON		POM		Year		PRM	MON	POM		Year	
Parameter	M	SD	M	SD	M	SD	M	SD	% change				Min	Max
Temperature (T°C)	31.50	4.20	30.33	1.83	19.56	5.84	27.64	6.56	61.06	-3.73	-35.50	21.82	11	37
Transparency (cm)	72.07	21.03	27.00	7.53	40.29	3.77	45.82	23.39	78.87	-62.54	49.23	65.57	16	106
pH	8.32	0.18	7.84	0.27	8.42	0.20	8.17	0.34	-1.13	-5.74	7.30	0.43	7.4	8.8
DO (ppm)	4.67	0.34	3.63	1.19	5.98	1.77	4.65	1.52	-21.91	-22.16	64.52	20.45	2.6	7.85
BOD_1 (ppm)	1.63	0.37	4.59	1.34	2.40	0.53	2.98	1.59	-32.33	182.57	-47.70	102.54	1.1	6.4
COD (ppm)	73.33	5.77	86.67	5.77	77.50	5.00	79.00	7.38	-5.38	18.18	-10.58	2.23	70	90
NH_4-N (ppm)	0.03	0.01	0.03	0.01	0.07	0.02	0.05	0.02	-50.75	7.87	88.21	45.34	0.026	0.093
NO_2-N (ppm)	0.04	0.01	0.01	0.01	0.03	0.03	0.03	0.02	35.31	-65.68	115.34	84.97	0.008	0.080
NO_3-N (ppm)	0.53	0.09	0.63	0.13	1.15	1.06	0.81	0.69	-53.62	17.73	83.12	47.24	0.000	2.459
OP (ppm)	0.19	0.05	0.50	0.11	0.13	0.06	0.26	0.18	41.17	167.64	-73.53	135.27	0.067	0.620
Total Alkalinity (ppm)	147.64	13.12	111.81	11.91	98.67	13.76	120.00	24.03	49.64	-24.27	-11.76	13.61	82	165
Total Hardness (ppm)	123.86	11.50	97.06	9.79	85.25	14.03	102.62	19.60	45.29	-21.63	-12.17	11.48	70	138
Gross Primary Productivity (GPP) (mgC/l/ day)	1.66	0.17	0.84	0.37	1.32	0.37	1.25	0.47	25.68	-49.70	58.18	34.16	0.30	1.80
Net Primary Productivity (NPP) (mgC/l/ day)	1.26	0.10	0.61	0.37	1.04	0.32	0.95	0.40	20.94	-51.35	69.96	39.55	0.15	1.38

M=Mean value, SD=Standard deviation, PRM=Pre-monsoon, MON=Monsoon, POM=Post-monsoon.

Table 3. Seasonal variations in Chhariganga oxbow lake sediment quality parameters and changes compared to previous season.

Season	PRM		MON		POM		Year		PRM	MON	POM		Year	
Parameter	M	SD	M	SD	M	SD	M	SD	% change				Min	Max
Sediment pH	7.14	0.26	7.67	0.18	7.80	0.09	7.53	0.34	-8.42	7.36	1.71	0.65	6.8	7.9
Sediment Org. C (%)	2.08	0.02	2.29	0.54	2.16	0.07	2.17	0.28	-3.86	10.11	-5.54	0.71	1.87	2.89

M=Mean value, SD=Standard deviation, PRM=Pre-monsoon, MON=Monsoon, POM=Post-monsoon.

Table 4. Correlation coefficients of Chhariganga oxbow lake water and sediment quality parameters.

