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Spatial analysis of diatom diversity and water chemistry of ropar wetland (Ramsar site) of Punjab, India

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Abstract

The monitoring of wetlands is essential as they provide significant ecosystem services to our biosphere. Diatoms are widely distributed, species rich community and respond quickly to changes in water quality parameters, and may be used for monitoring of water quality of any aquatic ecosystem. There is a scarcity of available information on diatom community structure of wetland of North India. Therefore, this study is first report, to determine the effect of physico–chemical parameters on diatom community composition of Ropar wetland of Punjab (India). In this study benthic, epiphytic, planktonic and epilithic diatom samples were collected from eight selected sites (RW1–RW8) from littoral zone and were analyzed according to standard methodologies. Principal component analysis (PCA) and canonical correspondence analysis (CCA) were employed to determine the response of diatom community structure to spatial change in physico–chemical parameters of study area. A total of 63 diatom taxa representing 39 genera, 25 families and 14 orders were identified from which 58 taxa are reported for first time from Punjab state of India. Results revealed that this wetland had lower diatom diversity with *Navicula*, *Cymbella, Gomphonema* and *Nitzschia* being the dominant genera. Further, PCA and CCA analysis revealed that total dissolved salts, total hardness, phosphate and nitrate are key physico–chemical parameters driving the diatom community structure of the study area. The information obtained from our study will be helpful to understand the ecological conditions of this wetland ecosystem and to develop the conservation and management strategies for similar habitats.

Keywords Algae · Aquatic ecosystem · Bio-indicator · Bio-monitoring · Community structure · Water quality

1 Introduction

Wetlands are one of the important aquatic ecosystems, which not only play a crucial role in the survival of macro and microorganisms but also govern their productivity (Lawson 2011; Batanero et al. 2022). It also renders useful services to the human beings in the form of many natural resources by ultimately catering their water, food and other survival requirements. Being an important source of freshwater, these are quite vulnerable to the various external factors affecting water quality viz. industrial effluents, urbanization,

agricultural runoff, domestic sewage, anthropogenic pressure etc. (Erwin 2009; Kock et al. 2019). The quality of water depends on its physical, chemical and biological properties. Even a slight change in these properties of water caused by external influencing factors, can have an adverse impact on the biodiversity as a whole (Li et al. 2010; Akhter and Brraich 2020a). Although, there are many biomonitoring methods for assessment of water quality are in practice, but diatoms-based monitoring has recognized as one of the important water qualities defining parameters around the world (Pandey et al. 2017; Kock et al. 2019).

Diatoms are unicellular and microscopic organisms having cell walls composed of silica, and are important primary producers of aquatic ecosystems (Antonelli et al. 2017; Kumar and Singh 2017). As one of the most abundant and diverse photosynthetic groups, the net primary production of these organisms is higher than all the worlds' tropical rainforests (Joseph and Francis 2019). These organisms play an important role in geochemical cycling of naturally occurring

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elements particularly in carbon and silicon at various suitable habitats (Benoiston et al. 2017). Due to long persistence of their siliceous cell walls they are favoured to be use in paleolimnological or archaeological studies (Morin et al. 2020). The occurrence of diatom species mainly depends on environmental conditions and water chemistry of a particular habitat (Muñoz-López and Rivera-Rondón 2022). Globally, these organisms are recognized as useful biological indicator for the assessment of water quality, due to their quick response to physico-chemical changes of the habitat (Kock et al. 2019; Mbao et al. 2022). The diatom community structure is mainly influenced by range of factors like physicochemistry (pH, EC, TDS, phosphate, TH), habitat type, inflow of different pollution sources etc. (Michelutti et al. 2013; Soeprobowati et al. 2016). The diatom communities provide holistic and integrated approach towards the integrity of lotic and lentic ecosystems due to these responses (Dalu et al. 2016; Shibabaw et al. 2021).

Currently, due to the insufficient knowledge about the diatom diversity from Indian water bodies these organisms are generally ignored in environmental monitoring programme (Murulidhar and Murthy 2014). According to the available literature, aquatic habitats of central and southern regions of India has been explored by various workers (Verma and Nautiyal 2010, 2016; Karthick 2010; Karthick et al. 2013; Thacker and Karthick 2022), but there is a general paucity of information on diatom diversity from various aquatic habitats including wetlands of Punjab and other states of North India. Although, the water quality conditions and phytoplankton diversity of wetlands of Punjab has been explored by various workers (Sharma et al. 2013, 2017; Brraich and Kaur 2015; Brraich and Saini 2015; Singh et al. 2020, 2022; Brraich et al. 2021; Komal et al. 2021). But, to the best of our knowledge only few reports are available in literature on diatoms diversity from water bodies of Punjab (Thakar and Singh 2010; Pareek et al. 2018; Sharma et al. 2019).

