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Rapid Assessment of Water Quality of Deepor Beel (Ramsar Site), North East India Using Aquatic Insects

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ABSTRACT

A rapid assessment of water quality of 10 selected sites of Deepor Beel was carried out using aquatic insect community during September 2012 to February 2013. Aquatic insects were collected from the sites in replicates by 'Kick' method. The insect community was represented by 13 families belonging to 5 orders. Physico-chemical parameters of water were analyzed by standard methods. Pearson correlation coefficient analyses revealed that aquatic insect density and family richness were mainly governed by air temperature, water temperature and rainfall. The Stream Invertebrate Grade Number-Average Level (SIGNAL) score, the Biological Monitoring Working Party ($BMWP^{THAI}$) score and the Average Score Per Taxon ($ASPT^{THAI}$) of the sites revealed severe, moderate and probable moderate pollution, respectively. According to Canonical Correspondence Analysis, total alkalinity and pH were the major governing factors. The present investigation confirmed that aquatic insects are very good biological indicator of water quality of a freshwater system.

Key Words: Insect Density; Total Alkalinity; Biological Indicator; $BMWP^{THAI}$ Score; $ASPT^{THAI}$ Score

INTRODUCTION

Wetlands act as important storehouse of aquatic biodiversity (Prasad et al. 2002). They support vertebrate and invertebrate species, improve water quality, reduce flood and storm damage (Yuan and Zhang 2010, Ramsar Convention Secretariat 2013), thus known as "Kidneys of Landscape" and "biological super market" (Allen-Diaz et al. 2004). Since biological integrity of the aquatic ecosystem has become an important component for assessing wetland condition rapid wetland assessment methods have been utilized in wetland assessment and management applications worldwide (Stapanian et al. 2004, Cohen et al. 2005, Fennessy et al. 2007).

Aquatic insects are good indicators in terms of anthropogenic disturbance and habitat quality due to their wide assortment of adaptations and various environmental disturbance tolerant levels (Clarke et al. 2002, Braccia and Voshell 2005, Arimoro and Ikomi 2008, Varandas and Cortes 2010). Since physico-chemical monitoring of a water body is known to be insufficient to fully characterize its status (Mandaville 2002) biological monitoring has been recognized as a vital component of an integrated assessment utilizing both physico-chemical and biological measures as it provides an indication of past as well as current conditions (Hellawell 1986, Resh et al. 1996, Suhaila et al. 2014). In India, only few studies have been carried out on the ecological aspects of aquatic entomofauna of wetlands (Khan and Ghosh 2001, Abhijna et al. 2013, Jaiswal 2013). In northeast India too there are a few studies on the lentic systems (Hazarika and Goswami 2010, Takhelmayum and Gupta 2011 a,b, 2014, 2015, Gupta and Narzary 2013, Saha and Gupta 2015). The Deepor Beel situated on the southern bank of the River Brahmaputra is the only Ramsar site of Assam since 2002 (Figure 1). Previous studies on the aquatic insect community of Deepor Beel (Chetri et al. 1997, Sharma and Sharma 2013, Choudhury and Gupta 2015) did not prospect its water quality using aquatic insects. Against

