Temporal composition and distribution of benthic macroinvertebrates in wetlands

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Studies on the composition, distribution and seasonality of the benthic invertebrates of the Nangal wetland were undertaken for two years from February 2013 to January 2015. Twenty-four genera of benthic macroinvertebrates were recorded, out of which five belonged to Ephemeropteras, two to Plecoptera, five to Hemiptera, three to Diptera, two to Tricoptera, two to Coleoptera, one to Araneae, one to Odonata, two to Annelida and one to Gastropoda. The range, mean and standard deviation of macrobenthos have been recorded. The abundance of macroinvertebrates ranged between 79 and 534 individuals/m^2 (mean 297 [RS1]individuals/m^2) during 2013–14 and 109–612 individuals/m^2 (mean 400 individuals/m^2) during 2014–15. Statistical relationship between different physico-chemical parameters and macroinvertebrates was also computed. The Simpson's index ranged from 0.9428 during 2013–14 to 0.9493 during 2014–15. The Shannon index was 3.117 during 2013–14 and 3.154 during 2014–15, which indicates that the wetland is moderately polluted that further affects the occurrence of benthic macroinvertebrates.

Keywords: Abundance, biodiversity, macroinvertebrate, wetlands.

BENTHIC macroinvertebrates are relatively large-sized organisms (usually above 6 mm) present at the substratum of lakes, ponds, streams and rivers and belonging to several categories, viz. sponges, worms, insects, molluscs, etc. They mainly dwell at the bottom, but may occasionally travel upwards[1]. These organisms may be sensitive to changes in the environment such as pollution, habitat fragmentation and other stresses that degrade biodiversity[2]. Freshwater ecosystems are inhabited by a great variety of organisms. Therefore, aquatic macroinvertebrates have been identified as an excellent tool for biomonitoring studies as they respond rapidly to the environmental changes. Their abundance, diversity and short life cycle make them ideal subjects for assessment of ecological conditions of wetlands[3,4].

Macro as well as microinvertebrates play an important role in the ecosystem. The benthic macrofaunas reside on or inside the deposit of bottom soil and feed on debris. They play a vital role in the circulation and recirculation of nutrients in aquatic ecosystem by accelerating the breakdown of decaying organic matter into simpler inorganic forms[5]. This can further accelerate the occurrence of other biotic components because they also serve as food for a wide range of fishes, birds and other aquatic organisms[6–9].

Macroinvertebrates are an important group of organisms which are found in sediment present beneath the water column and act as key components in any aquatic ecosystem. Their study is important because the macrobenthic organisms are well-known indicators of anthropogenic stress due to their sedentary habitat[10]. Further, they maintain various levels of interaction between the community and environment. The structure of the benthic macroinvertebrate community provides precise and local information on recent events[11]. They are the first causalities of any environmental change[12].

Distribution of macrobenthos is based on biological characteristics and physico-chemical nature of the habitat. The physical alterations in the preferred habitats also play an important role on the spatial changes in the abundance of flora and fauna[13]. For survival, specific ranges of environmental conditions such as temperature, oxygen level, pH and salinity are needed by the macroinvertebrates[14]. Benthic species richness of an aquatic ecosystem has been attributed to the conducive physico-chemical conditions which encourage their fast colonization. The low number of species and density of benthic life is attributed to low bottom oxygen[15].

In aquatic ecosystems, macrophytes play a significant role by providing attachment sites and materials to build protective retreats to invertebrates[16–18]. The dead and decaying matter sustain the benthic food chain and hence most of them are scavengers or detrivores[19]. Further, benthic fauna forms an important component of the food chain for the higher animal taxa, transferring energy and matter from phytoplankton, zooplankton and macrophytes to fishes, amphibians, reptiles, birds and mammals[20] as they act as a major food source for them[21].

In the polluted aquatic systems, some macrobenthos may be eliminated and some remain abundant due to less competition and/or tolerance to adverse conditions[22]. Considering this aspect, macrobenthic communities play a twofold role: first, they act as a connecting link in the food web and secondly, they purify the polluted water. Further, different soil and water characteristics also have

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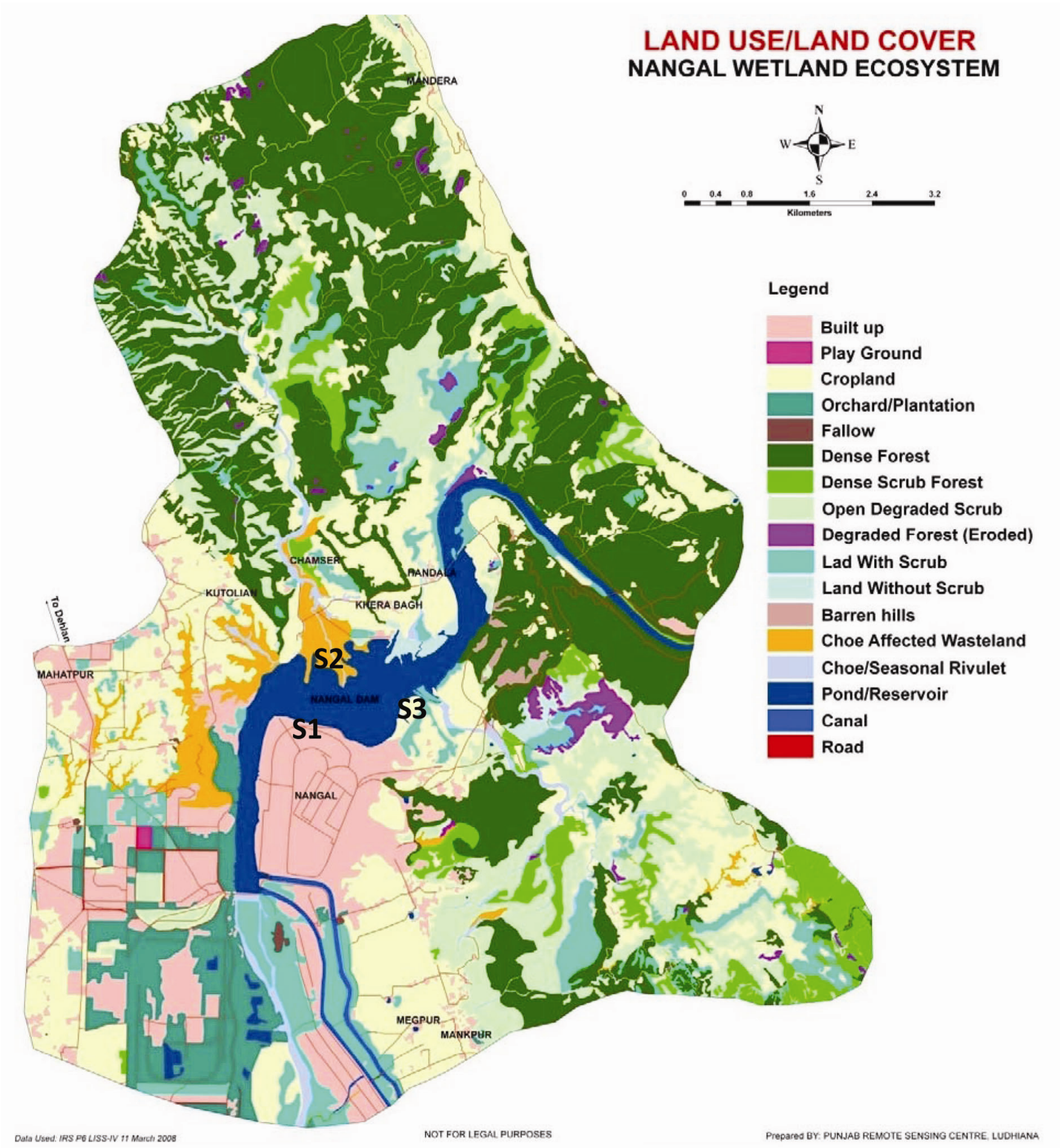

Figure 1. Map showing the Nangal wetland.

a pronounced influence on the diversity of macrobenthos[23,24]. As these highly sensitive organisms spend most of their lifetime at the same place because of less mobility, the effect of pollution and eutrophication is clearly evident on them[25]. The objective of the present study was to find the abundance, diversity and seasonal variations of macrobenthic fauna, since the occurrence of many higher organisms is dependent on them.

Study area

The Nangal wetland (Figure 1) came into existence with the construction of a barrage on the River Satluj at Nangal city, Ropar district, Punjab, India. Further, it was constructed to the downstream of the Bhakra Dam as balancing reservoir. It acts as sponge to absorb surplus water released by the dam during the rainy season. It is situated at 31°24′13.52″N and 76°22′03.05″E at 1172 feet elevation. The wetland covers an area of 700 acres and supports different forms of biological diversity and hydrology. It attracts lot of migratory avifauna during the winter season, because it provides different habitats and breeding places for birds, fishes, reptiles, mammals and plants[26]. Due to its unique characteristics, the ecosystem was nominated to the Ministry of Environment and Forests, Government of India for inclusion under the National Lake Conservation Programme. The Ministry designated it as a ‘Wetland of National Importance’ in 2008.

Materials and methods

Analysis of physico-chemical parameters

Water samples were collected in 2 litres polythene bottles during morning hours between 7 : 00 a.m. and 11 : 00 a.m. The exact sample location was determined by global positioning system (GPS). Physico-chemical parameters such as air temperature, water temperature, relative humidity, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), pH and salinity were determined *in situ* with the help of water analysis kit. Total alkalinity, turbidity, chlorides, total hardness and calcium and magnesium hardness were analysed in the laboratory following standard methods[27,28].

Sampling of benthic macroinvertebrates

Three sampling sites (S_1, S_2 and S_3) were identified keeping in view the accessibility, variations in the microhabitat and representativeness of the entire ecosystem. These sites were given identification marks. Study of benthic macroinvertebrates and analysis of water quality were conducted for two annual cycles (February 2013–January 2015). Regular monthly sampling was undertaken between 9 : 00 a.m. and 11 : 00 a.m. at each site throughout the study period. All the data were pooled and statistical mean and standard deviation were calculated. The macroinvertebrates colonizing the substrate and surface were collected with the help of the Surber sampler (0.50 mm mesh net) and by hand-picking from beneath the stones and macrophytes. The macroinvertebrates were preserved in 5% formalin at the sampling sites. For quantitative analysis, macroinvertebrates were examined using inverted microscope and identified with the help of standard monographs and identification keys[28–31]. The benthic macroinvertebrates were identified up to genus level.

Community analysis

The basic statistical calculations such as range, statistical mean and standard deviation (SD) were made and regression analysis (R) was carried out.

Biological indices such as Shannon−Weaver's index of diversity[32], index of dominance[33] and evenness index[34] were used for further analysis.

(1) Shannon–Weaver's diversity index (H') is a measure of species abundance and evenness and is expressed as

$$H' = -\sum (P_i \ln P_i),$$

where P_i is the proportion of the first species. Also, $P_i = n_i/n$.

(2) Simpson index (λ) is determined by the equation

$$\lambda = -\sum n_i(n_i - 1)/n(n-1).$$

(3) Species equitability or evenness (E) is determined by the equation

$$E = \frac{H}{H_{\max}} = \frac{H}{\ln S},$$

where H is the Shannon–Weaver diversity index and S is the number of species in the sample.

Results and discussion

The benthic macroinvertebrate community composition of a particular habitat reflects the habitat characteristics. The presence of a particular population is governed by a specific set of ecological conditions prevailing at that period of time. In the present study, altogether 10 groups of benthic macroinvertebrates were recorded, viz. Ephemeropteras, Plecoptera, Hemiptera, Diptera, Tricoptera, Coleoptera, Araneae, Odonata, Annelida and Gastropoda. The benthic macroinvertebrate density was found to vary in different years. The total abundance of benthic macroinvertebrates was found to be high during 2014–15 compared to 2013–14 during the present study (Table 1).

The variation in the abundance of individuals indicates that temperature has a pronounced influence on their life cycle. In the wetland ecosystem, the significance of bottom fauna as a link in the energy flow from primary productivity to fish yield is well known. The abundance, population density and diversity of benthic fauna mainly depend on physical and chemical properties of its habitat as it responds quickly to any change in water quality[35,36]. Macrobenthic fauna can be used as indicators for bio-assessment[37] because of the presence or absence of particular benthic species in a particular environment and habitat condition. It can also be used as a barometer of overall biodiversity of an aquatic ecosystem[15].

The occurrence and distribution of benthic invertebrates are known to be intimately associated with the substrate condition and the surrounding environment. Silty loam or clayey substratum with dense macrophytes is known to be preferred by benthic macroinvertebrates[38]. It was observed during the present study that similar habitat exists in and around the Nangal wetland, which provides suitable environment for the occurrence of diverse macroinvertebrates. Table 1 provides a list of different types of macrobenthic invertebrates and their number of individuals/m^2.

