

Spatiotemporal Occurrence of Odonata Fauna with Reference to Habitat Quality from Two Different Study Sites of Durgapur, West Bengal, India

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Received September 26, 2022; Revised January 13, 2023; Accepted February 15, 2023

Cite This Paper in the Following Citation Styles

(a): [1] Utpal Singha Roy, "Spatiotemporal Occurrence of Odonata Fauna with Reference to Habitat Quality from Two Different Study Sites of Durgapur, West Bengal, India," *Advances in Zoology and Botany*, Vol. 11, No. 5, pp. 317 - 335, 2023. DOI: 10.13189/azb.2023.110501.

(b): Utpal Singha Roy (2023). *Spatiotemporal Occurrence of Odonata Fauna with Reference to Habitat Quality from Two Different Study Sites of Durgapur, West Bengal, India*. *Advances in Zoology and Botany*, 11(5), 317 - 335. DOI: 10.13189/azb.2023.110501.

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Abstract The diversity and abundance of dragonflies and damselflies (Odonata) from two different study sites (Durgapur Barrage and Ambuja Wetland) of the Durgapur industrial region of Paschim Bardhaman District of West Bengal, India were investigated from January 2016 to December 2016. Seventeen different physicochemical factors along with Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) were recorded during the present study for a better understanding of the influence of habitat quality on odonate density and diversity. A combination of direct search and opportunistic sighting methods was applied to record 41 different Odonata species. Among the dragonflies, the most diverse family was Libellulidae while among damselflies Coenagrionidae was the most diverse family. Monsoon and post-monsoon seasons were recorded as the months with the highest odonate diversity and density while the winter season was recorded to support the lowest odonate diversity and density. Significant positive correlations were noted between water temperature and odonate diversity. However, negative correlations were noted between water pH, TSS, BOD, COD, and odonate density as well as diversity. The diversity of odonates for the Durgapur Barrage was found to be significantly higher ($p < 0.05$, ANOVA with Tukey's comparisons) in comparison to the Ambuja Wetland almost throughout the year. The present study clearly indicated a negative influence of habitat alteration and disturbance on odonate

density and diversity. These are early warnings of the deterioration of odonates and hence other biota thriving in the present study location.

Keywords Bioindicators, Density, Diversity, Habitat Alteration, Limnology, Odonata, Pollution, Water Quality

1. Introduction

Industrialization coupled with urbanization has perturbed almost all habitable corners of the earth. Odonates are tiny creatures of the earth that conquered the air for the first time among all animals. Their life history is even more interesting as they spend most of their life in the aquatic medium as larvae, voracious eaters before molting into winged adults. Their fascinating role in the ecosystem both as prey and predator along with their life history traits and unique behavioral patterns have made them the subject of choice in recent times to assess biodiversity, habitat quality, monitoring aquatic health and studying ecology and evolution [1]. Durgapur is an industrial city of West Bengal and like most of the other parts of the country is suffering from habitat alteration and destruction. Hectares of green patches are being cleared off to construct industrial and/or human settlements. Wetlands have been converted to promote multiplexes. To add salt to the wound agricultural runoffs, domestic as well as industrial

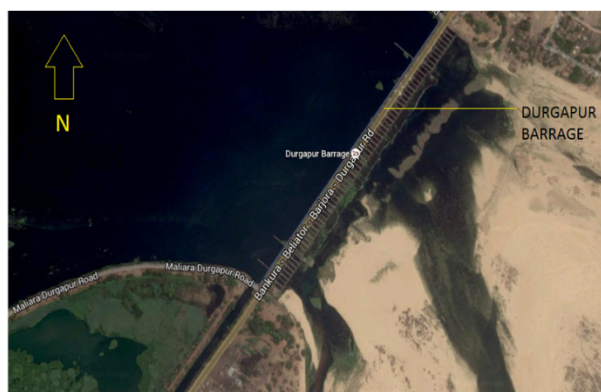
wastewater are polluting all the waterbodies of Durgapur and surrounding areas. Toxic gases from industries and vehicles are polluting the air while solid wastes, mostly non-biodegradable are polluting the land. In a nutshell, the urban industrial city of Durgapur is facing the threat of pollution and contamination that may lead to irreversible adverse conditions in the near future [2]. Since urbanization is ever accelerating, regular monitoring and management of bio-resources have become a challenge, even more so because of the shortage of funds. This was the background scenario that motivated the present work to be undertaken. To enlist the odonate diversity and their habitat preference pattern covering different seasons was the primary objective that was dealt with in the present study. Also, the idea to apply odonates as bio-indicators to assess habitat quality and aquatic health in a short time span spending less money was tested in the present investigation. The present findings might prove to be helpful in the future for the conservation and management of aquatic health and biodiversity which are critical to the interests of humankind itself.

2. Materials and Methods

2.1. Study Area

The present study was carried out in the industrial city of Durgapur, Paschim Bardhaman. The city covers an area of approximately 154 km² and is situated at the transition zone between Chhota Nagpur plateau and Gangetic plains (23.48° N, 87.32° E, elevation 65 m MSL) (Figure 1). Previously vegetation of this region mainly comprised dry deciduous forests, scrubland, and a few agricultural lands. However, with accelerating urbanization and industrialization the landscape of this region has changed dramatically over the past few decades. Many small and heavy industries have been established in this area including Durgapur Steel Plant, Alloy Steel Plant, Durgapur Thermal Power Station and Durgapur Projects Limited. Even so, the city is both interspersed and surrounded by small forest patches of plants like *Shorea robusta*, *Ficus benghalensis*, *Ficus religiosa*, *Mangifera indica*, *Azardicta indica*, *Polyalthia longifolia* and *Eucalyptus paniculata* [3]. The average temperature of the study site has been reported to vary between 8°C – 43 °C while average rainfall ranges between 6 – 213 mm. Three different types of soils can be found in this area, these are laterite soil with gravel, silty clayey soil, and sandy clayey soil [4]. The selection of study sites was made based on the variety of habitat types and ease of sampling for the observation of Odonata diversity. The focal points of sampling for the present study were – Durgapur Barrage and adjoining wetland areas and Ambuja Wetland of Durgapur. Durgapur Barrage (23°28'30.61" N, 87°18'8.20" E) and adjoining wetland areas mainly comprise wetland-dependent mixed vegetation with a perennial river, Damodar (Figure 1). On the other hand, Ambuja Wetland

(23°32'25.82" N, 87°18'23.15" E) is a large waterbody, located at the heart of Durgapur city with wetland-dependent mixed vegetation (Figure 1).



(a)



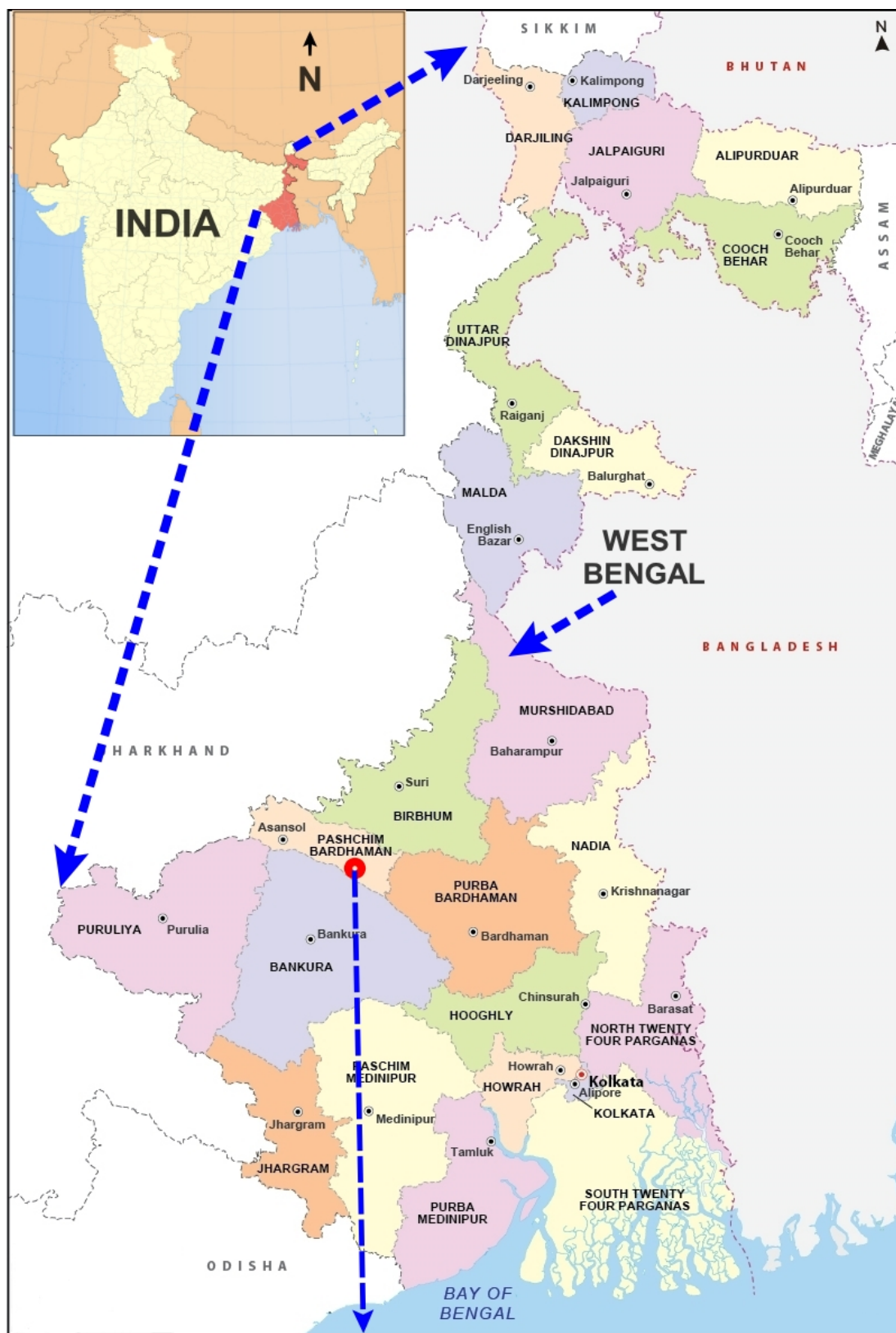
(b)



(c)



(d)



(e)

Figure 1. Present study location. a – Satellite image of Durgapur Barrage. b – Satellite image of Ambuja Wetland. c – Image of Durgapur Barrage. d – Image of Ambuja Wetland. e – Map of India showing the location of state West Bengal along with the present study area. (Satellite image source: Google)

2.2. Water Sample Collection

Water samples were collected from selected study sites (Durgapur Barrage and Ambuja Wetland) from January 2016 to December 2016. Samples were collected during the first week of all the months at three selected times of the day, namely, 08.00hrs, 12.00hrs and 16.00hrs to have a good mean value for each month. The water from selected sites was collected in clean stopper glass bottles (1 L) by immersing them completely into the water (about 10 – 12 cm below the surface of the water) [5]. Prior to the collection, the bottles were cleaned thoroughly with water, 1N nitric acid, and distilled water.