Punjab has around 40 important wetlands, covering an area of 76,476 ha, out of which six wetlands namely Beas Conservation Reserve, Harike, Kanjli, Keshopur Miani, Nangal and Ropar are recognized as Ramsar sites. Ropar wetland is not only an important aquatic ecosystem with profuse biodiversity and ecological properties but also, one of the significant recreational, socio-economic and scientific development centers (Akhter and Brraich 2020a; Singh et al. 2022). The partial water sampling and monitoring of this important wetland is of a concern as it is threatened by the industrial expansion, indiscriminate use of agricultural land, human interferences and recreational activities (Brraich et al. 2021; Komal et al. 2021). The present study has been carried out with the objective to investigate and document the diversity of diatoms as well as their response to the spatial variation in selected physico-chemical parameters of Ropar wetland of Punjab.

2 Materials and methods

Study area – Punjab is one of the agrarian states of India with about 84% land in under cultivation and has nearly 40 important wetlands covering nearly 1% of the total geographical area (Ladhar 2002; Kumar and Singh 2020; Singh et al. 2022). These wetlands play an important role as source of irrigation, power generation and as suitable habitats for number of plants and animals. Six wetlands (Beas Conservation Reserve, Harike, Kanjli, Keshopur-Miani, Nangal and Ropar) are having the tag of Ramsar site and other are declared as the wetlands of national importance. The Ropar wetland, is manmade fresh water riverine and lacustrine wetland, located at 31° 01′ North and 76° 30′ East (Fig. 1) on Sutlej River at an elevation of 275 m above sea level. Climatically this area falls under semi-arid zone of Punjab with mean annual rainfall of 1518 mm (Brraich and Akhter 2019). It came into existence in 1952 with the construction of water headwork on Sutlej River to supply and divert water for irrigation through canals, industrial and drinking water supply (Ladhar 2002). This wetland covers an area of 1365 ha including 800 ha area under water (ENVIS 2015). The evergreen forest and marshy area of this wetland are important and vital habitats for the migratory birds. Ropar wetland is recognized as Ramsar site in the year 2002, as it supports habitat for a number of threatened and endangered species (Ladhar 2005).

Water sampling and physico-chemical analysis – Water samples (n = 24, three from each site) were collected in clean and sterilized plastic bottles of five-liter capacity from eight selected sites (RW1–RW8) during October, 2020 from Ropar wetland (Ramsar site) of Punjab (India). A total of seventeen parameters were analyzed to study the physico-chemical properties of this wetland. The water temperature (WT, ℃) (Perfit), pH (Hanna Instruments, India), electrical conductivity (EC, µS/cm) (Hanna Instruments, India) and total dissolve salts (TDS, mg/l) (HM digital, Inc., CA, USA) were noted down on the spot at the time of sampling. Whereas, rest of the parameters including carbonate (CO_3, mg/l), bicarbonate (HCO_3, mg/l), total alkalinity (TA, mg/l), total hardness (TH, mg/l), calcium (Ca, mg/l), magnesium (Mg, mg/l), chloride (Cl, mg/l), phosphate (PO_4, mg/l), ammonium (NH_4, mg/l), sulphate (SO_4, mg/l), nitrate (NO_3, mg/l), sodium (Na, mg/l), potassium (K, mg/l) were analyzed within the 24 h of sampling by following standard procedure (APHA 2012).

Sampling and identification of diatoms – To study the relationship between diatom and physico-chemical parameters of Ropar wetland, a total of 32 samples were collected from eight selected sampling sites (RW1–RW8) according

Fig. 1 Map showing sampling sites at Ropar wetland, Punjab
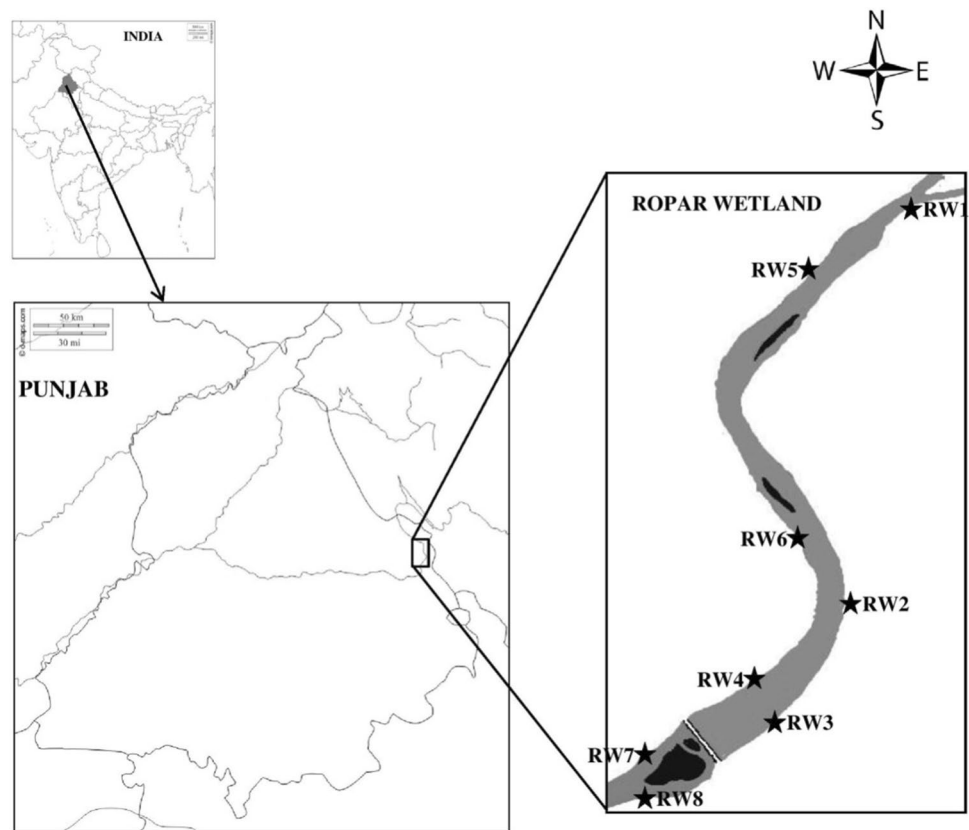
to different microhabitats of diatoms. As Ropar wetland is a Ramsar site, maximum care was taken before sampling. Diatom samples were collected not only from point of view of taxonomists but also as perception of ecologist's without disturbing the other biota of wetland ecosystem. The benthic, epilithic, epiphytic and planktonic diatom samples were collected separately from each sampling site. The benthic, epilithic and epiphytic samples were collected with the help of pipette/dropper/forceps/knife etc., whereas concentrated 100 ml planktonic samples were collected with plankton net (20 μm) by filtering 25 L water. All the collected samples were transferred to sterilized glass bottle (100 ml) containing the preservative solution (4% formaldehyde) and brought to the laboratory for further analysis. The organic matter present in the samples was digested by boiling the samples with concentrated nitric acid. The cleaned samples were then transferred to centrifuge tubes and centrifuged at 4000 rpm for 10 min and rinsed five times with distilled water to remove the excess acid; subsequently a drop of diatom samples from a pipette was put on a cover slip and allowed to dry overnight at room temperature in a clean chamber (Karthick et al. 2013). Permanent slides were prepared using Naphrax and light microscopy (Leica) observations were done at 10X, 40X, 100X combination of lenses using immersion oil. Plates of microphotographs were prepared using Inkscape 0.92.3 software. Identification of diatom taxa was done on the basis of their morphological characteristics by following Karthick (2010), Karthick et al. (2013) and Cantonati et al. (2017). The relative abundance of diatom taxa was determined by using drop count method (Trivedy and Goel1984), whereas evenness was measured on the basis of presence and absence of each identified organism in each collected sample (Bak et al. 2004).

Statistical analysis – To illustrate the variation in parameters, descriptive statistics, viz. mean and standard deviation were calculated. One-way analysis of variance (ANOVA) was applied to find out the significant differences in the water chemistry among different sampling sites. Principal Component Analysis (PCA) was used to find out the spatial pattern of water quality parameters and relationships among sampling site on the basis their water chemistry by using log $(x + 1)$ transformed data. Canonical Correspondence Analysis (CCA) was employed on the basis of calculated relative abundance to find out the influence of different physico-chemical parameters on the distribution of diatoms. The diatoms taxa of having > 50% relative abundance (RA) were taken in consideration for CCA. The software used for statistical analysis includes Microsoft Office Excel 2010, SPSS statistics 18 and XLSTAT version 2020.5.

3 Results

Spatial variation in water chemistry – During this study, a total of 17 physico-chemical parameters of water were analyzed from eight selected sampling sites (RW1–RW8) to understand the spatial variation in water chemistry of Ropar wetland. The variations (mean, standard deviation and range) in the various physico-chemical parameters have been presented in Table 1. All the physico-chemical parameters showed significant variations among sampling sites ($p < 0.05$) (Table S1). At time of sampling, the water temperature of Ropar wetland was ranged from 14.0 ± 0.20 ℃ (RW1) to 16.02 ± 0.20 ℃ (RW6). The water of Ropar wetland was alkaline in nature and showed slight variations in different sites with a range of 7.80 ± 0.05 (RW2) to

8.20 ± 0.20 (RW8). Significant variation was observed in the values of electrical conductivity (EC) among different sampling sites. The maximum value (339.56 ± 19.68 μS cm^{-1}) of EC was recorded from RW8, whereas minimum value (257.12 ± 3.17 μS cm^{-1}) was observed from RW4 (Table 1).

– The amount of TDS in all sampling sites of study area was ranged in between 200.00 ± 2.00 mg l^{-1} (RW5) to 279.00 ± 3.00 mg l^{-1} (RW8). The concentration of carbonate in water of all sampling sites was ranged from 22.49 ± 0.62 mg l^{-1} (RW4) to 32.36 ± 1.52 mg l^{-1} (RW8), whereas the values of bicarbonate were ranged in between 97.35 ± 3.79 mg l^{-1} (RW1) to 131.87 ± 1.05 mg l^{-1} (RW8). The values of total alkalinity showed significant variations ($p < 0.05$) among different sampling sites and varied from 25.37 ± 1.11 mg l^{-1} at site RW4 to 36.85 ± 1.09 mg l^{-1} at site RW8. In present study the

Table 1 Mean ± SD values of the studied physico–chemical parameters of each sampling site of Roper wetland

Parameters	Sites							
	RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Temperature (℃)	14.00 ± 0.60	14.05 ± 0.60	15.00 ± 0.50	15.00 ± 0.30	15.00 ± 0.20	16.02 ± 0.20	16.00 ± 0.30	16.00 ± 0.10
pH	8.10 ± 0.17	7.80 ± 0.05	7.80 ± 0.10	7.90 ± 0.10	8.00 ± 0.10	8.10 ± 0.10	8.10 ± 0.10	8.20 ± 0.10
Electrical conductivity (μS cm^{-1})	300 ± 8.67	286.78 ± 19.67	266.67 ± 9.51	257.12 ± 3.17	276.45 ± 10.85	275.78 ± 9.39	296.34 ± 10.07	339.56 ± 19.68
TDS (mg l^{-1})	270.00 ± 10.0	264.00 ± 4.00	254.00 ± 4.00	232.00 ± 5.29	200.00 ± 10.0	258.00 ± 2.00	266.56 ± 3.10	279.00 ± 3.00
Carbonate (mg l^{-1})	29.80 ± 1.90	27.48 ± 1.23	23.74 ± 1.11	22.49 ± 0.62	24.47 ± 1.10	26.05 ± 1.01	25.84 ± 1.03	32.36 ± 1.52
Bicarbonate (mg l^{-1})	97.35 ± 3.79	99.46 ± 2.16	107 ± 2.65	109.23 ± 2.84	113.12 ± 3.8	119.01 ± 1.46	125.33 ± 2.66	131.87 ± 1.05
Total Alkalinity (mg l^{-1})	29.80 ± 1.90	26.16 ± 1.43	25.73 ± 1.78	25.37 ± 1.11	27.94 ± 0.95	29.65 ± 1.75	29.54 ± 1.67	36.85 ± 1.09
Hardness (mg l^{-1})	131.53 ± 1.95	119.96 ± 1.00	124.13 ± 1.19	130.26 ± 0.34	140.43 ± 0.56	138.73 ± 0.26	139.65 ± 0.57	142.49 ± 0.58
Calcium (mg l^{-1})	18.70 ± 0.65	19.40 ± 0.21	21.89 ± 0.81	26.90 ± 0.07	27.01 ± 0.25	24.11 ± 0.21	26.60 ± 0.28	28.88 ± 0.85
Magnesium (mg l^{-1})	22.65 ± 0.27	19.73 ± 0.17	15.65 ± 0.37	16.56 ± 0.25	17.18 ± 0.39	21.65 ± 0.14	20.15 ± 0.03	24.46 ± 0.35
Chloride (mg l^{-1})	28.93 ± 0.47	27.30 ± 0.19	23.97 ± 0.18	23.34 ± 0.24	23.30 ± 0.12	25.40 ± 0.23	27.80 ± 0.05	29.14 ± 0.06
Phosphate (mg l^{-1})	0.201 ± 0.019	0.162 ± 0.011	0.130 ± 0.010	0.120 ± 0.017	0.063 ± 0.006	0.161 ± 0.009	0.192 ± 0.013	0.223 ± 0.008
Ammonium (mg l^{-1})	0.377 ± 0.012	0.300 ± 0.017	0.292 ± 0.009	0.252 ± 0.011	0.203 ± 0.009	0.202 ± 0.011	0.308 ± 0.007	0.360 ± 0.010
Sulphate (mg l^{-1})	0.903 ± 0.011	0.790 ± 0.010	0.688 ± 0.022	0.623 ± 0.010	0.613 ± 0.007	0.643 ± 0.011	0.823 ± 0.019	0.911 ± 0.018
Nitrate (mg l^{-1})	0.342 ± 0.011	0.252 ± 0.017	0.220 ± 0.010	0.211 ± 0.012	0.180 ± 0.026	0.242 ± 0.009	0.340 ± 0.010	0.362 ± 0.011
Sodium (mg l^{-1})	0.871 ± 0.011	1.201 ± 0.018	1.541 ± 0.018	0.981 ± 0.01	0.923 ± 0.011	1.211 ± 0.01	1.428 ± 0.014	0.953 ± 0.012
Potassium (mg l^{-1})	0.928 ± 0.017	1.323 ± 0.01	1.442 ± 0.011	0.96 ± 0.011	0.943 ± 0.021	1.361 ± 0.011	1.053 ± 0.01	1.192 ± 0.009

maximum value (142.49 ± 0.58 mg l^{-1}) of total hardness was recorded from sampling site RW8, whereas minimum (119.97 ± 1.00 mg l^{-1}) from site RW2. The chloride content in water of study area was varied from 23.30 ± 0.12 mg l^{-1} (RW5) to 29.14 ± 0.06 mg l^{-1} (RW8). The concentration of sulphate was ranged from 0.61 ± 0.007 mg l^{-1} (RW5) to 0.91 ± 0.01 mg l^{-1} (RW8) in water all sampling sites of study area. The maximum phosphate (0.22 ± 0.008 mg l^{-1}) and nitrate (0.36 ± 0.01 mg l^{-1}) content was estimated from the water samples collected from site RW8, whereas minimum phosphate (0.06 ± 0.006 mg l^{-1}) and nitrate (0.18 ± 0.02 mg l^{-1}) from site RW5 (Table 1).

Principal component analysis (PCA) – PCA analysis revealed that the first two principal components (PCs) explained more than 76.69% of the total variance in analyzed physico-chemical parameters (Table 2; Fig. 2). PC1 had high correlation with EC (0.94), TDS (0.80), PO$_4$, (0.93), NO$_3$ (0.94), SO$_4$ (0.94), Mg (0.90), NH$_4$ (0.80), TA (0.82), Cl (0.73), while TH (0.93), HCO3 (0.93), Ca (0.89), WT (0.79) and pH (0.64) were highly correlated with PC2. The PC1 represents the parameters which would correspond

to natural weathering of rocks from the surrounding area and waste water discharges to the wetland. PCA identified three groups on the basis of individual physico-chemical parameters. Group I include two sites RW1 and RW8, were distinguished from others by their relatively higher values of EC, TA and TDS and PO$_4$, NO$_3$, SO$_4$, Mg, NH$_4$, and Cl content. Group II includes another two sites RW2 and RW6, may be grouped together based on their similar sodium and potassium content. Site RW7 may be distinct from rest of the sites and represent third PCA group due to relatively higher values of pH and carbonate and calcium content. While sites RW3, RW4 and RW5 were independent due to intermediate concentration of the water quality parameters.

Diversity of diatom in Ropar wetland – A total of 63 diatom taxa belonging to 39 genera, 25 families of 14 orders were identified on the basis of their morphological characteristics from study area (Table 3; Fig. 3a–c). In this wetland, most of the reported diatom taxa were benthic (39) followed by epiphytic (12), planktonic (09), and epilithic (03) in nature. The diatom community was mainly dominated by biraphid diatoms (viz. *Navicula, Nitzschia, Gomphonema, Cymbella*,

Table 2 Total variance explained by PCA

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	8.51	4.52	2.22	0.91	0.45	0.30	0.08
Variability (%)	50.07	26.61	13.06	5.37	2.65	1.79	0.45
Cumulative %	50.07	76.69	89.74	95.11	97.76	99.55	100.00

Fig. 2 PCA biplot showing relationship between sampling sites and physico-chemical properties
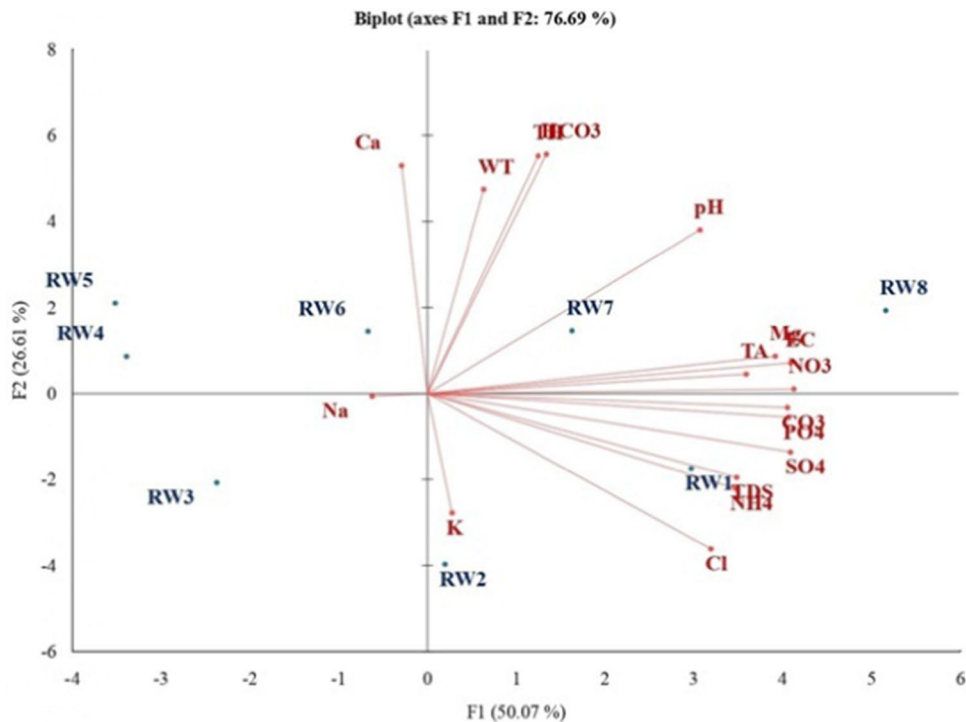
Table 3 Taxonomic assignment, habit, distribution pattern, evenness and abundance of identified diatom taxa at selected sites of study area

S. no.	Taxonomic assignment	Habit	Fig	Distribution and abundance Sites								Evenness (%)	Relative abundance
				RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8		
	Order: Naviculales												
	Family: Naviculaceae												
1	*Navicula rostellata* Kützing	Benthic	3a, (a)	18	–	12	–	–	–	14	19	21.8	1.50
2	*Navicula capitatoradiata* H.Germain ex Gasse	Benthic	3a, (b)	17	11	10	–	9	0	15	19	43.75	1.93
3	*Navicula erifuga* Lange-Bertalot	Epiphytic	3a, (c)	17	12	–	10	–	20	–	39	31.25	1.78
4	*Navicula wikowskii* Lange-Bertalot, Iserentant & Metzeltin	Epiphytic	3a, (d)	17	–	12	–	10	–	–	–	53.12	0.93
5	*Navicula viridula* (Kützing) Ehrenberg	Planktonic	3a, (e)	19	15	12	–	11	–	–	18	87.5	1.78
6	*Caloneis aequatorialis* Hustedt	Epiphytic	3a, (f)	21	–	16	12	11	–	–	20	18.7	1.90
7	*Caloneis silicula* (Ehrenberg) Cleve	Epiphytic	3a, (g)	–	17	14	–	–	15	–	22	34.3	1.62
	Family: Sellaphoraceae												
8	*Fallacia pygmaea* (Kützing) