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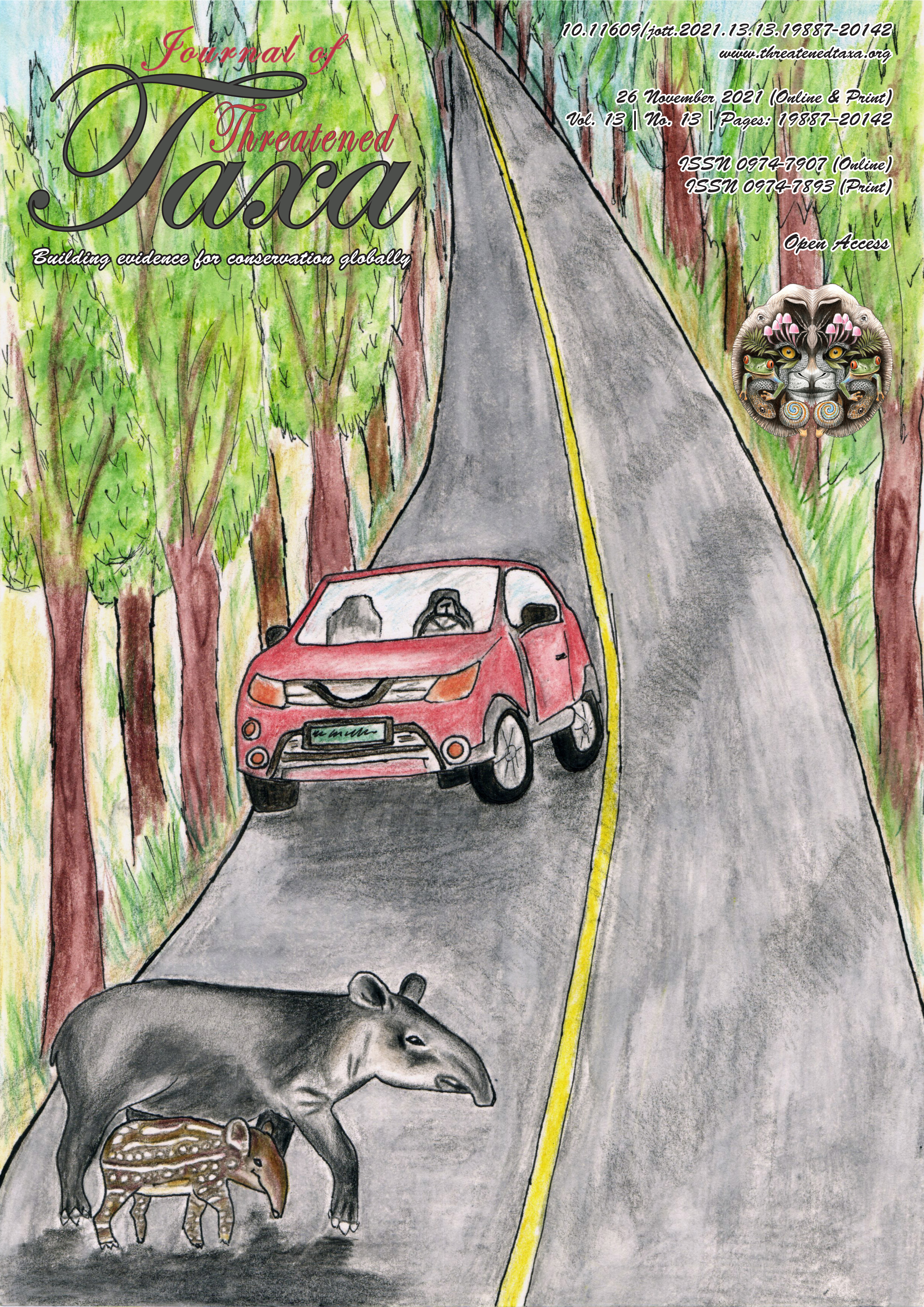

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continued on the back inside cover

Caption: Lowland Tapir *Tapirus terrestris* (Medium—watercolours on watercolour paper) © Aakanksha Komanduri.

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COMMUNICATION

Diversity of aquatic insects and biomonitoring of water quality in the upper Ganga River, a Ramsar site: a preliminary assessment

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Abstract: Monitoring of freshwater habitats through aquatic insects is widely used. A study was carried out in March, 2019 at 14 sites in the Upper Ganga River between Brijghat and Narora, a riverine Ramsar site in India, to document the diversity of three major aquatic predatory insect groups—Odonata, Coleoptera, and Hemiptera—and determine their biomonitoring potential. The study recorded three species of Coleoptera, four Hemiptera, 14 dragonflies, and eight damselflies. The Shannon diversity index (H') ranged from 2.465 to 2.782, Pielou's Evenness index (J') from 0.841 to 0.894, and Berger–Parker index of dominance (d) from 0.122 to 0.243. Families Libellulidae (Odonata), Coenagrionidae (Odonata) and Gerridae (Hemiptera) had high relative abundance and dominant status. The stream invertebrate grade number-average level (SIGNAL2) score (for family) ranged from 2.316 to 3.174, lying within quadrant 2 of the SIGNAL2 (family) quadrant diagram. This suggested that the water in the area is likely to have high levels of turbidity, salinity, or nutrients, caused naturally or by anthropogenic activities, and the water has low levels of most toxic chemicals.

Keywords: Coleoptera, Hemiptera, Odonata, SIGNAL2 (family) score.

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Author contributions: KD—conceptualization, field work, formal analysis, writing original draft; AS—field work, writing original draft; KS—field work, writing original draft; VPU—supervision, review and editing the draft; JAJ—supervision, review and editing the draft; SAH—supervision, review and editing the draft, funding acquisition.

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NAMAMI GANGE

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INTRODUCTION

Freshwater habitats occupy 1% of the earth's surface (Strayer & Dudgeon 2010), and in addition to supporting many species freshwater ecosystems provide goods and services of critical importance to human societies. Nevertheless, they are among the most heavily altered ecosystems, with proportional loss of biodiversity (Geist 2011), owing to human activities that have led to widespread habitat degradation, pollution, flow regulation, water extraction, fisheries overexploitation, and alien species introductions (Strayer & Dudgeon 2010). Alterations of natural flow regimes by manmade dams, land use changes, river impoundments and water abstraction often have profound impacts on lotic communities (Geist 2011). Aquatic insects are an indispensable part of food webs and of nutrient cycling in freshwater ecosystems, and they are essential components of the diets of fish, amphibians and many birds and mammals (Morse 2017). Their abundance and responses to changes in their environment make aquatic insects key indicators for monitoring the effects of human activity on water quality (Adu & Oyeniyi 2019), and they widely used for freshwater ecosystem monitoring (Souto et al. 2019).

In India, 42 wetlands of international importance (i.e., Ramsar sites) cover 1,081,438 ha according to the Ramsar Sites Information Service (https://rsis.ramsar.org/sites/default /files/rsiswp_search/exports/Ramsar-Sites-annotated-summary-India.pdf?1625598230). Among these wetlands, information on aquatic insect communities and their utility is scant. There are a few studies available on aquatic insect communities of Indian Ramsar sites such as eastern Kolkata wetlands in West Bengal (Sahaet al. 2007), Pong Dam in Himachal Pradesh (Babu et al. 2009), Loktak Lake in Manipur (Takhelmayum & Gupta 2011, 2015), Deepor beel in Assam (Sharma & Sharma 2013; Choudhury & Gupta 2017), and Nalsarovar Bird Sanctuary in Gujarat (Rathod & Parasharya 2018).

The use of insects as bioindicators is a low-cost strategy for preliminary assessments of the water quality of inland freshwater bodies, as it avoids the use of expensive analytical methods (Pal et al. 2012). The top predators among insects in aquatic ecosystems include aquatic Coleoptera, Hemiptera, and Odonata (Klecka & Boukal 2012). This study assessed diversity of these groups in the upper Ganga River, a Ramsar site; the goal of using them as indicators of water quality.

MATERIALS AND METHODS

The study was conducted in an 85-km stretch of the river Ganga from Brijghat to Narora in Uttar Pradesh (Figure 1). This section of the river was declared a Ramsar site in 2005 and is generally characterized by shallow water, although some deep water pools are present inhabited by conservative significant species such as Ganges River Dolphin, Gharial, crocodiles, turtles, otters, 82 species of fish and more than a hundred species of birds. The study was carried out during March 2019. The study area was stratified into 14 sampling sites with a distance of ~5 km between two sites and insect sampling was done at each site. At each study site, sampling was done between 0930 h and 1130 h along the left bank (because of accessibility to the river bank) of the main channel of the river Ganga.

To collect odonates, a 100 m × 20 m transect (subdivided into 20 segments of 5 m) (Juen & De Marco 2011) was placed at each sampling site parallel to and ~1 m beside the main river channel. Adult odonates present in each of these segments were captured using insect collection nets (mesh size 60 µm) and released after identification using published pictorial field guides (Andrew et al. 2008; Subramanian 2009; Nair 2011). For Coleoptera and Hemiptera, a circular net (mesh size 60 µm) was dragged in the open water for one minute and continued three times per site (Subramanian & Sivaramakrishnan 2007). All samples were preserved in 70% ethanol and brought to the laboratory for further analysis. They were later identified at species level using a stereo zoom microscope with the help of taxonomic literature (Bal & Basu 1994a,b; Biswas & Mukhopdhyay 1995; Biswas et al. 1995; Chandra & Jehamalar 2012).

The aquatic insect data were subjected to Shannon diversity index (H'), Pielou's evenness index (J'), and Berger–Parker index of dominance (d) index analysis. The dominant status of the insects was calculated according to Engelmann's scale (1978) in which if relative abundance of a species is up to 1%, it is considered as subrecedent; if between 1.1–3.1%, recedent; if between 3.2–10%, subdominant; if between 10.1–31.6 %, dominant, and if 31.7% or more then eudominant.

By evaluating comparative performance of several aquatic health indices, Cox et al. (2019) found that the stream invertebrate grade number-average level (SIGNAL2) is the most sensitive index, family richness percentage is the most robust index, family richness and family richness percentage are the best ranked indices for both measures of usability; but Australian River Assessment System (AUSRIVAS OE50), Ephemeroptera

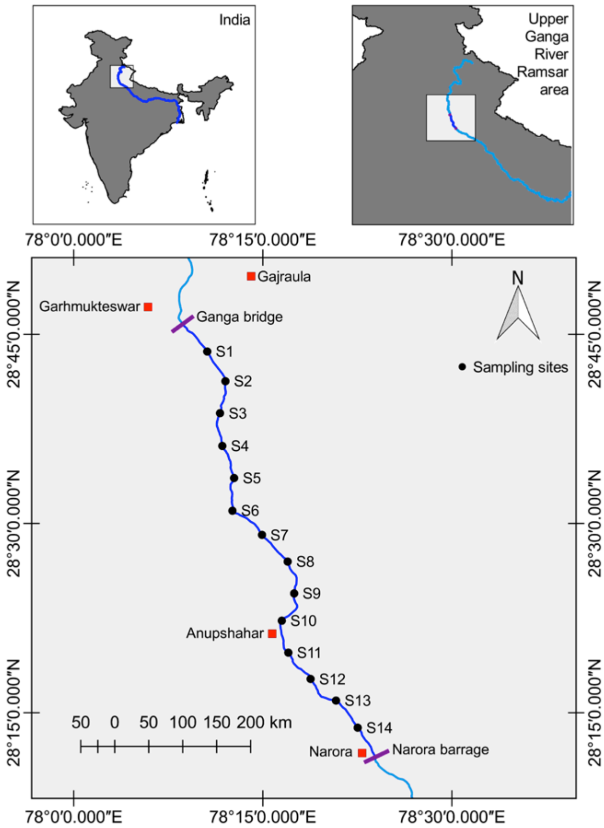

Figure 1. Location of sampling sites (S1–S14) in the Ganga River from Brijghat to Narora, Uttar Pradesh.