Indicator	S pH	SOC	Tr	W pH	T°C	DO	BOD	COD	NH_4-N	NO_2-N	NO_3-N	OP	TH	TA	GPP
SOC	0.67														
Tr	-0.89	-0.94													
W pH	-0.18	-0.85	0.61												
T°C	-0.72	0.03	0.32	-0.56											
DO	0.25	-0.54	0.22	0.91	-0.86										
BOD	0.56	0.99	-0.88	-0.92	0.18	-0.66									
COD	0.60	1.00	-0.90	-0.89	0.12	-0.62	1.00								
NH_4-N	0.70	-0.05	-0.30	0.57	-1.00	0.86	-0.20	-0.14							
NO_2-N	-0.67	-1.00	0.94	0.85	-0.03	0.54	-0.99	-1.00	0.05						
NO_3-N	0.75	0.02	-0.37	0.51	-1.00	0.82	-0.12	-0.07	1.00	-0.02					
OP	0.19	0.86	-0.63	-1.00	0.54	-0.90	0.92	0.90	-0.56	-0.86	-0.50				
TH	-0.99	-0.59	0.83	0.06	0.79	-0.36	-0.46	-0.51	-0.78	0.59	-0.82	-0.08			
TA	-1.00	-0.62	0.85	0.11	0.77	-0.32	-0.49	-0.54	-0.75	0.62	-0.80	-0.12	1.00		
GPP	-0.69	-1.00	0.94	0.84	-0.01	0.53	-0.99	-0.99	0.03	1.00	-0.04	-0.85	0.60	0.63	
NPP	-0.62	-1.00	0.91	0.88	-0.10	0.60	-1.00	-1.00	0.12	1.00	0.04	-0.89	0.53	0.56	1.00

PRM=Pre-monsoon, MON=Monsoon, POM=Post-monsoon, SpH=Sediment pH, SOC=Sediment organic carbon (%), Tr=Transparency (cm), WpH=Water pH, TH=Total Hardness (ppm), TA=Total alkalinity (ppm), GPP/NPP=Gross/Net primary productivity (gC/m^3/d).

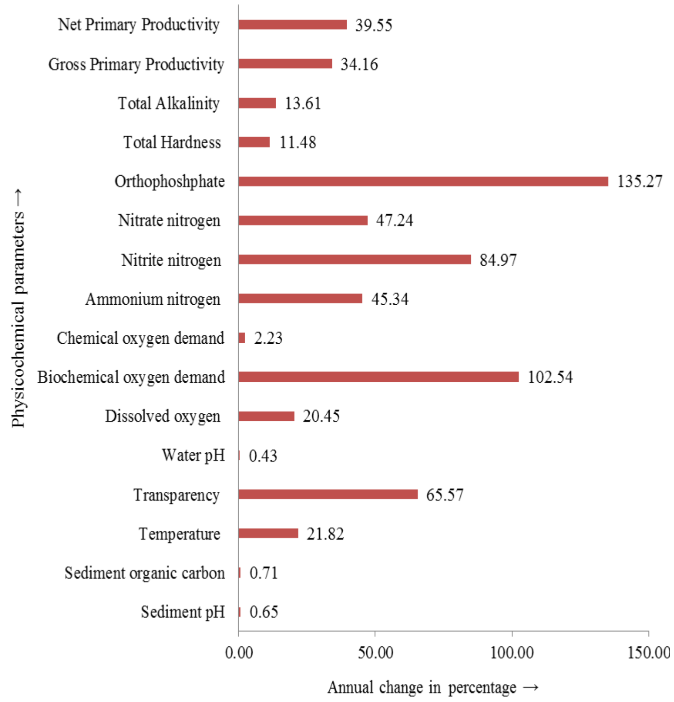

Figure 1. Annual changes of physicochemical parameters.

tion generally ranges from 20mg/l or less in unpolluted waters to greater than 200 mg/l in waters receiving industrial effluents (Geocities, 2009). Quite higher COD range of 32-182 mg/l was also reported (Koliyar and Rokhare, 2008). The higher increase in COD (range 70-90 ppm) values in the present study during jute retting period indicates moderate pollution status of the lake especially during monsoon compared to the rest of the year. Present finding of quite low range (0.026-0.093mg/l) of ammonium nitrogen level, even under high organic loading condition, has been due to prevailing nitrification process over denitrification process, in comparison with other studies (Joo and David, 1995; Joadder, 2009; Feresin *et al.*, 2010). Lower nitrite nitrogen values were observed in the present study compared to other studies (Das *et al.*, 2009; Joadder, 2009). Present study noted higher nitrate nitrogen values due to higher rate of nitrification compared to other studies (Joo and David, 1995; Feresin *et al.*, 2010; Das *et al.*, 2009, 2011a; Ziauddin *et al.*, 2013). The present findings on orthophosphate content are concurrent with other studies (Joo and David, 1995; Das *et al.*, 2009; Feresin *et al.*, 2010). However, we found bit higher orthophosphate values compared to other studies (Vass and Zutshi, 1979; Das *et al.*, 2011a; Biswasroy *et al.*, 2011; Ziauddin *et al.*, 2013). On the basis of orthophosphate concentrations observed the studied water body may be categorized into oligo to mesotrophic oxbow lake as per different trophic categories as stated by Wetzel (1983). As for any productive water, the N/P ratio should range from 4:1 to 10:1 (Jhingran, 2002), present finding of the N/P ratio (0.51:1 to 4.24:1) was not so conducive for fish productivity.