2.3. Physicochemical Character of Water Samples

The geographic coordinates of the study sites were recorded with the help of the Garmin Oregon 550 GPS device and all the physical and some of the chemical factors of both the water bodies were tested on the spot using appropriate instruments. The solar intensity was measured by Digital Lux Meter (LX-101A) and later converted to calorific value per unit area following [6]. The relative humidity of the study sites was measured by a Haier hygrometer. A digital thermometer with a 1 m long probe was used to record the air as well as water temperature. The metallic probe of the digital thermometer was placed above 1 M height of the water table to note the air temperature. For water temperature, the probe was immersed 30 cm below the water surface. A dissolved Oxygen Meter (Hanna: HI 9146) was used to measure dissolved oxygen (DO) potentiometrically. Eutech Multi Pocket Tester (PSCTEST35) was used to monitor the pH, salinity, conductivity, and total dissolved solids (TDS) of the aquatic systems. Standard methods [7] were followed to analyse Total Suspended Solids (TSS) gravimetrically. NO_3^- , PO_4^{3-} , Cl^- , Total Hardness, and Alkalinity were analyzed on the site using E. Merck, Germany, Field Testing Aquamerck reagent kits [8]. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were analysed following Standard Methods [7]. For BOD analysis, the water samples were diluted (1:5) with dilution water. The initial dissolved oxygen was measured by modified Winkler's method. The bottles were kept at 20 °C in an incubator for 5 days and the dissolved oxygen was measured again. The difference in the dissolved oxygen values was used to determine the BOD content of the water. Seeding of microorganisms was not done as the sample water was expected to contain microbial flora. COD was analyzed by refluxing the water samples with potassium dichromate (0.25 N) using mercuric sulfate (to remove chloride interference) and silver sulfate (to break long-chain fatty acids). The excess dichromate was then back-titrated with Mohr's Salt (Ferrous Ammonium Sulphate) using Ferroin as an indicator to estimate the COD.

Primary productivity was assessed by the light and dark bottle method [7]. At each site, the initial DO was

measured, and water-filled light and dark bottles were immersed in the water tied to each other. The bottles were kept for 2 hours (from 10:00 hrs–12:00hrs), and the DO of the dark bottle and the light bottle was measured finally. Solar irradiance was measured (using a Lux meter) every 10 minutes during the productivity analysis. Conversion of measured oxygen values to carbon was done following the factor 0.375 (12 mg carbon is equivalent to 32 mg oxygen). The photosynthetic quotient, which is the ratio of moles of oxygen released to moles of carbon fixed, was taken as 1.2.

The Net Primary Productivity (NPP), Community Respiration (CR), and Gross Primary Productivity (GPP) were calculated according to the following formulae:

$$NPP \text{ (mg carbon m}^{-3}\text{day}^{-1}\text{)} = [(\text{Light bottle DO} - \text{Initial DO}) \times 12 \times 12 \times 1000] / 2 \times \text{photosynthetic quotient} \times 32$$

$$CR \text{ (mg carbon m}^{-3}\text{day}^{-1}\text{)} = [(\text{Initial DO} - \text{Dark bottle DO}) \times 12 \times 24 \times 100] / 2 \times \text{photosynthetic quotient} \times 32$$

$$GPP \text{ (mg carbon m}^{-3}\text{day}^{-1}\text{)} = [(\text{Light bottle DO} - \text{Dark bottle DO}) \times 12 \times 24 \times 100] / 2 \times \text{photosynthetic quotient} \times 32$$

Irradiance energy received by the water bodies was approximated by multiplying the illuminance values in Lux, recorded on the spot by 149×10^{-7} [6] and expressed in $\text{Kcal m}^{-2} \text{day}^{-1}$. Conversion of O_2 values to calorific values was calculated following [9]. The net and gross primary productivity (NPP and GPP) and community respiration was also expressed in $\text{Kcal m}^{-2} \text{day}^{-1}$. The Gross efficiency (Lindemann's efficiency) was calculated by the fraction of the received solar energy that is being converted to primary production by the autotrophs. The net production efficiency was calculated by the fraction of the primary production that was available for the next level of the food chain after utilization of a fraction of the produced energy by the autotrophs at the time of respiration. The net-gross ratio was calculated by the ratio of net primary production and gross primary production.

2.4. Odonate Diversity Estimation

A combination of direct search techniques [10] and opportunistic sighting methods were applied during the present study to record odonate diversity and abundance. Observations were made throughout the year covering both study sites at least once every month involving different habitat types of odonate colonization. Encounter rates for odonates were not the same for the two sites. During each sampling, these frequencies were considered. The relative abundance of odonate species has been represented based on encounter rates. Most seen odonate species based on sighting frequencies have been designated as '++++' followed by '+++', '++' and '+'. These symbols denoted 75–100 %, 50–75 %, 25–50 % and less than 25 % of sighting from the sites of their occurrence throughout the entire study period respectively. Olympus (8X21) Field Binocular was used for odonate species observation while Canon Powershot SX30 was used to photograph the odonate species. The identification of odonates was done following suitable literature [11–18].

However, for robust estimation of odonate density from the Durgapur Barrage and Ambuja Wetland point transect method and mark–recapture techniques were used from January 2016 to December 2016.

2.4.1. Point Transect Method

This method entails the observer remaining at one point for a fixed time and recording the odonates seen by the observer. Distances may be recorded in terms of concentric zones around the point (for example 5 m, 10 m) up to some limit beyond which the odonates are not identifiable. Density is estimated by using the following formula:

$$\check{D} = (n_1 + n_2 / \pi r^2 m) \log_e (n_1 + n_2/n_2)$$

Where, r = radius of concentric zone from the point of observation (5 m and 10 m),

n_1 = number of odonates counted within r ,

n_2 = number of odonates counted beyond r ,

m = total number of replicates.

By using this formula, the number of odonates per 10 square meters has been determined [10].

2.4.2. Mark–Recapture Technique

This technique relies on the fact that when a sample of animals from a population is caught and marked before release, they do mix thoroughly with the rest of the population. Now, when the second sample of animals from the same population is caught, they contain marked as well as unmarked animals. Clearly, it can be assumed that the proportion of marked animals in the second sample is the same as that in the population at large. If n_1 is the number of animals first marked and released, if n_2 is the size of the second sample and if m_2 is the number of marked animals in that sample, and if we consider N as the total population size, then it stands as $m_2/n_2 = n_1/N$. It is obvious that, since n_1 , n_2 and m are known, N can be estimated [10].

2.5. Study of Diversity Indices

Indices relating to diversity, dominance, evenness, richness, and similarity of the odonate communities of the study sites were calculated to compare and comment on the diversity of odonates from Durgapur Barrage and Ambuja Wetland. Diversity indices considered for the present study included Shannon–Wiener Species Diversity Index, Pielou’s Evenness Index, Margalef’s Richness Index, Simpson’s Dominance Index and Sorenson’s Similarity Index. The diversity indices were calculated using the statistical software PAST 3.0.

2.6. Statistical Analysis

Pearson product–moment correlation was employed to identify the relationship, if any, between the

physicochemical factors and odonates at the present study sites (Durgapur Barrage and Ambuja Wetland). The p value less than 0.05 has been considered significant and used for the current analyses. Principal Component Analysis (PCA) was done for generating PCA scatter plots which permitted to find of the relationships between the sampling months that were not ordinarily obvious by routine statistical analysis and thereby, allowed better interpretation of the results.

Hierarchical cluster analysis was done following average linkage method and the result was displayed in the form of two–dimensional plot, known as a dendrogram.

Two–way Analysis of Variance (ANOVA) was used to check for the significance of seasonal and spatial variations in the community composition of the odonate community.

Basic statistical analyses like nonparametric statistics, correlation, simple regression, ANOVA, and multivariate exploratory statistical analyses like factor analyses and PCA were conducted using the software PAST 3.0.