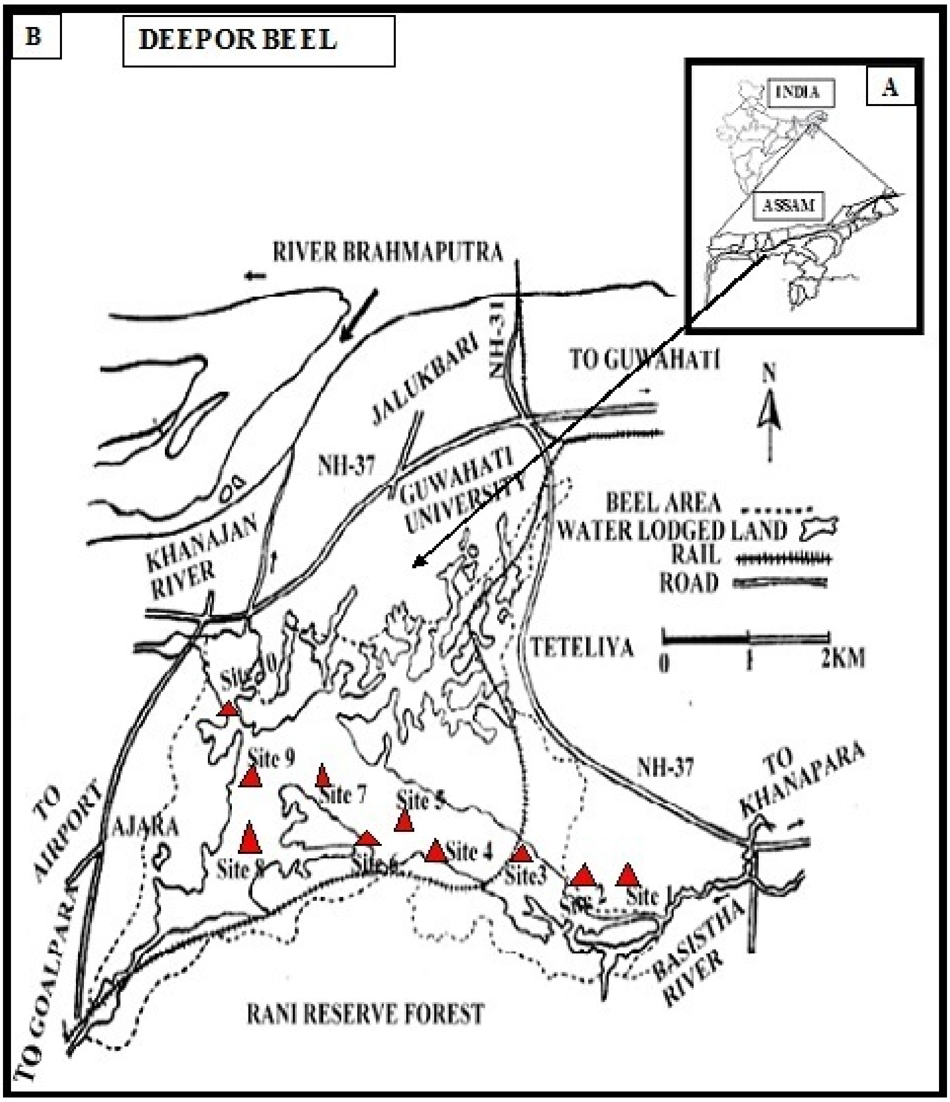

Figure 1. Map showing location of selected sites (1-10) in Deepor Beel (B) in Assam (inset A).

this backdrop, we investigated the density and richness of aquatic insect families and tested the suitability of using aquatic insects for rapid assessment of water quality.

STUDY AREA

The study was carried out during September 2012 to February 2013 at 10 selected sites in Deepor Beel (91° 35' E to 91° 43' E, 26° 0.5' N to 26°11' N). The water filled area of the wetland is 4.1 km^2 (MoEF 2008). It is surrounded by Jalukbari and Dharapur to the north, Dakhin Jalukbari, Tetelia and Pachim Baragoan to the east, Rani, Gorbhanga Reserve Forest, Chakardew Hill and Chilla Hill to the south and two small towns- Azara and Kahikuchi to the west. Deepor Beel is a cradle to a variety of vertebrates and invertebrates species including commercially important fishes and migratory birds. During winter season, the wetland is regularly visited by a large number of migratory birds including globally threatened species like the spotbilled pelican (*Pelicanus philippensis*), lesser and greater adjutant stork (*Leptoptilos javanicus* and *Leptoptilos dubius*) and Baer's pochard (*Aythya baeri*) (Bhattacharyya and Kapil 2010) and is included in the list of Important Bird Areas (IBA) by Birdlife International since 2004 (Islam and Rahmani 2004). During winter big herds of endangered Indian elephant (*Elephas maximus indicus*) frequently visit the wetland and its adjoining areas in search of food and water. Fishing is one of the main livelihood occupations of the inhabitants of the wetland.

Among the ten selected sites, Site 1 (26º 6' 45.92" N, 91º 40' 39.78" E) is a low lying area of the wetland, close to MSW dump site of Guwahati city and covered by dense mat of water hyacinth (*Eichhornia crassipes*). Site 2 to Site 10 are inside the main water body of the Beel. Site 2 (26° 6' 45.19" N, 91° 40' 29.70" E) is the closest site of Site 1 while Site 10 is the most distant site from Site 1. Site 3 (26° 6' 49.07" N, 91° 40' 19.32" E) is close to the Northeast Frontier Railway train bridge (Bridge no. 744 - Deusotal-Boragaon] and receives sewage and storm water from the entire Guwahati city through different channels such as Marabharalu and Basistha-Bahini rivers. Site 4 (26° 6' 53.21" N, 91° 39' 51.92" E) is an important fishery point located near a buffalo's khuti (a place where buffaloes are herded together at night), and abound with macrophytes. Site 5 (26° 7.2' 86" N, 91° 39' 21.07" E) and Site 6 (26° 7.9' 01" N, 91° 38' 56.44" E) are close to the watch tower of the Beel near the Rani-Garchuk road where Site 6 is again abound with macrophytes. Site 7 (26° 6' 52.13" N, 91° 38' 29.03" E) is near a land area (about 1.8 ha) inside the wetland, known as Litimabori. Site 8 (26° 6' 34.10" N, 91° 38' 2.53" E), Site 9 (26° 7.2' 32" N, 91° 38' 0.61" E) and Site 10 (26° 7' 26.63" N, 91° 38' 0.85" E) are important fishing points. Site 10 is close to a rivulet Khanajan.