Alkalinity values (range 82-165mg/l, year mean 120±24.03 mg/l) of the present study are in tune with the result of Trisal (1985) in contrast with other reports (Zutshi *et al.*, 1972; Joo and David, 1995; Das *et al.*, 2009, 2011a; Joadder, 2009; Feresin *et al.*, 2010; Ziauddin *et al.*, 2013). Jute retting causes increase in the alkalinity and water becomes richer in nutrients with higher concentrations of alkalinity (Saha *et al.*, 1999) and the water bodies should have total alkalinities of 200-300 mg/l for successful fish culture (Boyd, 1992). The increased level of alkalinity in the present study has been due to high rate of photosynthesis and primary productivity in the oxbow lake ecosystem, particularly when subjected to high organic loading arising from the jute retting and increased nutrient rich surface run off. The alkalinity concentration of the studied oxbow lake indicated its moderate nutrient richness. The present observed values (70-138 mg/l) of total hardness clearly showed a soft to moderately hard water characteristics (Moyle, 1945) of the oxbow lake. High hardness values were observed with maximum in pre-monsoon and minimum in post-monsoon like other studies (Koliyar and Rokhare, 2008; Das *et al*., 2011; 2011a**;** Ziauddin *et al*., 2013) unlike the studies (Das *et al*., 2009; Joadder, 2009). Slight higher hardness values attribute the present oxbow lake water as moderate in nutrient richness and fish culture.

We found GPP range of 25-150 with an annual mean of 104.07±39.17) mgC/m^3/h and NPP range of 12.5-115.0 with year mean of 79.44±33.48) mgC/m^3/h. The range of GPP values have been reported as low as 4-5 mgC/m^2/day to 2600-2700 mgC/m^2/day with an annual mean of 847.5 mgC/m^2/day (Olive *et al*., 1968) while the NPP values were reported to range from 34 to 2459 mgC/m^3/h with mean of 725±729mgC/m^3/h (Joo and David, 1995). The results of the present study are within the limit (Srinivasan, 1967; Olive *et al*., 1968). The results of the present study have quite lower NPP compared to the findings of Joo and David (1995) and lower GPP compared to another finding of Feresin *et al.* (2010).

Almost similar sediment organic carbon content and a sediment pH like present results are observed in the Arpara Beel, an oxbow lake adjacent to the oxbow lake under study at Nakashipara Block in Nadia district (Bala and Mukherjee, 2011) but present results are considerably higher compared to other result in Assam oxbow lakes (Das *et al*., 2011a) which are due to geographical and other differences. However, the annual average value of sediment's pH and organic carbon content of the studied oxbow lake indicate its nutrient richness. The COD was observed to be strongly correlated with sediment organic carbon content (SOC) and BOD, (Table 4) but was inversely correlated with NO_2-N and NPP. Nitrogen species like nitrate nitrogen and ammonium nitrogen were found to be inversely related to water temperature whereas orthophosphate was inversely correlated with water pH. However, strong correlations were noticed in NO_2-N with primary productivity, NH_4 with NO_3-N, total alkalinity and hardness, and GPP with NPP.

In present study on oxbow lake, we found strong correlation between sediment organic content and COD; BOD and COD; water ammonium nitrogen and water nitrate nitrogen content; total hardness and alkalinity content; GPP and NPP. Similarly significantly positive correlations were also found between water BOD and sediment organic content; nitrate nitrogen and DO; orthophosphate and sediment organic content/COD/BOD; transparency and hardness/alkalinity; transparency/water pH and water GPP/NPP. But present results also clearly demonstrated inverse correlation between water temperature and water ammonium nitrogen content; sediment organic content and water nitrite nitrogen; COD and nitrite nitrogen content; water temperature and nitrate nitrogen content; water pH and orthophosphate content; sediment pH and water total alkalinity; sediment organic content and GPP/NPP; and BOD/COD and NPP. Similarly significantly inverse correlations were also found between orthophosphate and nitrite nitrogen /DO content; alkalinity and nitrate nitrogen; and GPP and BOD/COD/orthophosphate.