Plecoptera & Trichoptera index (EPT), and Bray-Curtis index (BCI) have poor performance to asses river health condition.

In this study, for the assessment of the bioindicator potential of the insects, SIGNAL2 (family) score was used which is a family-level water pollution index based on the known tolerances of aquatic macro-invertebrate families to various pollutants which has a gradient from 1 to 10 (ranging from a pollution tolerant to a pollution sensitive community) (Chessman et al. 1995). The SIGNAL2 (family) scores were plotted in a quadrant diagram (SIGNAL2 score in the y axis and the numbers of families in the x axis) which includes four quadrants. The first quadrant indicates favourable habitat and chemically dilute waters, the second quadrant indicates high salinity or nutrient levels (may be natural), the third quadrant indicates toxic pollution or harsh physical conditions and the fourth quadrant indicates urban, industrial or agricultural pollution, or downstream effects of dams (Chessman et al. 1995).

All the analyses were performed in the software Past 3 (Hammer et al. 2001) and R 3.5.3 (R Core Team 2019).

RESULTS

A total of 29 species of aquatic insects were recorded (Table 1), including three species of Coleoptera belonging to two families, four species of Hemiptera belonging to four families, and 22 species of Odonata belonging to three families. Among the odonates, 14 were dragonflies (Suborder Anisoptera) and eight were damselflies (Suborder Zygoptera). Nine species were recorded from all 14 sampling sites: *Gerriss pinolae* Lethierry & Severin, 1896; *Anisops campbelli* Brooks, 1951; *Brachythemis contaminata* Fabricius, 1793; *Diplacodes trivialis* Rambur, 1842; *Orthetrum sabina* Drury, 1770; *Trithemis aurora* Burmeister, 1839; *Ceriagrion coromandelianum* Fabricius, 1798; *Pseudagrion decorum* Rambur, 1842, and *Pseudagrion rubriceps* Selys, 1876.

The Shannon diversity index (H') ranged from 2.465 (at S8) to 2.782 (at S14) (mean= 2.579, SD= 0.086); Pielou's evenness index (J') was maximum at S7 (J'= 0.894), and Berger-Parker index of dominance (d) ranged from 0.122 (S7) to 0.243 (S11) (mean= 0.170, SD= 0.037). Variation of Shannon diversity index (H'), Pielou's evenness index (J'), and Berger-Parker index of dominance (d) are given in Figure 2.

For families, Gerridae (Hemiptera) was dominant in >92 % of sampling sites, and Notonectidae (Hemiptera) in >28 % of sites. Libellulidae (Odonata) was eudominant in >64 % of sampling sites and dominant in >35 % of sites, while Coenagrionidae (Odonata) was eudominant in >71 % of the sampling sites, and dominant in >28 % of sites. Dominance status in different sites is given in Table 2.

The family richness and the family richness percentage varies from 7 to 9 and 77.77 to 100 %, respectively. Highest family richness and family richness percentage was found at S10.

The SIGNAL2 (family) score ranges between 2.316 (S6) and 3.174 (S11) (mean= 2.579, SD= 0.086). The family richness, family richness percentage and SIGNAL2 (family) score showed an increasing trend in values from S1 to S14 (Figure 3).

The SIGNAL 2 quadrant diagram plots SIGNAL 2 scores (on y axis) against numbers of aquatic invertebrate families (on x axis). Each diagram has four quadrants which represent different status of water and habitat qualities (Chessman 2003). In the present study, the SIGNAL2 (family) score ranged from 2.316 to 3.174 (Figure 3) and fell within the quadrant 2 (Figure 4).