METHODS

Aquatic Insect Sampling

Aquatic insects were collected from the selected sites in replicates by 'Kick' method using a net of mesh size 500 µm whereby the vegetation was disturbed and the net was dragged around the vegetation for a unit of time (Macan and Maudsley 1968, Brittain 1974). Three such drags constituted a sample (Subramanian and Sivaramakrishnan 2007). Organisms were sorted, counted, preserved in 70% ethyl alcohol and then identified up to family level using Motic Stereoscopic Zoom trinocular microscope (SMZ-168TL) with the help of standard keys (Kimmins 1950, Kumar 1973, Bal and Basu 2004, Bouchard 2004, Nieser and Chen 2005, Epler 2010, Nesemann et al. 2011, Polhemus and Polhemus 2013).

Environmental Variables

Water samples were collected from all the sites in replicates for analysis by standard methods. The air temperature (AT) and water temperature (WT) were measured using mercury bulb thermometer. The pH was measured by pH meter (Digital pH Meter MK VI). Electrical conductivity (EC) and total dissolved solids (TDS) were measured using Conductivity/TDS meter (microprocessor based conductivity / TDS meter model-1601). Transparency (TRAN) was measured by Secchi disc. Total alkalinity (TA) was determined titrimetrically against 0.02N HCI using phenolphthalein and methyl orange as an indicator (APHA 2005). Free-carbon-dioxide (F-CO_2) was titrated against 0.025N NaOH with phenolphthalein indicator (APHA 2005). Dissolved oxygen (DO) of the water samples was estimated by Winkler method (APHA 2005). Rainfall (RF) data were collected from Regional Meteorological Centre, Lokpriya Gopinath Bordoloi International (LGBI) Airport, Guwahati.

Data Analyses

Three biological monitoring scores namely, SIGNAL (Stream Invertebrate Grade Number-Average Level) (Chessman 2003), $BMWP^{THAI}$ (Biological Monitoring Working Party) and $ASPT^{THAI}$ (Average Score Per Taxon) (Mustow 2002) were used to assess the water quality of Deepor Beel. Pearson Correlation Coefficients (2-tailed) analysis was used to measure the associations among different environmental variables, insect density (ID) and family richness (FR). One-Way Analysis of Variance (One-Way ANOVA, *F*-tests) was used to determine the significance of variations among the study sites, aquatic insect family diversity and environmental variables of water of the wetland using Statistical Program for Social Sciences (SPSS version 20.0).

Canonical Correspondence Analysis (CCA) was applied to evaluate the relationships among the environmental variables (water variables) and aquatic insect families in different sites by package CANOCO 4.5 for windows (Ter Braak 1988) where the family diversity data were logarithmic-transformed (log_{10}) so as to down-weight large numbers.

A similarity index, Bray-Curtis cluster analysis (Single link), based on the density of aquatic insects of different families recorded in various study sites, was computed using Biodiversity Professional Version 2 for Windows 1997 (The Natural History Museum and Scottish Association for Marine Science).

RESULTS AND DISCUSSION

Diversity, Density and Biotic Indices

During the study we recorded 5 orders (Hemiptera, Diptera, Coleoptera, Odonata, Ephemeroptera) and 13 families of aquatic insects from different sites of Deepor Beel. Diptera, Ephemeroptera, Hemiptera were recorded from all the study sites. Hemiptera, with 7 out of 13 families recorded, was the largest order in terms of aquatic insect diversity during the study period (Table 1). In addition, the Hemiptera has the highest proportion (56%) followed by that of order Ephemeroptera (21%; Figure 2). The order Hemiptera is a very large and diverse order found all over the world with 80,000 described species in 37 families (Forero 2006). In India, aquatic Hemiptera is represented by 15 major families, 78 genera and about 269 species (Thirumalai 1999). Several previous studies in northeast India also have documented Hemiptera as the most diverse order in different types of freshwater systems (Gupta and Narzary 2013, Takhelmayum et al. 2013, Barman and Gupta 2015). Among all the families, Corixidae had the highest share (34%), followed by family Baetidae (21%) (Figure 3). The families recorded at all the ten sites were Corixidae, Baetidae and Chironomidae where Corixidae had highest relative abundance at all the sites except Site 1 (Figure 4). The family Corixidae has an amazing ability to survive in polluted waters and the members of this family are used as indicators of water quality (Jansson 1977, Wollmann 2000). In the present investigation, the highest number of families (12) was recorded at Site 1 and lowest (6 families) at Site 5(Table 1).

Biotic index systems give numerical scores to specific "indicator" organisms at a particular taxonomic level (Armitage et al. 1983). Changes in their presence/absence, numbers, morphology, physiology or behavior can indicate their preferred environment (Rosenberg and Resh 1993). The tolerance values based on BMWP^{THAI} (Mustow 2002) of all the 13 families recorded from the studied sites in Deepor Beel ranged from 2 to 6. Presence of such tolerant and semi-tolerant insect families indicated that the water quality of the selected sites of Deepor Beel is poor as Hynes (1998) opined that occurrence of numerous families of highly tolerant organisms indicates poor water quality.