The results on correlation coefficients corroborate the study of Edward *et al.* (2014) in terms of the following physicochemical parameters: water pH with temperature, alkalinity, DO, transparency, OP, NO_3-N; temperature with alkalinity, DO, transparency, NO_3-N; DO with NO_3-N; transparency with OP, NO_3-N; and OP with NO_3 and also the findings of Mbalassa *et al.* (2014) in terms of water temperature with transparency; DO with pH, transparency; and pH with transparency. In general analyses of physicochemical parameters, compared to their values in pre-monsoon, the mean monsoon values were increased in sediment organic carbon content, BOD and COD. The increases may be due to jute retting and inflowing higher organic matters. The highest concentration of NH_4-N and NO_3-N during post-monsoon and OP during monsoon in the present study may be also due to the allochthonous organic input and the decomposition of the aquatic macrophytes and jute retting. The sharp fall in mean values of water transparency during monsoon compared to pre-monsoon indicated high level of total dissolved solids due to heavy organic matter load restricting light penetration into oxbow lake. Consequently concentration of dissolved oxygen decreases due to reduced rate of photosynthesis. Significant changes in water transparency, BOD, and OP content of water in the present study are attributed to overall organic pollution in oxbow lake throughout the year in general, and during monsoon, in particular.

The present discussion on the physic-chemical study indicate that the high values of parameters like pH, Secchi disc transparency, total hardness, total alkalinity, orthophosphate and low values of DO, BOD, COD, N/P ratio, GPP and NPP showed the present semi-closed oxbow lake water of poor to moderate quality and it may be classified as oligo-mesotrophic in nutrient status with high to moderate organic pollution due to jute retting. The poor health status assessed with the physicochemical properties does also corroborate with the findings of the studies on the same oxbow lake assessed with rotifer diversity indices (Ghosh and Biswas, 2014), zooplankton diversity indices (Ghosh and Biswas, 2015a), macrophytes diversity (Ghosh and Biswas, 2015d), phytoplankton diversity (Ghosh and Biswas, 2015e), fish diversity (Ghosh and Biswas, 2017a; 2017c), fish productivity (Ghosh and Biswas, 2017b) during the same period of study on the same oxbow lake.

Conclusion

The present study concluded that jute retting contributed moderate pollution status of the lake especially during monsoon compared to the rest of the year. The results showed the highest mean values of BOD (4.59ppm), COD (86.67ppm), OP (0.50ppm), sediment organic carbon (2.29%)were observed during monsoon whereas the lowest values of oxbow lake water's transparency (27.00cm), pH (7.84), DO (3.63ppm) and NO_2–N (0.01ppm) contents were found during monsoon when jute retting process gets intensified in the oxbow lake. GPP was recorded in the range of 25-150 (with an annual mean of 104.07±39.17) mgC/m^3/h and NPP range of 12.5-115.0 (with year mean of 79.44±33.48) mgC/m^3/h. Positive correlations were found between sediment organic content and COD; BOD and COD; water ammonium nitrogen and water nitrate nitrogen content; total hardness and alkalinity; GPP and NPP. Similarly significantly positive correlations were also found between water BOD and sediment organic content; nitrate nitrogen and DO; orthophosphate and sediment organic content/COD/BOD; transparency and hardness/alkalinity; transparency/water pH and water GPP/NPP. The present semi-closed oxbow lake water was of poor to moderate quality and it was classified as oligo-mesotrophic in nutrient status with high to moderate organic pollution due to jute retting process which needs to be controlled and regulated for sustainable aquaculture in oxbow lake ecosystem.

ACKNOWLEDGEMENT

Authors acknowledge the facilities of research provided by the Department of Ecological Studies of University of Kalyani; Department of Fisheries of Govt. of West Bengal and Kutirpara Fishermen Co-operative Society Ltd. of Nakashipara Dev. Block, Nadia, West Bengal, India.

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