Table 1. List of Coleoptera, Hemiptera, and Odonata recorded from across the study area in different sites of Upper Ganga Ramsar site (+ represents presence and - represent absence).

Species	Sampling sites													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Order: Coleoptera														
Family: Dytiscidae (Predaceous Diving Beetle)														
1. *Cybister limbatus* (Fabricius, 1775)	+	-	-	-	+	+	+	+	-	+	+	+	+	-
2. *Eretes sticticus* (Linnaeus, 1767)	-	+	-	-	+	-	+	-	+	+	+	+	-	-
Family: Hydrophilidae (Water Scavenger Beetle)														
1. *Hydrophilus senegalensis* (Percheron 1835)	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Order: Hemiptera														
Family: Belostomatidae (Water Bug)														
1. *Diplonychus rusticus* (Fabricius, 1781)	-	+	+	+	-	+	-	+	-	+	+	+	-	-
Family: Gerridae (Water Striders)														
1. *Gerris spinolae* Lethierry & Severin, 1896	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Family: Nepidae (Water Scorpion)														
1. *Ranatra elongate* Fabricius, 1790	+	-	+	+	+	+	+	-	+	+	+	-	+	+
Family: Notonectidae (Backswimmers)														
1. *Anisops campbelli* Brooks, 1951	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Order: Odonata														
Suborder: Anisoptera (Dragonflies)														
Family: Gomphidae														
1. *Platygomphus dolabratus* Selys, 1854	-	-	-	-	-	-	-	-	-	-	+	-	-	+
2. *Ictinogomphus rapax* Rambur, 1842 (Indian Common Clubtail)	-	-	-	-	-	-	-	-	-	+	+	+	+	+
Family: Libellulidae Leach, 1815														
1. *Acisoma panorpoides* Rambur, 1842 (Trumpet Tail)	+	+	+	-	+	+	+	+	+	-	+	+	+	+
2. *Brachydiplax sobrina* Rambur, 1842 (Little Blue Marsh Hawk)	-	-	-	-	-	-	-	-	-	-	-	+	-	-
3. *Brachythemis contaminate* Fabricius, 1793 (Ditch Jewel)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4. *Crocothemis servilia* Drury, 1770 (Ruddy Marsh Skimmer)	+	-	-	+	+	+	+	+	+	+	+	-	+	+
5. *Diplacodes trivialis* Rambur, 1842 (Blue Ground Skimmer)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6. *Neurothemis tullia* (Drury, 1773) (Pied Paddy Skimmer)	-	-	-	-	-	-	-	-	-	-	-	-	-	+
7. *Orthetrum sabina* Drury, 1770 (Green Marsh Hawk)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8. *Pantala flavescens* Fabricius, 1798 (Wandering Glider)	+	-	+	+	+	+	+	-	+	+	-	-	-	+
9. *Rhyothemis variegate* Linnaeus, 1763 (Common Picturewing)	-	-	-	-	+	-	-	-	+	-	-	+	+	+
10. *Tramea basilaris* Palisot de Beauvois, 1805 (Red Marsh Trotter)	-	+	+	+	+	-	-	+	-	-	+	-	+	+
11. *Trithemis aurora* Burmeister, 1839 (Crimson Marsh Glider)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
12. *Urothemis signata* Rambur, 1842 (Greater Crimson Glider)	-	+	-	+	+	+	+	+	+	-	-	-	+	+
Suborder: Zygoptera (Damselflies)														
Family: Coenagrionidae														
1. *Agriocnemis lacteola*Selys, 1877 (Milky Dartlet)	+	+	-	-	+	+	+	+	+	+	+	+	+	+
2. *Agriocnemis pygmaea* Rambur, 1842 (Pygmy Dartlet)	+	-	+	-	-	+	-	+	+	+	+	-	-	+
3. *Amphiallagma parvum*Selys, 1876 (Azure Dartlet)	+	+	+	+	+	-	+	-	-	-	-	-	+	+
4. *Ceriagrion coromandelianum* Fabricius, 1798 (Coromandel Marsh Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5. *Ischnura nursei* Morton, 1907 (Pixie Dartlet)	-	-	-	+	-	+	-	-	+	+	-	-	-	+
6. *Ischnura rubilio*Selys, 1876 (Western Golden Dartlet)	+	+	+	+	-	+	+	-	+	+	+	+	-	+
7. *Pseudagrion decorum* Rambur, 1842 (Three Lined Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8. *Pseudagrion rubriceps* Selys, 1876 (Saffron Faced Blue Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 2. Relative abundance (RA) and dominance status (DS) of different families of aquatic insects in different sampling sites (S1 to S14) of the upper Ganga River, a Ramsar site according to Engelmann's scale (1978)