Table 1. Distribution of different families of aquatic insects in different sites of Deepor Beel, *F*-ratio (One Way ANOVA) showing variation among the sites on the basis of aquatic insect family diversity and tolerance values as per BMWP^{THAI} of insect families. + = present, - = absent, * p <0.05

Order/Family	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	*F*-ratio	Tolerance value BMWP ^{THAI}
Hemiptera												
Corixidae	+	+	+	+	+	+	+	+	+	+	0.747	5
Nepidae	+	+	-	+	-	-	+	+	+	+	3.052*	5
Mesoveliidae	+	+	+	+	+	+	+	+	+	+	1.281	5
Gerridae	-	-	+	+	+	+	-	-	-	+	0.611	5
Notonectidae	+	+	+	+	-	-	+	-	+	+	0.208	5
Pleidae	+	-	+	-	-	+	-	+	+	+	1.787	5
Belostomatidae	+	+	+	-	-	-	-	+	+	-	1.932	5
Odonata												
Libellulidae	+	+	-	-	-	-	-	+	-	-	0.859	6
Coenagrionidae	+	-	+	+	-	+	+	+	-	-	0.578	6
Coleoptera												
Hydrophilidae	+	-	+	-	-	-	-	-	+	-	1.197	5
Dytiscidae	+	+	-	+	+	+	+	-	+	+	4.041*	5
Ephemeroptera												
Baetidae	+	+	+	+	+	+	+	+	+	+	2.328*	4
Diptera												
Chironomidae	+	+	+	+	+	+	+	+	+	+	2.311*	2

A SIGNAL score developed by Chessman (2003) gives an indication of water quality in the river. It also can be used in wetland studies where scores will be low as various sensitive insect families found in the rivers do not occur in wetlands. Each type of macro-invertebrate has a 'grade number' between 1 to 10. A low grade number means that the organism is tolerant of a range of environmental conditions, including common forms of water pollution (Chessman 2003). In our investigation, the highest (2.88), the lowest (2.44) and the average SIGNAL score (2.64), indicated severely polluted water of Deepor Beel (Gooderham and Tsyrlin 2002). Again $BMWP^{THAI}$ score of all the sites and average score revealed moderate water quality except Site 1 which showed good water quality (Chesters 1980). But $ASPT^{THAI}$ score of all the sites along with the average score depicted probable moderate pollution of water (Mandaville 2002) (Table 2).

Table 2. Spatial variations in $BMWP^{THAI}$ score, $ASPT^{THAI}$ score and SIGNAL2 score of 10 sites of Deepor Beel during the study period

Sites	SIGNAL2 score	Interpretation	$BMWP^{THAI}$ score	Interpretation	$ASPT^{THAI}$ score	Interpretation
Site 1	2.68	SP	58	G	4.83	PM
Site 2	2.83	SP	42	M	4.67	PM
Site 3	2.52	SP	47	M	4.7	PM
Site 4	2.75	SP	42	M	4.67	PM
Site 5	2.88	SP	26	M	4.33	PM
Site 6	2.53	SP	37	M	4.63	PM
Site 7	2.6	SP	37	M	4.63	PM
Site 8	2.61	SP	43	M	4.78	PM
Site 9	2.44	SP	46	M	4.6	PM
Site 10	2.58	SP	41	M	4.56	PM
Average	2.64	SP	41.9	M	4.64	PM

Note: SIGNAL scores are >6= Healthy habitat (HH), 5-6=mild pollution (MD), 4-5= moderate pollution (M), <4= severe pollution (SP) (Gooderham and Tsyrlin 2002); BMWP score and their related quality index are- 0-16= Poor water quality (P); 17-50-Moderate water quality (M); 51-100-Good water quality (G); 101-150-High water quality (H); 151+= Very high water quality (VH) (Chester et al. 1980); and ASPT Score and index of organic pollution are > 6= Clean water (C), 5-6= Doubtful quality (D), 4-5= Probable moderate pollution (PM), < 4=Probable severe pollution (PS) (Mandaville 2002).

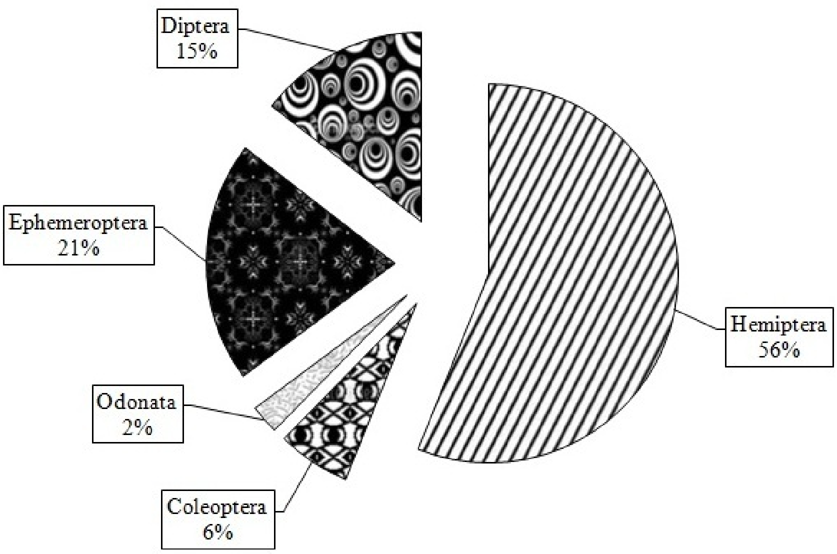

Figure 2. Percent composition of orders of aquatic insects of Deepor Beel during September 2012 to February 2013.