During the present study, a total of 24 genera of benthic invertebrates were recorded from the Nangal wetland, out of which five belonged to Ephemeropteras, two to Plecoptera, five to Hemiptera, three to Diptera, two to Tricoptera, two to Coleoptera, one to Araneae, one to

Table 1. Annual quantitative analysis of macroinvertebrates (individuals/m^2) of the Nangal wetland during February 2013–January 2015

Benthic macroinvertebrates	2013–14	2014–15	Average density	Range
Ephemeropteras				
Cloen spp.	10.16 ± 9.71	12.66 ± 10.35	11.416 ± 9.899	3–30
Ephemerella spp.	30.16 ± 22.61	31.41 ± 24.74	30.791 ± 23.189	18–67
Heptagenia spp.	26 ± 22.49	25.5 ± 18.77	25.75 ± 19.605	5–58
Rithrogenia spp.	21.25 ± 19.52	35.83 ± 22.75	28.541 ± 22.031	6–62
Baetis spp.	8.58 ± 10.52	10.83 ± 8.85	9.708 ± 9.415	5–29
Plecoptera				
Isoperla spp.	10.58 ± 11.63	14.83 ± 12.69	12.708 ± 12.102	2–37
Perla spp.	11.91 ± 11.26	21.08 ± 17.12	16.5 ± 14.928	2–48
Hemiptera				
Gerris spp.	11.66 ± 9.56	13.58 ± 9.52	12.625 ± 9.389	4–28
Notonecta spp.	14.75 ± 7.53	18.08 ± 11.02	16.416 ± 9.44	4–35
Micronecta spp.	12.16 ± 6.27	12.5 ± 9.81	12.333 ± 8.106	3–29
Lethocerus spp.	11.5 ± 6.80	13.16 ± 10.49	12.333 ± 8.646	4–29
Ranatra spp.	12.08 ± 7.45	20.25 ± 11.34	15.541 ± 9.877	2–38
Diptera				
Chironomus spp.	7 ± 9.01	15.25 ± 12.32	11.125 ± 11.372	4–34
Antocha spp.	5.33 ± 6.02	14.33 ± 11.57	9.833 ± 10.128	7–35
Culex spp.	7.91 ± 5.93	13.91 ± 12.65	10.916 ± 10.137	5–32
Tricoptera				
Rhyacophila spp.	16.33 ± 14.91	20 ± 15.62	18.166 ± 15.055	3–46
Hydropsyche spp.	17.16 ± 17.17	22.5 ± 19.45	19.833 ± 18.143	3–59
Coleoptera				
Gyrinus spp.	10.83 ± 11.34	14.08 ± 10.50	12.458 ± 10.818	4–35
Dytiscus spp.	11.66 ± 10.93	13.25 ± 9.50	12.541 ± 9.978	4–32
Araneae				
Argyroneta spp.	4.91 ± 6.25	8.91 ± 7.50	6.9166 ± 6.775	5–21
Odonata				
Macromia spp.	6.91 ± 6.84	10 ± 8.74	8.458 ± 7.712	3–26
Annelida				
Pheretima posthuma	13.66 ± 16.04	15 ± 17.04	14.333 ± 16.204	2–44
Glossiphonia spp.	0 ± 0	6.33 ± 6.67	3.166 ± 5.638	4–20
Gastropoda				
Lymnaea spp.	14.66 ± 17.64	18.25 ± 18.31	16.458 ± 17.680	2–52

Odonata, two to Annelida and one to Gastropoda. A total of 49 benthic invertebrates have been recorded from the Khurpatal and Naukuchiatal lakes, out of which 12 belong to Oligocheata, five to Diptera, five to Ephemeroptera, 12 to Odonata, seven to Coleoptera, one to Hemiptera, four to Mollusca and three to miscellaneous forms[39]. A total of 18 species of macroinvertebrates have been recorded during pre-drought and 17 species during post-drought period from the floodplain wetlands in Vaishali district, Bihar[40].

The range, mean and standard deviation (SD) of macrobenthos have also been recorded (Table 1). Out of 24 genera, 5 belong to group Ephemeroptera which includes: *Cloen* spp. 3–30 (11.416 ± 9.899), *Ephemerella* spp. 18–67 (30.791 ± 23.189), *Heptagenia* spp. 5–58 (25.75 ± 19.605), *Rithogenia* spp. 6–62 (28.541 ± 22.031) and *Baetis* spp. 5–29 (9.708 ± 9.415).

Group Plecoptera consists of two genera which include: *Isoperla* spp. 2–37 (12.708 ± 12.102) and *Perla* spp. 2–48 (16.5 ± 14.928). Group Hemiptera consists of five genera which include: *Gerris* spp. 4–28 (12.625 ± 9.389), *Notonecta* spp. 4–35 (16.416 ± 9.440), *Micronecta* spp. 3–29 (12.333 ± 8.106), *Lethocerus* spp. 4–29 (12.333 ± 8.646) and *Ranatra* spp. 2–38 (15.541 ± 9.877). Group Diptera consists of three genera which include: *Chironomus* spp. 4–34 (11.125 ± 11.372), *Antocha* spp. 7–35 (9.833 ± 10.128) and *Culex* spp. 5–32 (10.916 ± 10.137). Group Tricoptera consists of two genera which include: *Rhyacophila* spp. 3–46 (18.166 ± 15.055) and *Hydropsyche* spp. 3–59 (19.833 ± 18.143).

Group Coleoptera consists of two genera which include: *Gyrinus* spp. 4–35 (12.458 ± 10.818) and *Dytiscus* spp. 4–32 (12.541 ± 9.978). Group Araneae consists of one genus which includes *Argyroneta* spp. 5–21

(6.916 ± 6.775). Group Odonata consists of one genus which includes *Macromia* spp. 3–26 (8.458 ± 7.712). Group Annelida consists of two genera which include: *Pheretima* spp. 2–44 (14.333 ± 16.204) and *Glossiphonia* spp. 4–20 (3.166 ± 5.638). Group Gastropoda consists of one genus which includes *Lymnaea* spp. 2–52 (16.458 ± 17.680).

Figure 2 *a* and *b* shows monthly variation in total count (individuals/m^2) of different groups of benthic macroinvertebrates during 2013–14 and 2014–15 respectively. Maximum abundance is found in March and April during both the years, and minimum abundance in June and July in the first year and July and August in the second year of study. The abundance of benthic invertebrates at the Nangal wetland ranges from 79 to 534 individuals/m^2 (mean 297.417 individuals/m^2) during 2013–14 and 109 to 612 individuals/m^2 (mean 400.333 individuals/m^2) during 2014–15. The number of benthic invertebrates was higher during 2014–15 compared to 2013–14 during the present study, which could be due to improved nutrient content as they have positive correlation with the occurrence of these organisms. Other researchers have made similar observations and concluded that some macroinvertebrates are highly sensitive to water quality and slight change of nutrients can cause fluctuations in the growth of these organisms[41].

Based on the degree of sensitivity to different pollution levels, the macrobenthos can be classified into pollution-intolerant, facultative and pollution-tolerant. Among

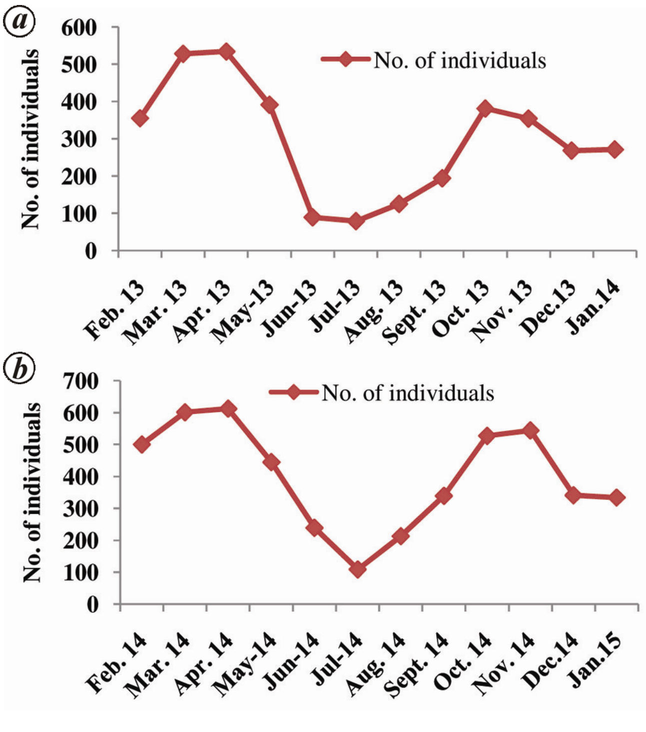

Figure 2. Monthly variation in total count (individuals/m^2) of different groups of benthic macroinvertebrates during 2013–14 (***a***) and 2014–15 (***b***).

arthropods, the abundance of coleopterans decreases with increasing pollution load; they are otherwise inhabitants of clean, clear water and thus can be authentically identified as pollution-intolerant macrobenthos. Similarly, ephemeropterans appear to be inhabitants of clear water. Pollution can cause a decline in ephemeropteran population[42]. It has also been reported that some oligochaetes and leeches are important indicators of pollution[22]. Further studies have shown that certain gastropods are also pollution indicators[43]. Similar results have been observed during the present study. Healthy population of both the groups mentioned above has been observed. This indicates that preferred conditions of water are available at this wetland, which may help enhance their population.