		Dytiscidae	Hydrophilidae	Belostomatidae	Gerridae	Nepidae	Notonectidae	Gomphidae	Libellulidae	Coenagrionidae
S1	RA	1.515	1.515		21.212	1.515	9.848		34.091	30.303
	DS	Recedent	Recedent		Dominant	Recedent	Subdominant		Eudominant	Dominant
S2	RA	1.724	1.724	1.724	12.069		0.862		44.828	37.069
	DS	Recedent	Recedent	Recedent	Dominant		Subrecedent		Eudominant	Eudominant
S3	RA		2.069	1.379	18.621	0.69	12.414		30.345	34.483
	DS		Recedent	Recedent	Dominant	Subrecedent	Dominant		Dominant	Eudominant
S4	RA		0.758	1.515	19.697	3.03	9.091		30.303	35.606
	DS		Subrecedent	Recedent	Dominant	Recedent	Subdominant		Dominant	Eudominant
S5	RA	2.564	1.709		16.239	0.855	7.692		45.299	25.641
	DS	Recedent	Recedent		Dominant	Subrecedent	Subdominant		Eudominant	Dominant
S6	RA	0.735	2.206	0.735	15.441	0.735	12.5		33.088	34.559
	DS	Subrecedent	Recedent	Subrecedent	Dominant	Subrecedent	Dominant		Eudominant	Eudominant
S7	RA	3.053	1.527		11.45	2.29	7.634		39.695	34.351
	DS	Recedent	Recedent		Dominant	Recedent	Subdominant		Eudominant	Eudominant
S8	RA	1.923	1.923	0.962	14.423		0.962		40.385	39.423
	DS	Recedent	Recedent	Subrecedent	Dominant		Subrecedent		Eudominant	Eudominant
S9	RA	0.73	1.46		15.328	2.19	12.409		43.066	24.818
	DS	Subrecedent	Recedent			Recedent	Dominant		Eudominant	Dominant
S10	RA	3.008	0.752	0.752	16.541	2.256	10.526	0.752	27.82	37.594
	DS	Recedent	Subrecedent	Subrecedent	Dominant	Recedent	Dominant	Subrecedent	Dominant	Eudominant
S11	RA	1.429		1.429	24.286	1.429	2.857	5	30	33.571
	DS	Recedent		Recedent	Dominant	Recedent	Recedent	Subdominant	Dominant	Eudominant
S12	RA	2.308	1.538	1.538	23.846	0	9.231	1.538	35.385	24.615
	DS	Recedent	Recedent	Recedent	Dominant		Subdominant	Recedent	Eudominant	Dominant
S13	RA	1.835	2.752		14.679	2.752	0.917	0.917	39.45	36.697
	DS	Recedent	Recedent		Dominant	Recedent	Subrecedent	Subrecedent	Eudominant	Eudominant
S14	RA		1.527		13.74	3.053	9.924	3.053	29.771	38.931
	DS		Recedent		Dominant	Recedent	Subdominant	Recedent	Dominant	Eudominant