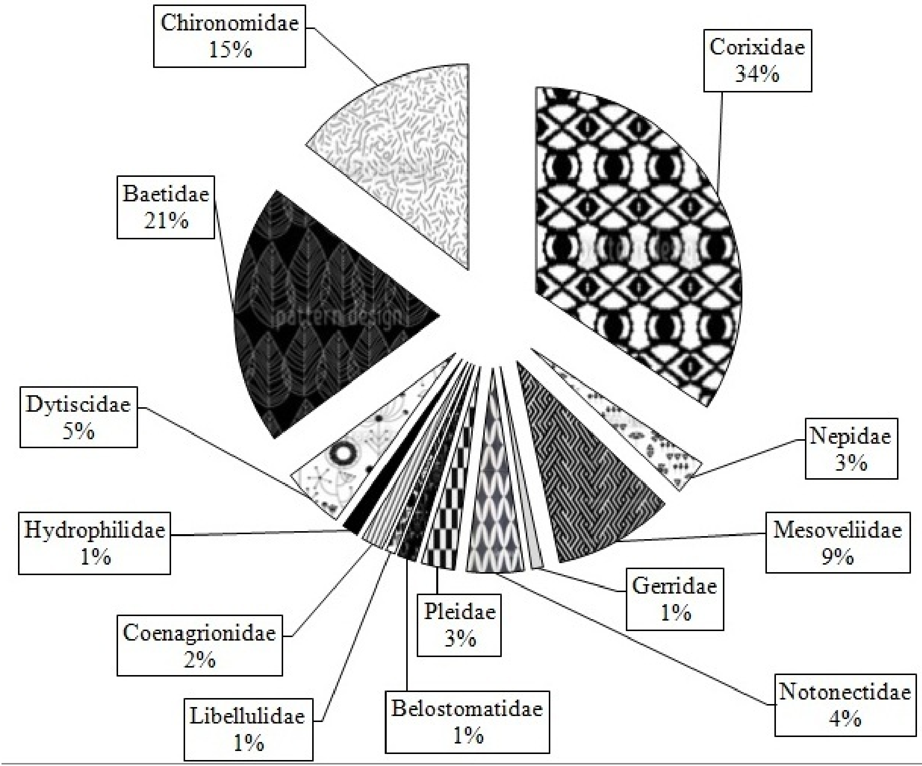

Figure 3. Percent composition of families of aquatic insects of Deepor Beel during September 2012 to February, 2013.

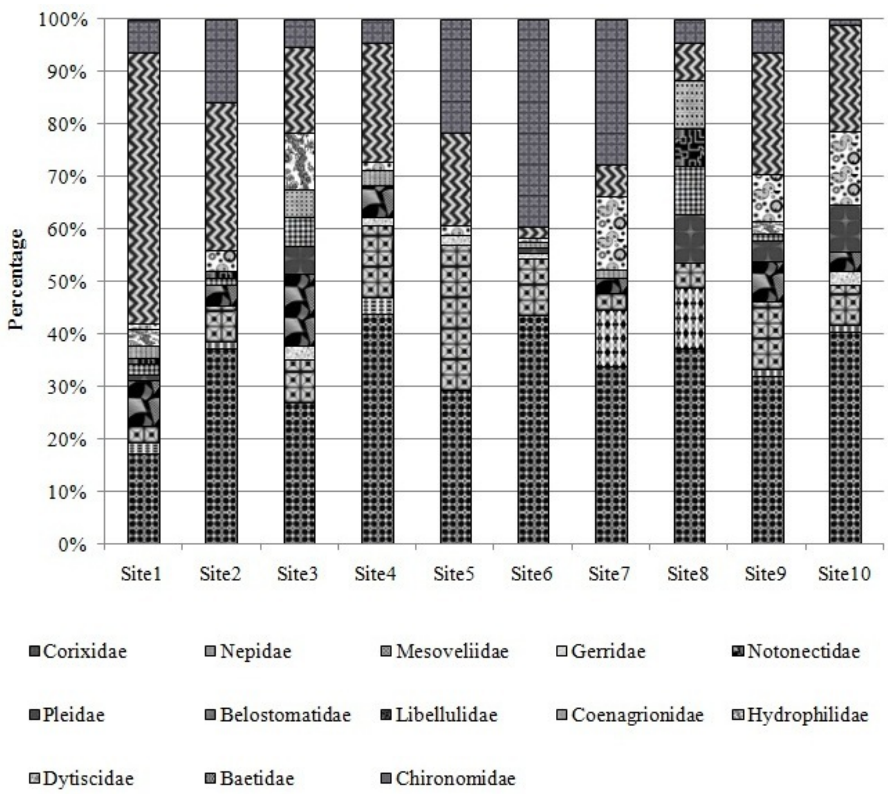

Figure 4. Spatial variations in relative abundance of aquatic insect families in different sites of Deepor Beel during the study period.