Diversity of composition of benthic population at all the sites revealed that the maximum diversity is observed at site S_2, while site S_3 recorded least population. Overall, density of macroinvertebrates was found to be maximum at S_2, which is due to the presence of riparian vegetation, suitable substrates and minimum water-level fluctuation. The riparian vegetation and substrates provide them protection from predators and suitable environment for the growth of algae, which is an important food source for many macroinvertebrates. Most of the invertebrates utilize plants as a direct source of food, sites for oviposition and source of respiratory oxygen[44–46]. Population of coleopterans and ephemeropterans was less at S_2 compared to the other two sites. This difference may be attributed to the anthropogenic disturbance caused by boating, leakage of oil from motorboats into water, tourist movement, washing of clothes at river banks, dumping of waste and other anthropogenic activities at this sampling site.

Glossophonia spp. was collected from the shallow sites in the study area. These species were not recorded from the relatively deeper sites during the present study. Other researchers have also reported that *Glossophonia* spp. prefer to live in shallow, warm, swampy areas and are tightly attached to the vegetation, as they feed on decaying plant matter[47]. Among dipterans, maximum population of *Chironomus* spp. was found at site S_2 as they are the pollution-tolerant species. *Chironomus* larvae have also been used as pollution indicators by a number of workers[48–50].

The growth and distribution of macrobenthic fauna are influenced by water temperature, which acts as regulator of their reproductive cycle[51]. In the study by Ingole and Parulekar[51], water temperature ranged from 25.1°C to 30.57°C. In the present study it ranged from 15°C to 29.2°C (Table 2), so this range is favourable for regulation of reproductive cycle of benthic macroinvertebrates.

Biological indices

During the present study (Table 3) good population of macroinvertebrates has been recorded that signifies its excellent ecological status. The occurrence of macroinvertebrate diversity can be used as a good indicator for biological and water quality assessment of this wetland. Similar studies have been reported earlier[52–54]. Biological indices like Shannon–Wiener index of diversity, Simpson index and evenness index were used for the analysis. As the species diversity index and species richness index depend upon the number of species as well as number of individuals in each species, they contribute equally to these index values[55]. Hence decrease or increase in any one of these two variables will influence the overall values of these indices.

In the present study, the value of Simpson index ranged from 0.9428 during 2013–14 to 0.9493 during 2014–15. The high value of indices showing high taxon richness, and high relative abundance of benthic macroinvertebrates was due to availability of food, type of substrate and physico-chemical factors at the study site. Similar observations have been made earlier[56–58].

Shannon–Wiener diversity index measures the number of species and the number of individuals in each species. A healthy benthic macroinvertebrate community should have a higher Shannon–Wiener diversity index. According to the Welch pattern[59], $H' > 3$ represents unpolluted regions, $H' < 1$ represents polluted status and $1 < H' < 3$ represents moderate pollution status. In the present study, the value of Shannon index was 3.117 during 2013–14 and 3.154 during 2014–15, which indicates nearly moderate pollution status in the study area, as also pointed out by earlier studies[36,60].

Evenness index measures the evenness or equitability of the community by scaling one of the heterogeneity measures relative to its maximal value that each species in the sample is represented by the same number of individuals. Evenness index ranges from 0 (low equitability) to 1 (high equitability). The mean results of evenness indices were 0.9819 during 2013–14 and 0.9762 during 2014–15. It is understood from the above values of the evenness indices that equitability of macrobenthic community in both the years is high. Our results are unlike low indices observed earlier, who reported 0.35 and 0.40 values of evenness indices[60]. However, higher evenness index values of 0.656–0.865 supporting high equitability of benthic macroinvertebrates have also been reported[9]. Evenness index, i.e. Pielou index value studied by Hazarika[61] is 0.862. This indicates that benthic macroinvertebrate species found in the studied habitat is almost evenly distributed because the calculated value is closer to 1.

Table 2. Mean value of physico-chemical characteristics of water in the Nangal wetland

Parameters	Mean ± S.D	Range
Air temperature (°C)	27.770 ± 8.736	15–42.5
Water temperature (°C)	20.729 ± 4.381	15–29.2
Humidity	55.5 ± 13.223	38–82
Conductivity (μS/cm)	212.083 ± 54.171	125–300
TDS (mg/l)	163.041 ± 46.954	108–255
Dissolved oxygen (mg/l)	7.437 ± 0.414	7.0–8.0
Turbidity (NTU)	14.179 ± 6.568	4–25
pH	7.32 ± 0.296	7–8.1
Alkalinity (mg/l)	99.958 ± 45.729	48–200
Salinity (mg/l)	204.166 ± 95.458	100–400
Chlorides (mg/l)	15.21 ± 8.576	4.85–32.8
Total hardness (mg/l)	111.708 ± 50.227	66–290
Ca^{++} hardness (mg/l)	21.692 ± 6.725	13.25–45.4
Mg^{++} hardness (mg/l)	15.21 ± 11.533	5.7–59.6

Table 3. Annual variation of diversity indices of benthic macroinvertebrates in the Nangal wetland

Diversity indices	2013–14	2014–15
Taxa (S)	23	24
Individuals	286	391
Simpson (1-D)	0.9428	0.9493
Shannon (H)	3.117	3.154
Evenness (H/S)	0.9819	0.9762

Correlation between physico-chemical parameters and benthic macroinvertebrates

Table 3 presents the monthly physico-chemical characteristics of the Nangal wetland and Table 4 presents their correlation with benthic macroinvertebrates. Water temperature of the wetland fluctuated with air temperature; it was maximum in June and minimum in February during both the years. In any aquatic ecosystem, physico-chemical parameters affect the whole benthic population either positively or negatively depending on their source. Physico-chemical parameters can cause long or short-term shifts in benthic community richness, abundance and species composition. The presence of a mixed population of benthic fauna indicates suitable water quality for their survival in the entire environment[62].

Table 4 shows the correlation value with macrobenthic organisms. Physico-chemical parameters such as turbidity (0.013198), pH (0.29535), chlorides (0.49244), total hardness (0.42282), calcium hardness (0.17483) and magnesium hardness (0.27892) show a positive correlation with macrobenthic organisms. And other physico-chemical parameters such as water temperature (–0.16561), electrical conductivity (–0.56475), TDS (–0.41236), DO (–0.3403), alkalinity (–0.29944) and salinity (–0.38921) are negatively correlated with macrobenthic organisms. Similar studies have also been carried out by other workers[9,63].

Regression analysis

Figure 3 shows the regression correlation of benthic macroinvertebrates with some important physico-chemical parameters.

Table 4. Correlation matrix between physico-chemical parameters and density of macroinvertebrates of the Nangal wetland during February 2013–January 2015

Parameters	Density	Air temperature (°C)	Water temperature (°C)	Relative humidity	Conductivity (μS/cm)	TDS (mg/l)	Dissolved oxygen (mg/l)	Turbidity (NTU)	pH	Alkalinity (mg/l)	Salinity (mg/l)	Chlorides (mg/l)	Total hardness (mg/l)	Ca^{++} hardness (mg/l)
Density														
Air temperature (°C)	–0.21058													
Water temperature (°C)	–0.16561	**0.92468**												
Relative humidity	**–0.66191**	**0.6218**	**0.51696**											
Conductivity (μS/cm)	**–0.56475**	**0.58027**	0.45903	**0.78719**										
Total dissolved solids (mg/l)	–0.41236	**0.6459**	**0.60522**	**0.65243**	**0.71317**									
Dissolved oxygen (mg/l)	–0.3403	–0.071201	–0.16858	0.35	0.32922	0.35088								
Turbidity (NTU)	0.013198	0.45394	0.38784	0.2587	0.28415	0.19611	–0.13232							
pH	0.29535	0.3991	0.28231	–0.11386	0.11437	0.070188	–0.40537	0.22472						
Alkalinity (mg/l)	–0.29944	0.47148	0.39911	**0.69105**	**0.67136**	**0.62632**	0.068401	0.1974	0.089451					
Salinity (mg/l)	–0.38921	0.29627	0.16185	**0.6768**	**0.67508**	0.4937	0.46811	0.10693	–0.070777	**0.7102**				
Chlorides (mg/l)	0.49244	–0.18635	–0.15791	–0.47825	–0.3127	–0.3083	**–0.54356**	–0.12058	0.28727	–0.09158	–0.18827			
Total hardness (mg/l)	0.42282	–0.38539	–0.37987	**–0.51395**	–0.39685	–0.48071	–0.35823	–0.22801	0.13423	–0.25867	–0.30986	**0.78734**		
Ca^{++} hardness (mg/l)	0.17483	**–0.63502**	**–0.55846**	**–0.51445**	–0.4348	–0.47686	–0.14082	**–0.53608**	–0.19866	–0.3795	–0.40169	0.39831	**0.73324**	
Mg^{++} hardness (mg/l)	0.27892	–0.36531	–0.39121	–0.39519	–0.33743	–0.44386	–0.23887	–0.22593	0.0071539	–0.23419	–0.29748	**0.67171**	**0.94523**	**0.75214**

Bold figures represent the high significance level of correlation.