3. Results and Discussion

The seventeen different physicochemical characteristics that were recorded during the present study from both the Durgapur Barrage and Ambuja Wetland varied widely and have been depicted in Table 1 and Table 2. Mean solar radiation was found to be higher in Durgapur Barrage (45708 ± 11409 Lux) over Ambuja Wetland (33550 ± 8174 Lux). May and June were the months when maximum solar radiation was noted while minimum solar radiation was noted in the months of November and December for both the sites. Relative humidity was higher in the rainy season (June and July) while minimal in the winter season (December and January). The mean relative humidity recorded from both sites was much similar (43.92 ± 10.85 for Durgapur Barrage and 37.76 ± 11.14 for Ambuja Wetland). May was recorded as the hottest month for both the sites (air temperature recorded as 42.0 °C and 39.5 °C for Durgapur Barrage and Ambuja Wetland respectively) while January was recorded as the coldest month (air temperature recorded as 22.5 °C and 19.3 °C for Durgapur Barrage and Ambuja Wetland respectively) for both the sites. As one can presume water temperature most intimately followed air temperature and a significant positive correlation was noted between air and water temperature for both the sites ($r = 0.98$, $p < 0.05$ and $r = 0.99$, $p < 0.05$ for Durgapur Barrage and Ambuja Wetland respectively). The mean pH value was found to be higher in the Durgapur Barrage (7.55 ± 0.31) in comparison with the Ambuja Wetland (6.85 ± 0.31). The mean dissolved oxygen (DO) value was found to be higher in the Durgapur Barrage (4.74 ± 1.74 mg L⁻¹) in comparison with the Ambuja Wetland (3.97 ± 1.22 mg L⁻¹). Colder months (December, January, and February) were recorded as the

months to show higher DO for both sites. Mean salinity was found to be higher in Ambuja Wetland ($228.99 \pm 25.35 \text{ mg L}^{-1}$) over Durgapur Barrage ($179.99 \pm 46.08 \text{ mg L}^{-1}$). Mean conductivity was also found to be higher in the Ambuja Wetland ($503.70 \pm 78.88 \text{ }\mu\text{S}$) over the Durgapur Barrage ($374.18 \pm 95.80 \text{ }\mu\text{S}$). Total dissolved solids (TDS) were found to be higher in Durgapur Barrage in comparison with Ambuja Wetland (mean values recorded

as 419.67 ± 113.14 and $331.83 \pm 43.21 \text{ mg L}^{-1}$ for Durgapur Barrage and Ambuja Wetland respectively). The mean total suspended solid (TSS) recorded from both sites were much similar (134.08 ± 104.05 for Durgapur Barrage and $131.76 \pm 105.43 \text{ mg L}^{-1}$ for Ambuja Wetland). Alkalinity value was recorded to be higher in Durgapur Barrage ($4.08 \pm 1.14 \text{ mmol L}^{-1}$) over Ambuja Wetland ($1.90 \pm 0.57 \text{ mmol L}^{-1}$).

Table 1. Physicochemical characteristics of water for Durgapur Barrage as recorded in the present study. (SR = Solar radiation, HUMD = Humidity, AT = Air temperature, WT = Water temperature, DO = Dissolved oxygen, SAL = Salinity, COND = Conductivity, TDS = Total dissolved solid, TSS = Total suspended solid, ALK = Alkalinity, HARD = Hardness, CHLD = Chloride, BOD = Biochemical oxygen demand, COD = Chemical oxygen demand, PHOS = Phosphate, NIT = Nitrate).

Parameters	MONTHS												Mean
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
SR (Lux) X 100	378	434	518	545	557	632	545	534	428	316	297	301	457.0
HUMD (%)	32	48	38	37	42	52	72	48	41	46	39	32	43.92
AT (°C)	22.5	32.5	37.4	40.6	42	40.3	40.5	37.1	38.1	36.2	31.3	30.6	35.76
WT (°C)	18.7	31.6	35.4	37.2	38.6	38.1	38.6	36.5	35.1	33.5	30.5	27.4	33.43
pH	8.2	7.9	7.6	7.5	7.4	7.3	7.5	7	7.3	7.6	7.5	7.8	7.55
DO (mg L ⁻¹)	5.6	7.2	5.4	4	7	5.5	2.3	1.3	4.8	3.5	4.2	5.6	4.7
SAL (mg L ⁻¹)	173	187	234	264	222	162	149	100	119	185	190	175	179.99
COND (μS)	359	390	487	549	461	337	310	208	248	385	394	363	374.18
TDS (mg L ⁻¹)	405	433	549	647	517	382	343	236	279	389	446	410	419.67
TSS (mg L ⁻¹)	362	232	32	69	122	130	104	28	34	67	175	254	134.08
ALK (mmol L ⁻¹)	3.5	4	4.2	5.4	5.4	3.8	3.1	2.8	2.1	5.6	5.3	3.8	4.08
HARD (mg L ⁻¹)	210	199	217	246	256	211	182	121	135	256	250	241	210.4
CHLD (mg L ⁻¹)	136	172	204	252	174	156	100	88	94	130	131	142	148.25
BOD (mg L ⁻¹)	52.9	66.5	64.2	55.3	60	40.4	28	30.6	28.9	53.2	61.4	59.8	50.1
COD (mg L ⁻¹)	92	136	128.2	123	130.1	84	53.2	54	57.4	110	96	134	99.83
PHOS (mg L ⁻¹)	0.1	0.07	0.17	0.1	0.13	0.07	0.13	0.03	0.12	0.17	0.2	0.13	0.12
NIT (mg L ⁻¹)	0.76	0.86	0.92	0.83	0.78	0.78	1	0.86	0.74	0.84	0.91	0.88	0.85

Table 2. Physicochemical characteristics of water for Ambuja Wetland as recorded in the present study. (SR = Solar radiation, HUMD = Humidity, AT = Air temperature, WT = Water temperature, DO = Dissolved oxygen, SAL = Salinity, COND = Conductivity, TDS = Total dissolved solid, TSS = Total suspended solid, ALK = Alkalinity, HARD = Hardness, CHLD = Chloride, BOD = Biochemical oxygen demand, COD = Chemical oxygen demand, PHOS = Phosphate, NIT = Nitrate).

Parameters	MONTHS												Mean
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
SR (Lux) X 100	320	315	326	352	502	479	210	259	337	310	322	294	335.5
HUMD (%)	25	41	31	27	28	35	64	53	39	40	35	34	37.76
AT (°C)	19.3	29.4	32.3	34.7	39.5	37.6	38.6	28.2	31.8	28.9	30	21.6	30.99
WT (°C)	17.8	27.2	31.9	33.1	38.2	36.4	35.2	27.1	30	27.6	29.5	20.1	29.51
pH	6.9	7.1	7.2	7	6.9	6.4	6.1	6.8	7.1	7	6.7	6.8	6.85
DO (mg L ⁻¹)	2.6	4.8	5.2	5.8	5.2	4.8	2.1	2.7	3.7	3.4	4.4	2.9	3.97
SAL (mg L ⁻¹)	208	255	255	245	256	187	198	202	223	229	236	255	228.99
COND (μS)	648	529	525	531	529	386	409	406	456	498	604	525	503.7
TDS (mg L ⁻¹)	295	375	371	367	374	271	290	260	326	328	352	373	331.83
TSS (mg L ⁻¹)	345	217	125	70	245	112	59	25	21	68	49	244	131.76
ALK (mmol L ⁻¹)	2.1	2.5	1.5	1.3	1	1.2	1.6	2.4	2.7	2.5	1.8	1.9	1.9

Table 2 continued

HARD (mg L⁻¹)	123	88	193	70	70	61	193	245	193	193	158	88	139.51
CHLD (mg L⁻¹)	33	37	48	56	105	122	135	86	65	61	48	39	69.58
BOD (mg L⁻¹)	58.7	73.7	71.2	61.3	66.6	44.8	31.1	33.9	32.1	59	68.1	66.3	55.57
COD (mg L⁻¹)	24.6	26.3	24.8	18.5	16.3	12.2	18.5	13.2	9.3	27.2	23.2	23.1	19.77
PHOS (mg L⁻¹)	0.34	0.42	0.64	0.44	0.31	0.42	0.56	0.63	0.47	0.31	0.31	0.42	0.44
NIT (mg L⁻¹)	1.02	0.99	0.97	0.98	0.91	0.93	2.56	2.49	1	1.07	1.01	1.07	1.25

Total hardness and Chloride were recorded to be higher in Durgapur Barrage (mean values recorded as 210.40 ± 45.35 mg L⁻¹ and 148.25 ± 47.56 mg L⁻¹ respectively) than in Ambuja Wetland (mean values recorded as 139.51 ± 63.48 mg L⁻¹ and 69.58 ± 34.52 mg L⁻¹ respectively). The mean BOD value was higher in the Ambuja Wetland (55.57 ± 15.84 mg L⁻¹) however mean COD value was higher in the Durgapur Barrage (99.83 ± 31.97 mg L⁻¹). Both phosphate and nitrate mean values were found to be higher in the Ambuja Wetland (mean values recorded as 0.44 ± 0.12 mg L⁻¹ and 1.25 ± 0.60 mg L⁻¹ respectively) in comparison to the Durgapur Barrage (mean values recorded as 0.12 ± 0.05 mg L⁻¹ and 0.85 ± 0.08 mg L⁻¹ respectively). Gross primary productivity (GPP) and net primary productivity (NPP) were both recorded to be higher in Durgapur Barrage (mean values recorded as 2840.38 ± 597.80 and 1480.95 ± 599.65 mg C m⁻² d⁻¹ respectively) than in Ambuja Wetland (mean values recorded as 1881.92 ± 642.60 and 983.18 ± 334.68 mg C m⁻² d⁻¹ respectively) and has been presented in Table 3 and Table 4.

The ratio of NPP and GPP and Lindeman efficiency were also found to be higher in Durgapur Barrage (mean % values recorded as 53.96 ± 12.76 and 6.83 ± 2.88 respectively) than in Ambuja Wetland (mean % values recorded as 52.67 ± 5.86 and 5.80 ± 2.11 respectively). A study of the correlation between primary productivity and physicochemical parameters revealed a negative correlation between water temperature and GPP for both Durgapur Barrage and Ambuja Wetland. NPP again was found to be positively correlated with pH for both the sites under the present study. Dissolved O₂ was found to be positively correlated with GPP in both study sites. Both phosphate and nitrate were recorded to have negative correlations with GPP and NPP for both study sites. Limnochemically both sites showed degrees of similarity and dissimilarity at the same time. The study of the hierarchical cluster in this regard has been considered handy.