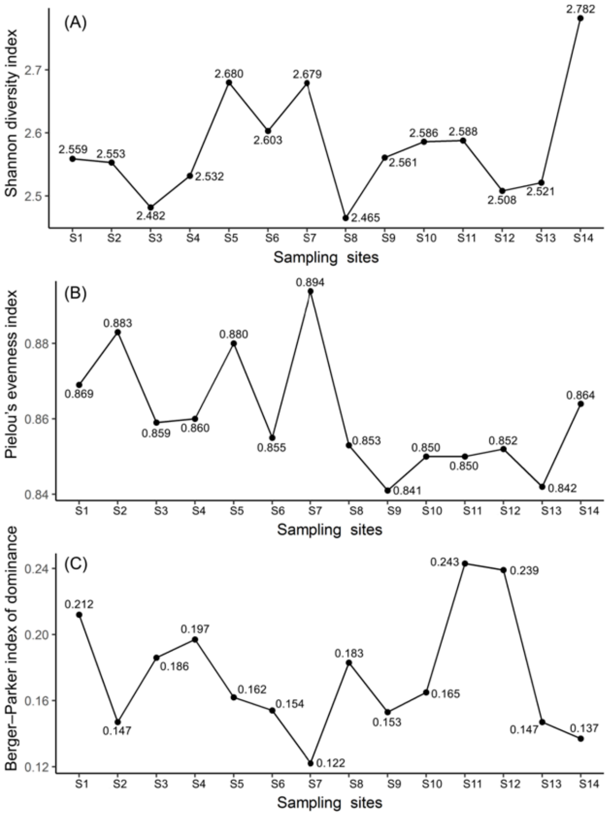

Figure 2. Variation of Shannon diversity index, Pielou's evenness index, and Berger-Parker index of dominance in different sites (S1–S14) of the upper Ganga River Ramsar site.

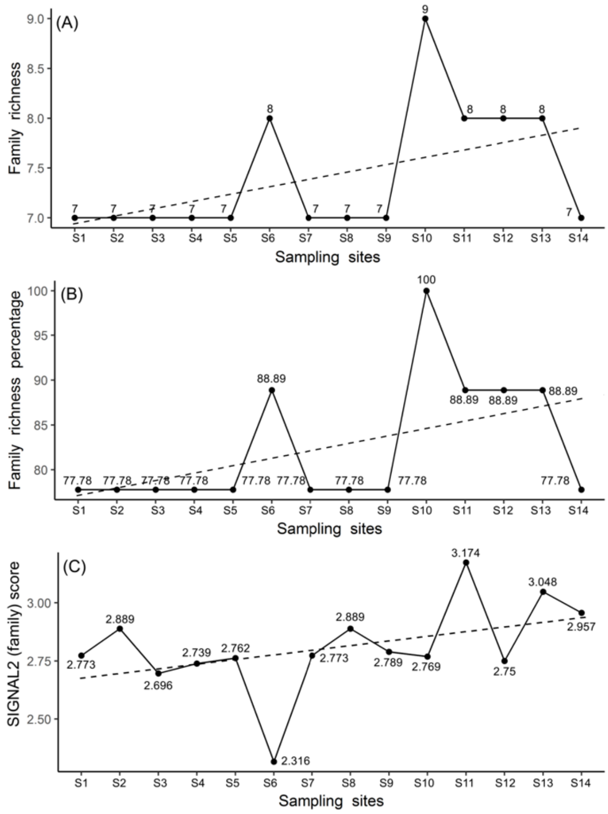

Figure 3. Variation of Family richness, Family richness percentage and SIGNAL2 (family) score in different sites (S1–S14) of the upper Ganga River Ramsar site. The linear trend lines are showing increase of values towards the Narora barrage (at S14).