Environmental Variables of Water

Table 3 lists mean values (with standard deviation) of environmental variables of water at different sites of the Deepor Beel and *F*-ratio (One-Way ANOVA) showing variations among the different sites on the basis of their values. Table 4 presents the spatial variation in mean aquatic insect density (ID) and family richness (FR) of the ten sites. Table 5 shows highly significant correlations ($p = 0.01$) among different environmental variables, aquatic insect density (ID) and family richness (FR).

AT of Deepor Beel ranged from 21.98 ºC (±3.28) at Site 3 to 27.75 ºC (±2.62) at Site 8. AT showed highly significant positive correlation with WT (r = 0.737, $p<0.01$), TRAN ($r=0.434$, $p<0.01$) and RF ($r=0.488$, $p<0.01$), and highly significant negative correlation with TDS ($r=-0.488$, $p< 0.01$). WT ranged from 16.0^{0}C (±4.54) at Site 3 to 19.5^{0}C (± 2.98) at Site 8. It showed

Table 3. Values of environmental variables of water in different sites of Deepor Beel and *F*-ratio (One-Way ANOVA) showing variations among the different sites on the basis of their values

Environmental variables	Study sites										
	1	2	3	4	5	6	7	8	9	10	*F*-ratio
AT (^{0}C)	23.75±4.30	23.66±3.15	21.98±3.28	22.91±3.94	23.25±1.21	25.43±5.13	26.83±5.93	27.75±2.62	27.5±3.93	24±1.48	1.723
WT (^{0}C)	17.5±3.96	16.5±3.96	16.0±4.54	16.08±3.29	19.5±1.87	17.0±2.68	18.5±2.07	19.5±2.98	18.5±3.99	18.4±3.3	1.069
pH	6.82±0.08	7.02±0.42	6.5±0.76	6.63±0.55	6.16±0.54	6.25±0.26	6.57±0.33	6.59±0.09	6.71±0.24	6.4±0.6	2.251*
EC (µS cm^{-1})	231.5±30.1	249.2±18.5	240.2±33.3	273.7±26.1	352.8±57.6	359.3±49.4	255.7±38.7	279.5±70.5	289.3±25.2	235.5±45.3	7.083*
TRAN (cm)	13.87±5.77	15.84±5.50	17.57±1.88	22.03±4.43	22.88±4.35	48.33±3.98	35.0±4.94	31.70±6.33	33.11±6.31	58.41±2.63	48.753*
TDS (mg L^{-1})	149.2±15.8	161.4±21.3	156.1±21.5	184.1±23.5	224.4±38.4	173.8±43.4	207.1±48.7	160.0±33.8	191.7±15.4	149.5±25.4	4.164*
TA (mg L^{-1})	102.4±23.0	122.8±14.3	130.6±7.4	124.8±5.2	132.5±5.3	126.9±6.5	136.0±9.1	125.3±16.6	117.3±18.2	111.0±10.9	3.359*
DO (mg L^{-1})	4.82±0.07	4.25±0.52	5.7±3.05	7.26±2.42	9.71±1.26	4.37±0.64	6.26±2.47	7.91±0.87	7.55±0.61	5.5±1.59	6.767*
F-CO_2 (mg L^{-1})	14.12±1.08	9.28±1.28	10.81±0.79	9.76±1.28	8.63±2.13	11.62±1.47	11.70±0.89	6.37±1.03	7.10±1.00	14.84±1.05	29.198*
RF (mm)	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	42.1±60.80	0.003

Note: Values are mean of three replicates ± Standard deviation; * p <0.05

Table 4. Spatial variation in mean aquatic insect density (ID; No. of individuals per unit time) and family richness (FR; No. of families per sample) of 10 sites of Deepor Beel during the study period

Site	ID	FR
Site 1	5.17	4.5
Site 2	4.17	3.83
Site 3	2.06	4.0
Site 4	3.67	3.67
Site 5	2.83	3.17
Site 6	5.61	2.83
Site 7	3.61	4.0
Site 8	2.39	3.5
Site 9	4.33	5.33
Site 10	4.39	4.33

Table 5. Highly significant correlations ($p = 0.01$ level) among the different environmental variables, aquatic insect density (ID) and family richness (FR) in Deepor Beel

Variables	*r* value	Variables	*r* value
AT vs. WT	0.737**	WT vs. FR	0.463**
AT vs. TRAN	0.434**	EC vs. DO	0.316**
AT vs.TDS	-0.488**	EC vs. TDS	0.511**
AT vs. RF	0.488**	TDS vs. TA	0.469**
AT vs. ID	0.558**	TDS vs. DO	0.520**
AT vs. FR	0.358**	TDS vs. F-CO_2	-0.331**
WT vs. TRAN	0.389**	DO vs. F-CO_2	-0.405**
WT vs. RF	0.512**	RF vs. ID	0.521**
WT vs. ID	0.550**	RF vs. FR	0.397**