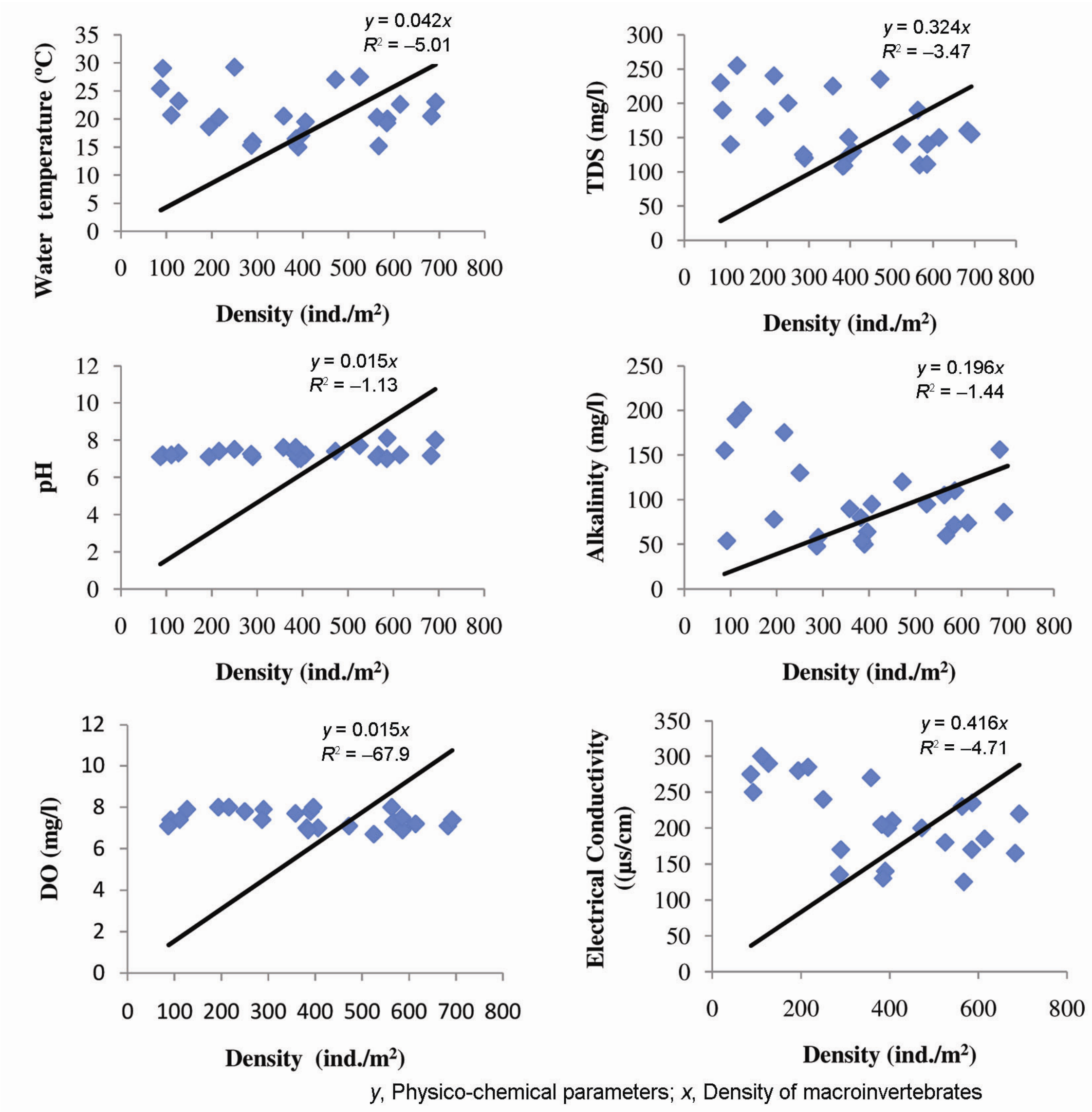

Figure 3. Coefficients of correlation between mean density of macroinvertebrates and physico-chemical parameters of the Nangal wetland.

Conclusion

The present study provides information on the diversity and community structure of benthic macroinvertebrates in the Nangal wetland. It also reveals the changes in abundance and community structure over the years. Overall, density of macroinvertebrates was found to be maximum at site S_2, which is due to the presence of riparian vegetation, suitable substrates and minimum water-level fluctuations. The high diversity of macroinvertebrates in this wetland is due to the availability of macrophytes which provide shelter, varied niches and comparatively clean physico-chemical conditions for water. The abundance of benthic communities in terms of species diversity indicates a good life-support system for fishes, birds and other aquatic organisms. In addition, the composition and distribution of macroinvertebrates are reflection of the health of the wetland and thus this information can be used to design further strategies. Further, conservation and management programmes for this wetland can be initiated as it has numerous socio-economic and ecological values in the area.

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