As depicted in the dendrograms (Figures 2, 3) months got segregated into definite clusters depending on their characteristic limnochemical characters. Two distinct

clusters could be found for the Durgapur Barrage (Figure 2). The first main cluster got divided again into two separate clusters, the first being formed by the months of November and December with October as the closest out-group while the second one was formed by February and September with January as the closest out-group. The second main cluster also got divided into two small clusters with June being equally distant from these clusters. March and August, and April and July formed two distinct clusters with May being an out-group to the April-July cluster. A study of the PCA scatter plot also supported the findings (Figures 4, 5).

The Diversity of odonate species varied widely during the present study both site and season-wise and has been presented in Table 5. The maximum odonate diversity was recorded in the rainy season followed by the summer and winter seasons. A total of 39 different odonate species were recorded from Durgapur Barrage while for Ambuja Wetland 14 different odonate species were recorded during the present study. Odonates recorded from Durgapur Barrage belonged to six families, three families were represented by dragonflies (Anisoptera), and three were represented by damselflies (Zygoptera) while for Ambuja Wetland three different odonate families were recorded of which two families were represented by dragonflies (Anisoptera), and one was represented by damselfly (Zygoptera) (Table 5). Among the dragonflies, the most diverse family was Libellulidae (21 species) while among damselflies Coenagrionidae (13 species) was the most diverse family. So far as the odonate species diversity was concerned among all the recorded species *Bradinopyga geminata* and *Diplacodes nebulosa* were recorded only from Ambuja Wetland and not from Durgapur Barrage. Apart from these two all the odonate species recorded from Durgapur Barrage. The seasonal occurrence pattern for odonates varied widely during the present study. It was found that 11 of the odonate species were occurred all throughout the year while the rest of the 30 species were absent during certain times of the year from the present study location. It was interesting to note that the citing frequency of the odonates that occurred throughout the year was higher than the odonate species which were not found throughout the year (Table 5).

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Table 3. Primary productivity as recorded for Durgapur Barrage during the present study. Parameters are abbreviated as: Gross primary productivity (GPP), net primary productivity (NPP), net-gross ratio (N/G), Lindeman efficiency (LE).

Months	NPP (mg C m ⁻² d ⁻¹)	GPP (mg C m ⁻² d ⁻¹)	N/G (%)	LE (%)
JAN	2425	3450	62.82	9.13
FEB	2650	3570	74.22	8.23
MAR	1225	2488	49.23	4.80
APR	784	1368	74.07	2.51
MAY	1025	2845	57.44	5.11
JUN	938	2625	35.71	4.15
JUL	1059	2371	44.67	4.35
AUG	1490	2818	52.86	5.28
SEP	1454	2956	49.19	6.91
OCT	1468	2987	49.15	9.45
NOV	1168	3256	35.87	10.96
DEC	2086	3350	62.27	11.13
Mean	1480.95	2840.38	53.96	6.83
SD	599.65	597.80	12.76	2.88
Min	784	1368	35.71	2.51
Max	2650	3570	74.22	11.13

Table 4. Primary productivity as recorded for Ambuja Wetland during the present study. Parameters are abbreviated as: Gross primary productivity (GPP), net primary productivity (NPP), net-gross ratio (N/G), Lindeman efficiency (LE).

Months	NPP (mg C m ⁻² d ⁻¹)	GPP (mg C m ⁻² d ⁻¹)	N/G (%)	LE (%)
JAN	1640	2800	58.57	8.75
FEB	1236	2654	46.57	8.43
MAR	1315	2760	47.64	8.47
APR	1150	2235	51.47	6.35
MAY	865	1856	46.61	3.70
JUN	758	1620	46.79	3.38
JUL	652	1250	52.16	5.95
AUG	624	1220	51.15	4.71
SEP	587	1150	51.04	3.41
OCT	730	1128	64.72	3.64
NOV	985	1650	59.70	5.12
DEC	1256	2260	55.58	7.69
Mean	983.18	1881.92	52.67	5.80
SD	334.68	642.60	5.86	2.11
Min	587	1128	46.57	3.38
Max	1640	2800	64.72	8.75

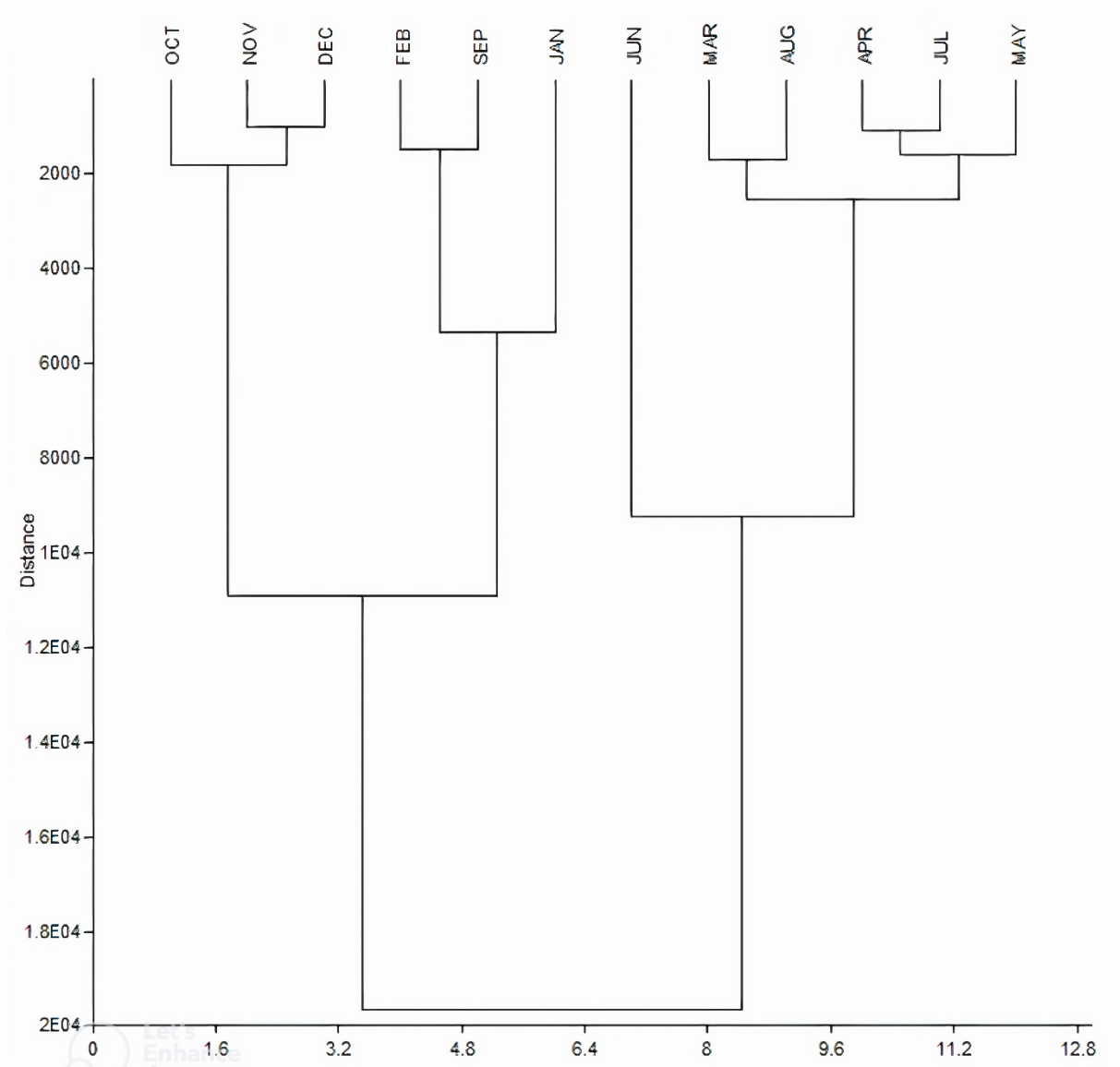


Figure 2. Dendrogram depicting relationships among different sampling months based on limnochemistry for Durgapur Barrage as recorded in the present study.

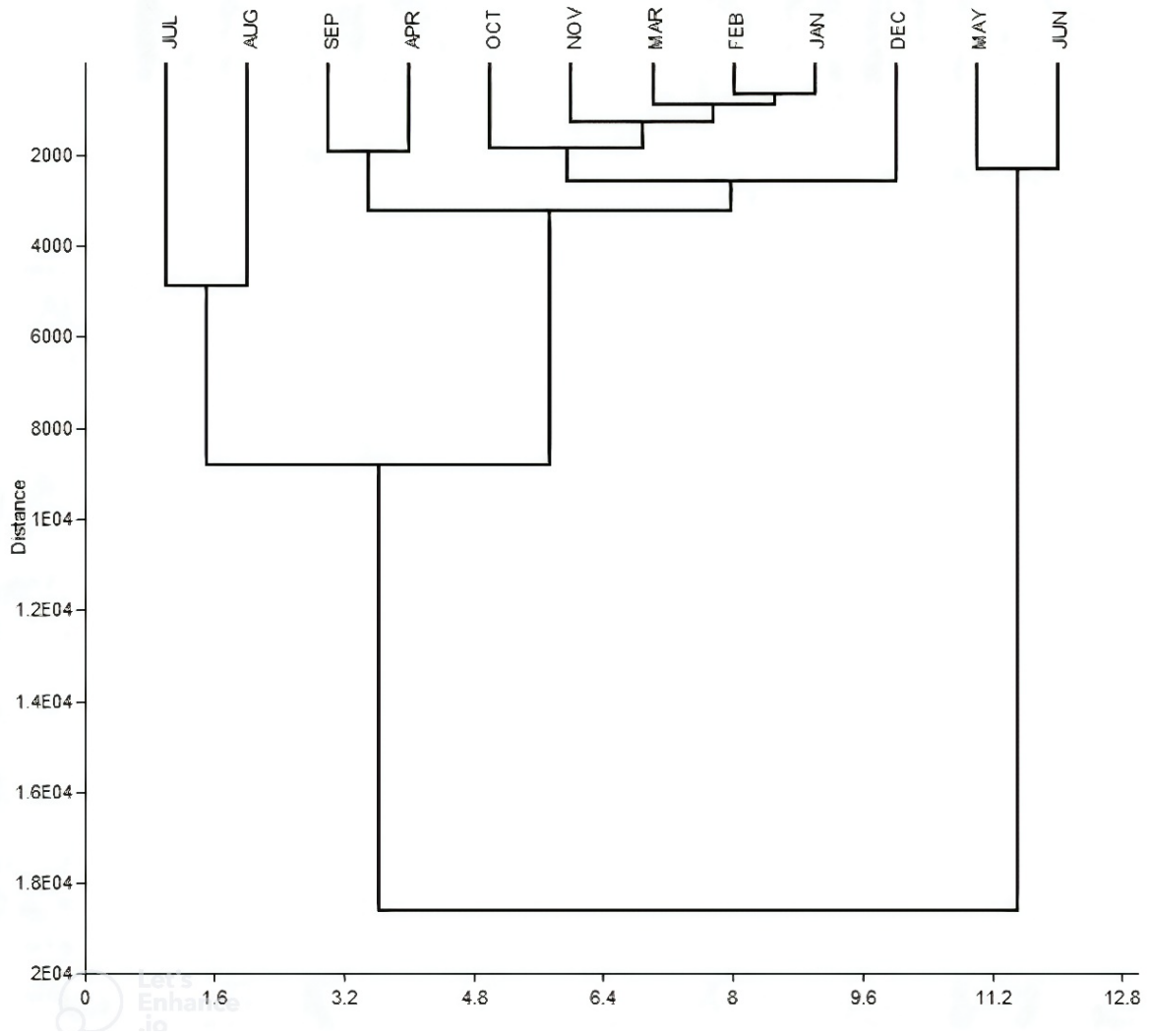


Figure 3. Dendrogram depicting relationships among different sampling months based on limnochemistry for Ambuja Wetland as recorded in the present study.

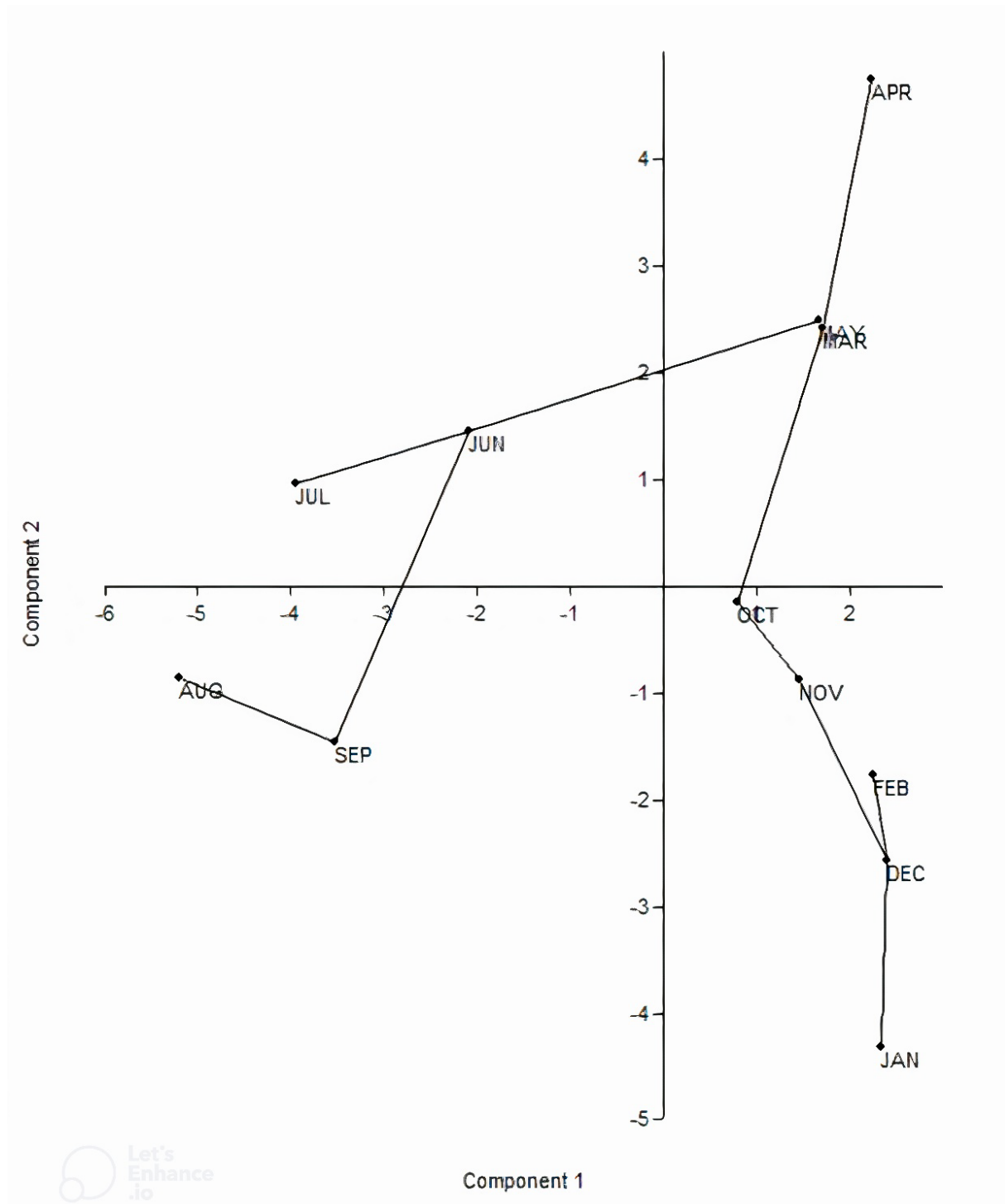


Figure 4. PCA scatter plot showing the relationships between different sampling months based on limnochemistry for Durgapur Barrage as recorded in the present study.

Table 5. Diversity of Anisoptera and Zygoptera from Durgapur Barrage (DB) and Ambuja Wetland (AW) along with month of occurrence. Sighting frequencies have been designated based on encounter rates “++++” stands for most encountered while, “+” stands for least encountered Odonata. TTY = Throughout the year, ER = Encounter rate.

Sl. No.	Species	DB	AW	Month of Occurrence	ER
Suborder: Anisoptera Selys, 1854					
Family: Aeshnidae Leach, 1815					
01	<i>Anax guttatus</i> (Burmeister, 1839)	P	A	May – Nov	++
Family: Gomphidae Rambur, 1842					
02	<i>Cyclogomphus ypsilon</i> Selys, 1854	P	A	Jun – Aug	++
03	<i>Cyclogomphus wilkinsi</i> Fraser, 1926	P	A	Jun – Aug	++
04	<i>Ictinogomphus rapax</i> (Rambur, 1842)	P	P	TTY	++++
05	<i>Platygomphus dolabratus</i> Selys, 1854	P	A	July	+
Family: Libellulidae Leach, 1815					
06	<i>Acisoma panorpoides</i> Rambur, 1842	P	P	May – Sep	+++
07	<i>Aethriamanta brevipennis</i> (Rambur, 1842)	P	P	May – Sep	+++
08	<i>Brachydiplax chalybea</i> Brauer, 1868	P	A	October	+
09	<i>Brachydiplax sobrina</i> (Rambur, 1842)	P	P	TTY	++++
10	<i>Brachythemis contaminata</i> (Fabricius, 1793)	P	P	TTY	++++
11	<i>Bradinyoga geminata</i> (Rambur, 1842)	A	P	TTY	++++
12	<i>Crocothemis servilia</i> (Drury, 1773)	P	P	TTY	++++
13	<i>Diplacodes nebulosa</i> (Fabricius, 1793)	A	P	May – Aug	+
14	<i>Diplacodes trivialis</i> (Rambur, 1842)	P	P	TTY	++++
15	<i>Macrodiplax cora</i> (Brauer, 1867)	P	A	Jun – Sep	+++
16	<i>Neurothemis tullia</i> (Drury, 1773)	P	P	Apr – Oct	+++
17	<i>Orthetrum pruinosum</i> (Burmeister, 1839)	P	A	Apr – Oct	++
18	<i>Orthetrum Sabina</i> (Drury, 1770)	P	P	TTY	++++
19	<i>Pantala flavescens</i> (Fabricius, 1798)	P	A	May – Nov	+++
20	<i>Potamarcha congener</i> (Rambur, 1842)	P	A	Feb – Novr	+++
21	<i>Rhyothemis variegata</i> (Linnaeus, 1763)	P	A	Mar – Nov	+++
22	<i>Tholymis tillarga</i> (Fabricius, 1798)	P	A	TTY	+++
23	<i>Trithemis festiva</i> (Rambur, 1842)	P	A	Aug – Nov	+
24	<i>Trithemis pallidinervis</i> (Kirby, 1889)	P	A	Feb – Nov	+++
25	<i>Urothemis signata</i> (Rambur, 1842)	P	P	Mar – Nov	+++
26	<i>Zyxomma petiolatum</i> Rambur, 1842	P	A	Mar – Nov	++
Suborder: Zygoptera Selys, 1854					
Family: Coenagrionidae Kirby, 1890					
27	<i>Agrion nemis pygmaea</i> (Rambur, 1842)	P	A	TTY	++++
28	<i>Ceragrion cerinorubellum</i> (Brauer, 1865)	P	A	Feb – Nov	++
29	<i>Ceragrion coromandelianum</i> (Fabricius, 1798)	P	P	TTY	++++
30	<i>Ischnura aurora</i> (Brauer, 1865)	P	A	Mar – Nov	+++
31	<i>Ischnura rufostigma</i> Selys, 1876	P	A	March	+
32	<i>Ischnura senegalensis</i> (Rambur, 1842)	P	P	TTY	++++
33	<i>Onychargia atrocyana</i> Selys, 1865	P	A	Feb – Nov	+++
34	<i>Paracercion malayanum</i> (Selys, 1876)	P	A	May – Oct	++
35	<i>Pseudagrion decorum</i> (Rambur, 1842)	P	A	Feb – Nov	+++
36	<i>Pseudagrion microcephalum</i> (Rambur, 1842)	P	A	Feb – Nov	++
37	<i>Pseudagrion rubriceps</i> Selys, 1876	P	A	Feb – Nov	+++
38	<i>Pseudagrion spencei</i> Fraser, 1922	P	A	Jul, Nov	+++
39	<i>Ischnura nursei</i> (Morton, 1907)	P	A	Oct, Mar	+
Family: Lestidae Calvert, 1901					
40	<i>Lestes umbrinus</i> Selys, 1891	P	A	October	+
Family: Platynemididae Yakobson & Bainchi, 1905					
41	<i>Copera ciliate</i> (Selys, 1863)	P	A	Feb – Nov	+++