Note: ** Correlation is significant at the 0.01 level (2-tailed) highly significant positive correlation with TRAN (r= 0.389, p<0.01) and RF (r=0.512, p<0.01). The difference in water temperature may depend on season, climate, sunlight and depth (Akinyemi and Nwankwo 2006). The range of pH [6.16 (±0.54) at Site 5 to 7.02 (±0.42) at Site 2] was found within the desirable limits set for drinking water (WHO 2011, BIS 2012) and also within the acceptable limit for survival of aquatic organisms in freshwater, 6.5-9 (EPA 2016). TRAN of all the study sites varied from 13.87 cm (±5.77) at Site 1 to 58.41 cm (±2.63) at Site 10. The Site 1 is the shallowest site with mud and decomposed macrophytes. Similar observation was found in Vanthakad Backwater in Kerala by Meera and Nandan (2010). EC is a function of total dissolved solids which determines the quality of water (Tariq et al. 2006). EC of all the study sites ranged from 231.50 µS cm^{-1} (±30.11) at Site 1 to 359.33 µS cm^{-1} (±49.43) at Site 6 which showed highly significant positive correlation with TDS (r=0.511, p<0.01) and DO (r=0.316, p<0.01). These EC values could be due to MSW leachate input from dump site as well as various types of human activities such as agricultural runoff, raising of livestock and discharge of urban wastewater. Highly significant positive correlation of EC with TDS is in agreement with the report of Vincy et al. (2012). TDS of all the sampling sites varied from 149.23 mg L^{-1} (±15.84) at Site 1 to 224.40 mg L^{-1} (±38.35) at Site 5 and were within the desired limit for TDS (BIS 2012). It showed highly significant positive correlation with DO (r=0.520, p<0.01) and highly significant negative correlation with F-CO_2 (r=0.331, p<0.01). TA values of all the study sites were within the desirable limit for drinking water (BIS 2012) varying from 102.37 mg L^{-1} (±23.01) at Site 1 to 136.0 mg L^{-1} (±9.10) at Site 7. F-CO_2 values varied from 6.37 mg L^{-1} (±1.03) at Site 8 to 14.84 mg L^{-1} (±1.05) at Site 10. High rate of dissolved CO_2 is detrimental to survival, physiological and metabolic activities of aquatic animals including fish (Lawson 2011). DO values ranged from 4.25 mg L^{-1} (±0.52) at Site 2 to 9.71 mg L^{-1} (±1.26) at Site 5. Apart from Site 2, Site 1 and Site 6 also had less than 5 mg L^{-1} DO which is prescribed for survival of aquatic life (USEPA 2000). There are also reports of fast decline in the fish population of the wetland. DO showed highly significant negative correlation with F-CO_2 (r=0.405, p<0.01). This classical inverse relationship indicated that photosynthesis is the primary source of DO in the system (Wetzel 1983). Both insect density (ID) and family richness (FR) showed highly significant positive correlation with AT (r= 0.558, p<0.01 for ID and r= 0.358, p<0.01 for FR), WT (r=0.550, p<0.01 for ID and r=0.463, p<0.01 for FR) and RF (r=0.521, p<0.01 for ID and r=0.397, p<0.01 for FR). The significant positive correlation between ID and RF might be related to seasonal fluctuation in water level and availability of food resources. This agreed with the findings of Takhelmayum et al. (2013) in a study made on River Moirang, Manipur, Northeast India.

According to One-Way ANOVA based on insect family diversity the families viz., Nepidae (F=3.052, p<0.05), Dytiscidae (F=4.041, p<0.05), Baetidae (F=2.328, p<0.05) and Chironomidae (F=2.328, p<0.05) showed significant spatial variation (Table 1). The same analysis based on the environmental variables found pH (F=2.251, p<0.05), EC (F=7.083, p<0.05), TDS (F=4.164, p<0.05), TRAN (F=48.753, p<0.05), TA (F=3.359, p<0.05), DO (F=6.767, p<0.05) and F-CO_2 (F=29.198, p<0.05) to have significant spatial variation (Table 3).

Canonical Correspondence Analysis (CCA)

Ordination techniques provide useful tools to assess changes in biological communities. CCA compares variation in community composition by constraining ordination axis to be linear combination of environmental variables (Pires et al. 2000). If the appropriate form of scaling is used, the length of an arrow indicates the importance of the environmental variable, the direction indicates how well the environment is correlated with the various species composition axes, the angle between arrows indicates correlations between variables, the location of site scores relative to arrows indicates the environmental characteristics of the sites, and the location of species scores relative to the arrows indicates the environmental preferences of each species (Ter Braak 1990). Eigenvalues associated with each axis equal the correlation coefficient between species scores and site scores (Gauch 1982, Pielou 1984). An eigen value close to 1 will represent a high degree of correspondence between species and sites, and an eigenvalue close to zero will indicate very little correspondence. In the present investigation, the total eigen value (0.481) indicated a moderate degree of correspondence between aquatic insects families and the study sites. The first two axes (eigenvalues: 0.165 and 0.111 respectively) accounted together for 57.4% of the data variance (Table 6). The CCA ordination diagram clearly separated the aquatic insect community on the basis of the sites. Some of the semi-tolerant families like Baetidae, Notonectidae, Hydrophilidae were associated

Table 6. Eigen values and cumulative variation (%) of species-environmental data for the first four axes of CCA performed among aquatic insects and environmental variables for the 10 selected sites.

CCA axes	Eigen values	Cumulative Variance
1	0.165	34.3
2	0.111	57.4
3	0.081	74.3
4	0.072	89.4
Total inertia	0.481	

with Site 1 and Site 9 and were positively correlated with pH. The family Coenagrionidae associated with Site 8 showed positive response to AT. Again, another family Dytiscidae associated with Site 3, Site 7 and Site 6 showed positive response to EC and TDS. The semi-tolerant family Corixidae and the only tolerant family Chironomidae associated with Site 3, Site 6 and Site 7 showed positive relationship with TA and TRAN. The families Mesoveliidae, and Gerridae were associated with Site 2, Site 4, Site 5 and Site 10, and responded positively to F-CO_2. Another family Pleidae associated with Site 1 and Site 9, placed very close to axis 1 showed that it is influenced equally by AT, WT and pH (Figure 5).

The Bray-Curtis cluster analysis based on the density of aquatic insects of different families at various sites (single link) (Figure 6) revealed that although the aquatic insect communities of Site 4 and Site 9 had the highest (80.55%) similarity, Site 2, 4, 9 and 10 were very closely related.

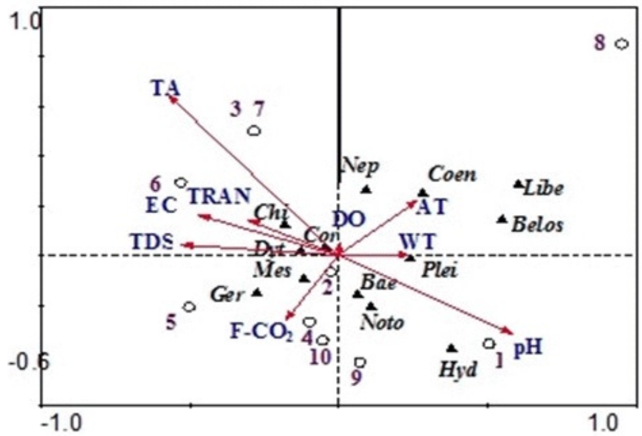

Figure 5. Triplot of Canonical correspondence analysis (CCA) ordination diagram showing the association of 13 families (▲) of aquatic insects and environmental variables (→) of selected sites (o) of Deepor Beel . The environmental variables are: TA= Total Alkalinity, TDS = Total Dissolved Solid, TRAN = Transparency, DO = Dissolved Oxygen, WT = Water Temperature, AT = Air Temperature, EC = Electrical Conducivity, F-CO_2 = Free Carbon-dioxide. The aquatic insects families are: Nepidae = Nep, Coenagrionidae = Coen, Libellulidae = Libe, Belostomatidae = Belos, Pleidae = Plei, Baetidae = Bae, Notonectidae = Noto, Hydrophilidae = Hyd, Mesoveliidae = Mes, Gerridae = Ger, Dytiscidae = Dyt, Chironomidae = Chi, Corixidae = Cor.

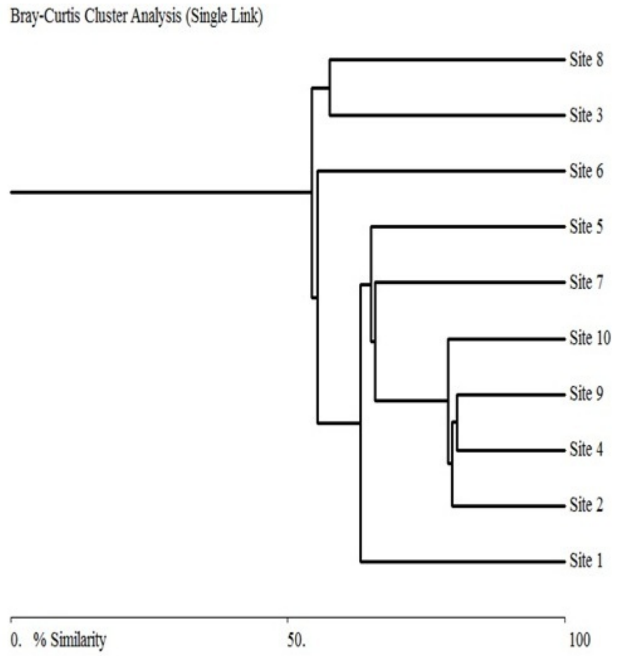

Figure 6. Dendrogram showing Bray- Curtis cluster analysis based on density of aquatic insects of different families in different study sites of Deepor Beel.

CONCLUSIONS

Rapid assessment of water quality of Deepor Beel using aquatic insects was performed successfully. Different biomonitoring scores and diversity indices revealed that water of Deepor Beel is moderately polluted. This study further confirmed that aquatic insect families which can be identified easily have the potential of becoming very useful bioindicators. It can be concluded that there should be adequate conservation and management measures for this pristine gift of nature.

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