DISCUSSION

Insects have the ability to move from unfavourable habitats to favourable ones. If a habitat becomes polluted or altered, tolerant species will thrive and sensitive ones will move to a more suitable habitat (Medina et al. 2007). Thus habitat alternation, either by natural process or by anthropogenic impacts, can shape invertebrate communities. Aquatic macroinvertebrates constitute important components of their ecosystems, and they exhibit differential tolerances to changes in environmental conditions (Adu & Oyeniyi 2019). In the present study, three species of Coleoptera from two families, four species of Hemiptera from four families, and 22 species of Odonata from three families were recorded. The coleopterans included predaceous diving beetles (family Dytiscidae) and water scavenger beetles (family Hydrophilidae). The hemipteran group included water bugs (family Belostomatidae), water striders (family Gerridae), water scorpions (family Nepidae) and backswimmers (family Notonectidae), and the odonates included dragonflies and damselflies.

In the present study Shannon diversity index (H'), Pielou's Evenness index (J') and Berger-Parker index of dominance (d) did not differ much between study sites, probably because of uniform geomorphological features of the area, as geomorphological heterogeneity plays a major role in determining species richness (Nichols et al. 1998). Libellulidae, Coenagrionidae, and Gerridae had high relative abundance and dominant status, probably because of their ability to tolerate a wide range of environmental factors (Spence 1983; Chang et al. 2014).

The SIGNAL 2 result suggested that the water of the study area was likely to have higher levels of turbidity, salinity or nutrients, which was perhaps caused either naturally, because of local geology and soil types, or as a result of human activities and physical conditions. Toxic chemicals were not present in large amounts (Chessman 2003).

The family richness, family richness percentage and SIGNAL2 (family) score showed an increase in values towards the Narora barrage, probably because of the increase in water quantity (as the barrage stores more water) which directly affects the physiochemical

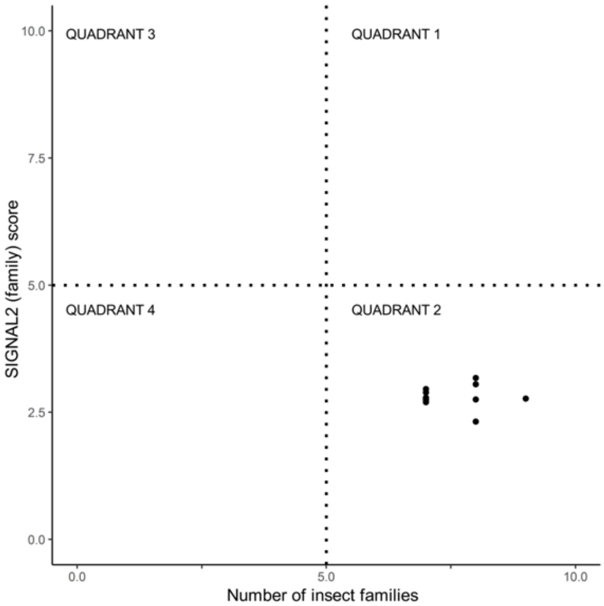

Figure 4. The quadrant diagram for the family version of SIGNAL 2 for the sampling sites.

properties of the water and habitat structures.

The upper Ganga Ramsar site is facing stress from anthropogenic pressure (Kuniyal 2013; Pandey & Sharma 2013). The study stretch between the Brijghat and Narora, the Ganga is characterized by the presence of agricultural lands and numerous ghats (steps leading down to the river) with religious and tourism importance on both the banks. Local people use the river bank and water for bathing, cremation and other religious activities. Activities like cattle grazing and fishing occur throughout the year. As a result, the river is exposed to various threats like waste discharge, sewage disposal, agricultural runoff, fishing, and river bank erosion.

While there is some regional information, knowledge remains limited concerning the natural ranges and ecology of species found in the Ganga (Nautiyal et al. 2014). Long-term seasonal monitoring of the physiochemical properties of the water, coupled with assessment of faunal and floral diversity as well as socio-economic factors influencing the conditions of the area is recommended in order to arrive at better management strategies.

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