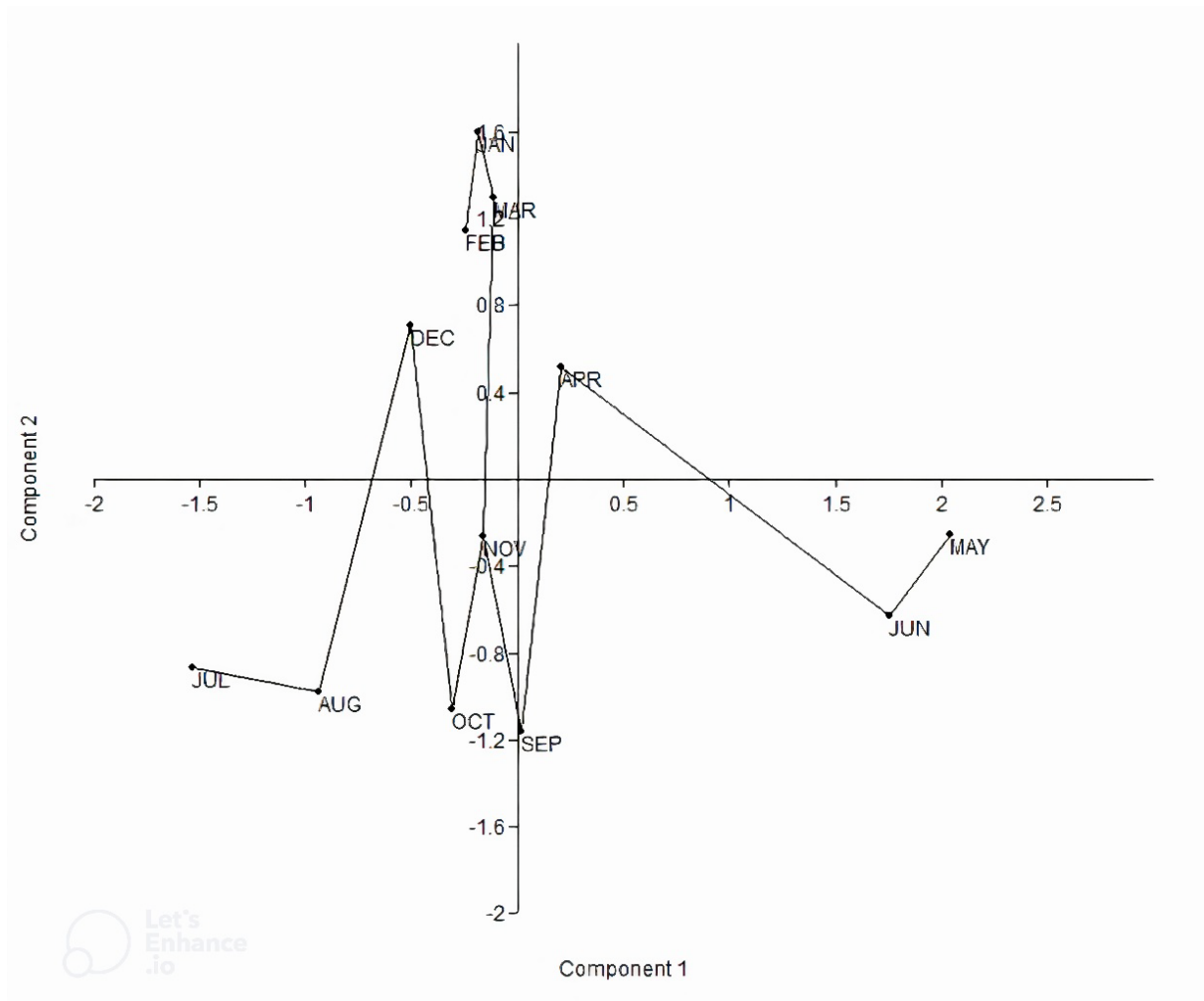


Figure 5. PCA scatter plot showing the relationships between different sampling months based on limnochemistry for Ambuja Wetland as recorded in the present study.

Although both study sites in the present investigation had anthropogenic disturbances, it was more prominent in the Ambuja Wetland. Lower odonate diversity at Ambuja Wetland might be attributed to a higher degree of anthropogenic intervention. This finding corroborates well with findings made by other researchers who have already reported the negative influence of habitat alteration and disturbances on Odonata diversity [19]. The yearlong

robust estimation of odonate diversity and density along with the physicochemical characteristics from Durgapur Barrage and Ambuja Wetland was also interesting in this regard. A comparative account of the density and diversity of all the odonates recorded from the Durgapur Barrage and Ambuja Wetland has been depicted in Figure 6. It was found that both the density and diversity of the two sites varied widely during the sampling period.

Spatiotemporal Occurrence of Odonata Fauna with Reference to Habitat Quality from Two Different Study Sites of Durgapur, West Bengal, India

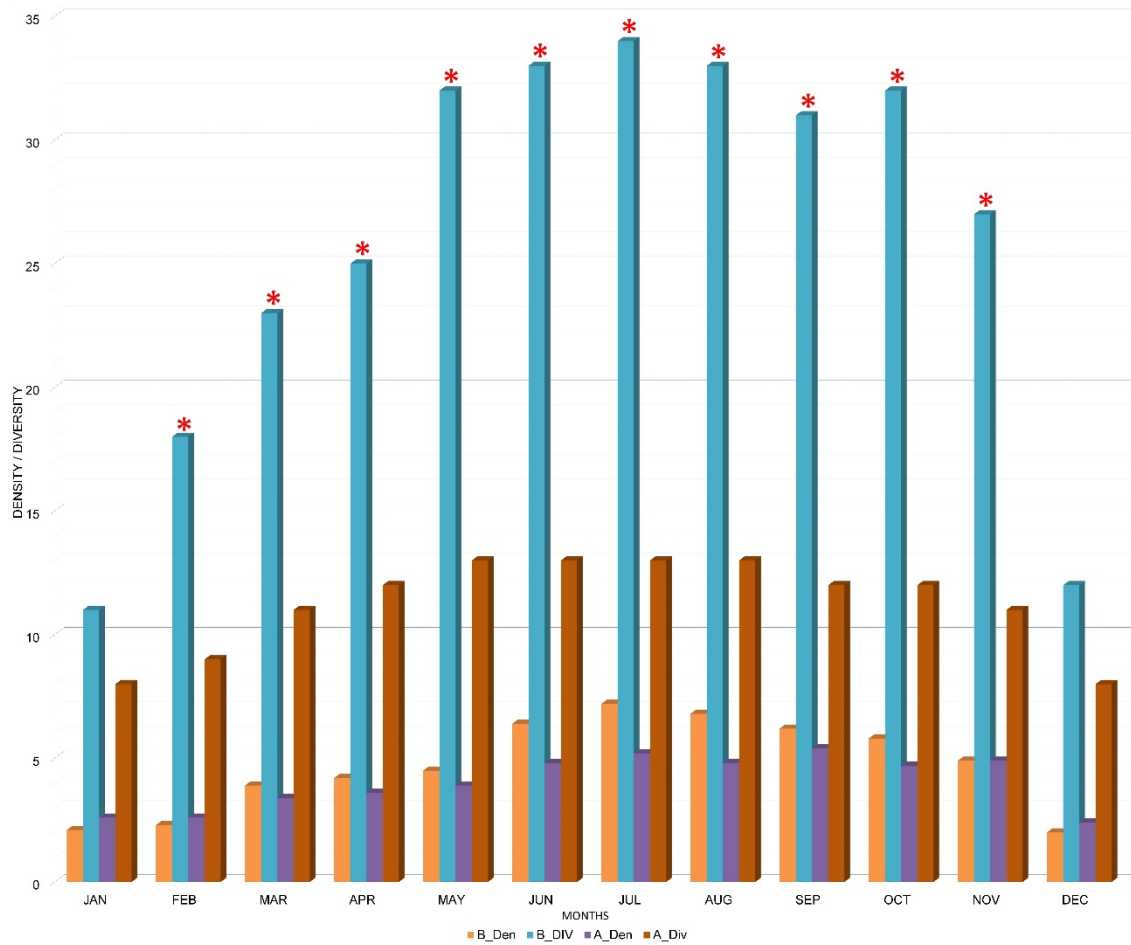


Figure 6. Odonate diversity (DIV) and density (DEN) [number of odonates / 10 square meter] from Durgapur Barrage (B) and Ambuja Wetland (A). Significant difference in spatial and temporal odonate occurrence have been indicated by asterisks (*) ($p < 0.05$, ANOVA with Tukey’s comparisons).

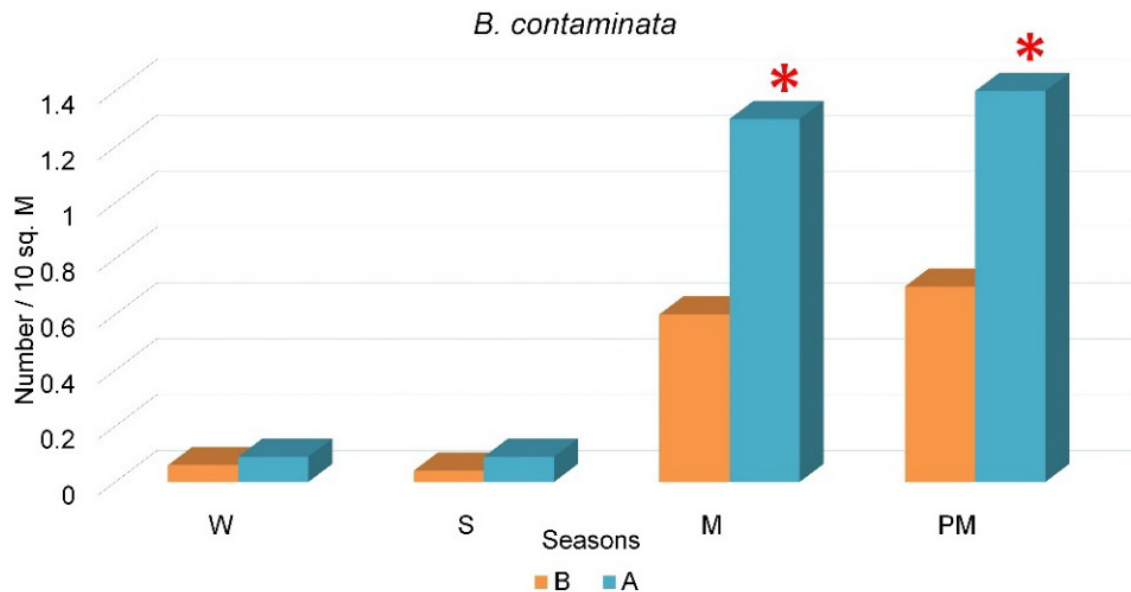


Figure 7. Seasonal (W = Winter, S = Summer, M = Monsoon and PM = Post monsoon) density (number of individuals / 10 square meter) of *Brachythemis contaminata* from Durgapur Barrage (B) and Ambuja Wetland (A). Significant difference in spatial and temporal density have been indicated by asterisks (*) ($p < 0.05$, ANOVA with Tukey’s comparisons).

Table 6. Diversity indices for odonates as recorded during the present study from Durgapur Barrage and Ambuja Wetland.

Diversity indices	Durgapur Barrage	Ambuja Wetland
Shannon–Wiener diversity index	2.432	1.658
Pielou's evenness index	0.949	0.678
Margalef's richness index	2.242	1.245
Simpson's dominance index	0.657	0.925
Sorensen's similarity index	0.452	

The diversity of odonates for the Durgapur Barrage was found to be significantly higher ($p < 0.05$, ANOVA with Tukey's comparisons) in comparison to the Ambuja Wetland almost throughout the year. It was interesting to note that the odonate density (number of individuals / 10 square meter) were higher in the Ambuja Wetland for the colder months (December to February). However, for the rest of the year density of odonates was higher for the Durgapur Barrage (Figure 6). Truly little is known about the ecological factors that limit odonate species distribution in a particular habitat, however, *Brachythemis contaminata* have been found to be associated with polluted water. Accordingly, they have been considered good bio-indicators [20]. Figure 7 represents the density of *Brachythemis contaminata* from the Durgapur Barrage and Ambuja Wetland. A significantly higher ($p < 0.05$, ANOVA with Tukey's comparisons) density of *Brachythemis contaminata* was noted from the Ambuja Wetland in comparison to the Durgapur Barrage during monsoon and post-monsoon seasons. A higher abundance of *Brachythemis contaminata* in the present study was a clear indication of elevated pollution levels.

Greater diversity and abundance of odonates from the Durgapur Barrage resulted in higher scores for the Shannon-Wiener diversity index, Pielou's evenness index, and Margalef's richness index for the Durgapur Barrage over the Ambuja Wetland. Whereas, Simpson's dominance index, which puts greater emphasis on common species was higher in the Ambuja Wetland (Table 6). Therefore, these indices point out the occurrence of many rare species in the Durgapur Barrage, while the reverse situation was evident in the Ambuja Wetland. The composition of odonate diversity from both the study sites was clearly different resulting in a lower similarity index value (0.452).

Since little is known about the ecological factors that play a major role in the distribution of odonates in a specific aquatic habitat, the study of limnochemistry is considered a suitable measure to get some insight, since the larval stages of odonates solely depend on the aquatic medium. During the present study, interesting correlations

were noted between odonate diversity, density, and certain physicochemical factors.

Though odonates belong to the group of poikilotherms, they can maintain body temperature to some extent by means of several behavioural and physiological activities [21, 22] and hence, have been aptly classified as facultative endotherms [23]. The minimum temperature required for muscles to support flight is critical for odonate survival. The present findings of positive correlations between solar radiation, air and water temperature from both sites corroborate well with that of [24] (Figures 8, 9).

The highest odonate diversity and density were noted in the monsoon and post-monsoon seasons (Figure 6) which corroborates well with previous findings [25]. During the present investigation, mostly alkaline ranges of pH were observed, which can be correlated with the presence of carbonate and bicarbonate alkalinity in both study sites. The pH of the water was considered a measure of environmental suitability for aquatic life and a range of 7.0 to 8.5 is considered to support higher aquatic diversity [26]. Total alkalinity again is very closely related to aquatic productivity and more than 200 mg/L is considered good for biological productivity [27]. The total hardness of water depends upon the presence of calcium and magnesium salts and the permissible limits of total hardness in potable water range within 500 mg/L. In the present study, the obtained total hardness was within the safe limit for aquatic life to flourish (Tables 1, 2). TDS in water is constituted by many inorganic salts and a small number of organic matters and less than 500 mg/L TDS is desirable for drinking water supply in India [28]. The present findings indicate a suitable TDS condition for the occurrence and growth of odonate larvae in the Durgapur Barrage and Ambuja Wetland area. Total suspended solids (TSS) are well known for their adverse effects on aquatic life [29]. During the present study, significant negative correlations were noted between TSS and odonate density and diversity from both Durgapur Barrage and Ambuja Wetland.

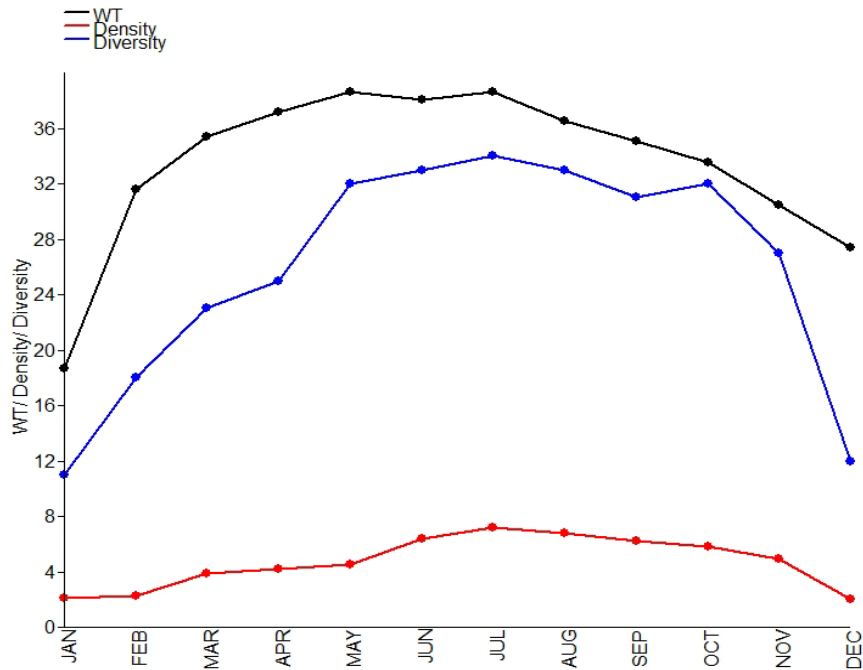


Figure 8. Relationship between water temperature and odonate density and diversity recorded during the present study from Durgapur Barrage.

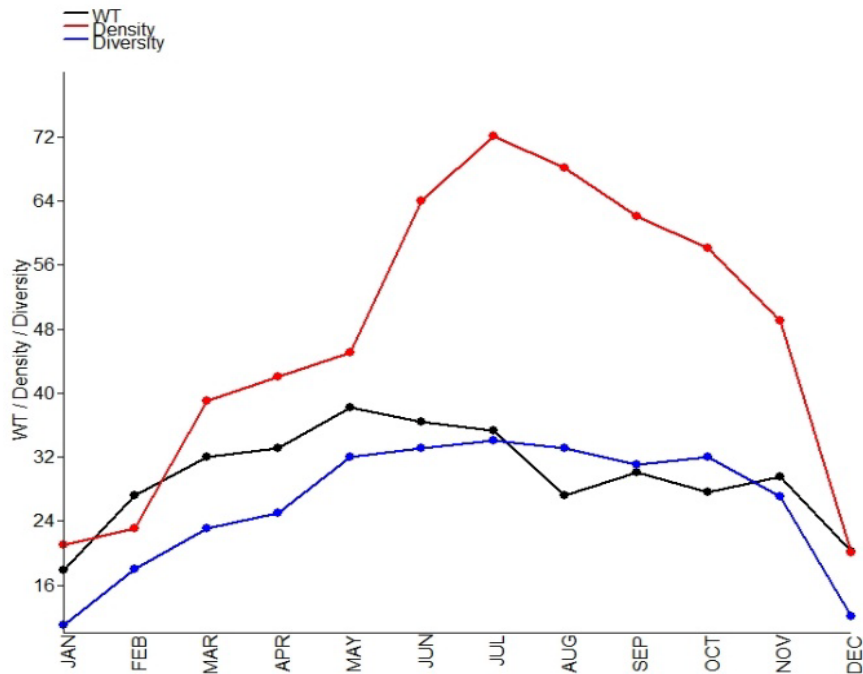


Figure 9. Relationship between water temperature and odonate density and diversity recorded during the present study from Ambuja Wetland.

The availability of dissolved oxygen in water most intimately controls the abundance, activity, behaviour, and survival of odonates [30, 31]. The concentration of oxygen has been reported to determine the diversity of odonates from different habitat types [24, 30, 32]. Again, dissolved oxygen most intimately follows primary productivity and accordingly, a positive correlation was noted between them in the present study. However, during

the present study, a negative correlation was noted between oxygen concentration and odonate density and diversity. Likewise, primary productivity was also found to be negatively correlated with odonate density and diversity. Mention may be made that odonate diversity and density were maximum in the monsoon and post-monsoon seasons while it was least in the winter season. However, during the present study highest

primary productivity and DO were recorded in the colder months. This is mostly because lower water temperature encourages higher photosynthesis in tropical waters [9], which was evident in this study. Higher demand for CO_2 for photosynthetic uptake encouraged higher reverse reaction from CO_3^{2-} to HCO_3^- and ultimately supplied CO_2 for the photosynthetic process. Such reverse reactions influenced the higher alkaline conditions of the water during the colder months which have favourable temperatures for enhanced rates of photosynthesis. Because the CO_3^{2-} and HCO_3^- alkalinity are the major contributors to total hardness, a positive correlation exists between total hardness and total alkalinity [33] and this fits well for the present study as well.

As far as the water quality of both the sites was concerned high BOD and COD values were noted. All the records noted during the present study (Tables 1, 2) were higher than the WHO recommended value for potable water (5 mg/L for BOD and 10 mg/L for COD).

The addition of nutrient-rich domestic, agricultural, and industrial wastewater both into Durgapur Barrage and Ambuja Wetland increased the total nutrient content of the water, which was reflected in higher phosphate and nitrate concentrations.

The mean BOD values recorded during the present study from the Ambuja Wetland were higher than that for the Durgapur Barrage (mean values recorded as

55.57 ± 15.84 and 50.10 ± 14.28 mg/L respectively). This clearly indicates a higher load of biological waste at this site. Mean COD values, however, were noted to be much higher for the Durgapur Barrage over the Ambuja Wetland (mean values recorded as 99.83 ± 31.97 and 19.77 ± 6.00 mg/L respectively). Mention may be made that the Durgapur Barrage site receives untreated effluents from several small- and large-scale industries throughout the year.

Habitats with higher values of BOD and COD have been reported to exert a negative influence on odonate diversity [34] and the present findings corroborate well with that (Figures 10, 11).

The present study clearly indicated a negative influence of habitat alteration and disturbance on odonate density and diversity. These are early warnings of the deterioration of odonates and hence overall biodiversity from the present study location. These findings may be helpful in designing future restoration as well as management plans for these kinds of habitats. Studying of density and diversity of odonates in the present investigation proved to be especially useful as bio-indicators. Future studies including more animal taxa coupled with odonates may deliver exciting results. Specifically, studying the prey and predator population of both adult and larval odonates will be much helpful in this regard.

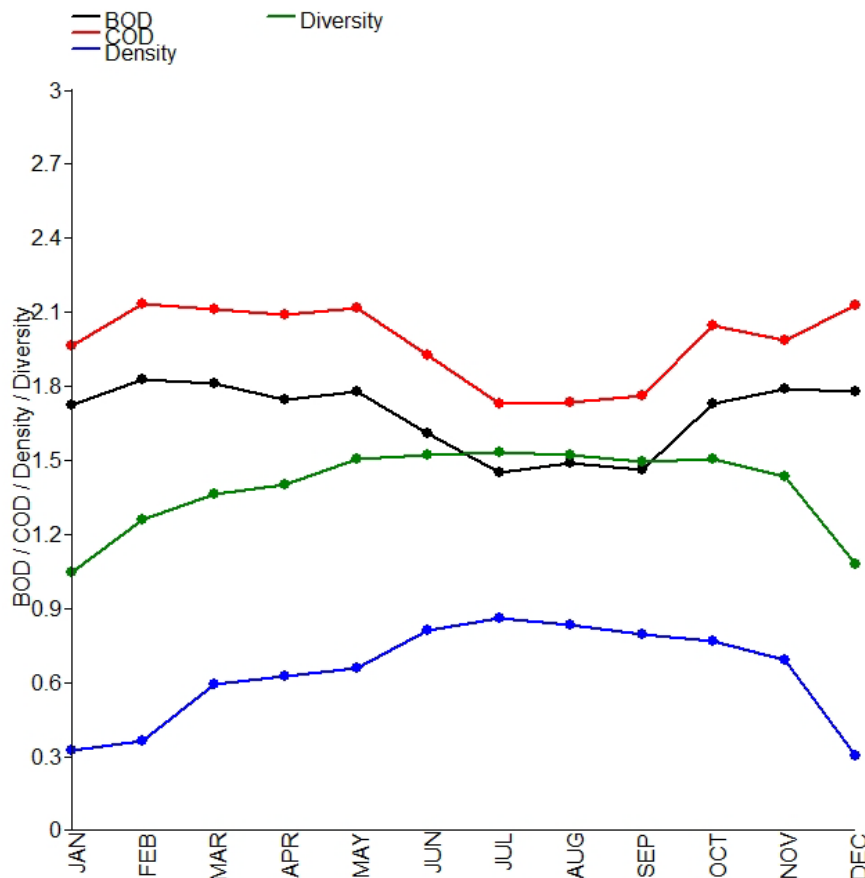


Figure 10. Relationship between BOD, COD and odonate density and diversity recorded during the present study from Durgapur Barrage.

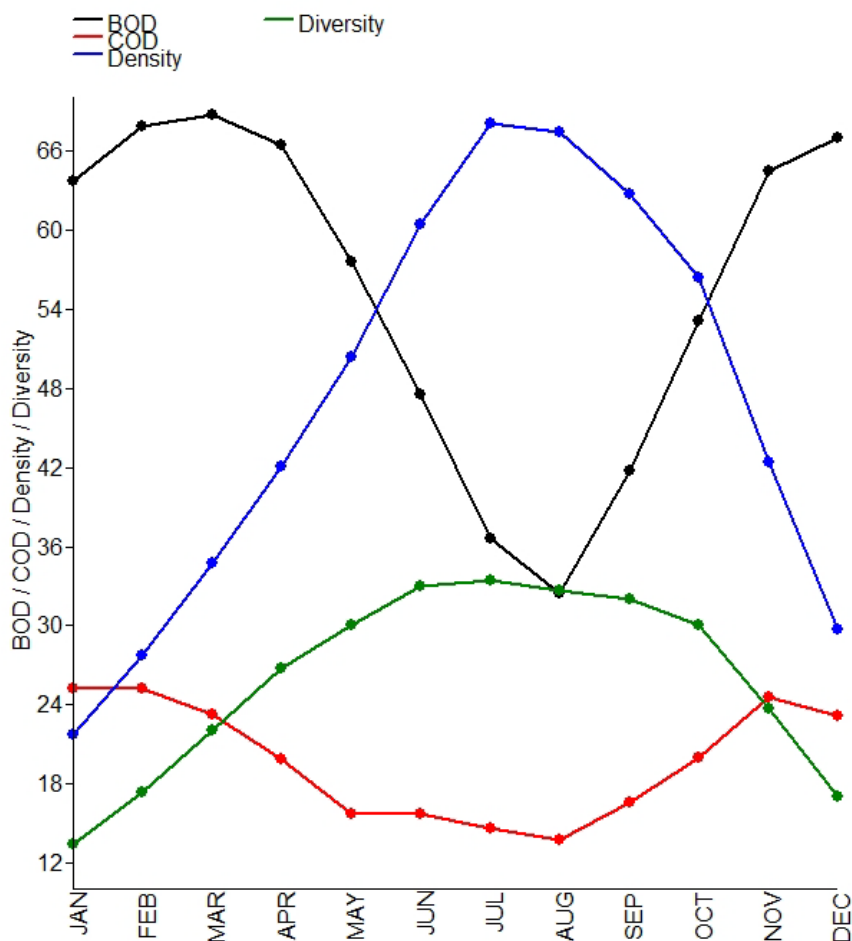


Figure 11. Relationship between BOD, COD and odonate density and diversity recorded during the present study from Ambuja Wetland recorded during the present study from Ambuja Wetland.

4. Conclusions

A higher abundance of *Brachythemis contaminata* in the present study was a clear indication of elevated pollution levels. However, the simultaneous occurrence of 40 other odonate species was noteworthy. Significant evidence was found that physicochemical conditions of the waterbody along with habitat quality influenced the occurrence pattern of odonates from both the study sites. Present findings indicated that the odonate diversity of the Durgapur industrial area constituted a valuable natural resource in ecological, aesthetic, scientific, and educational terms and its conservation and management were critical to the interests of humankind itself. To this, all concerned, conservationists, government, and nongovernmental agencies have a major role to play in creating public awareness and support to protect and conserve the odonate populations.

Acknowledgements

The author thankfully acknowledges the Director of Public Instruction, Government of West Bengal, India,

and Officer-in-Charge, P. R. Thakur Government College, Thakurnagar for their sustained goodwill and all the infrastructural support extended by them. The author is also thankful to the local people around Durgapur Barrage and Ambuja Wetland who cooperated in many ways to complete the fieldwork. This study was supported by University Grants Commission [Minor Research Project, Sanction No. F. No. PSW-013/14-15(ERO), Dated 03.02.2015].

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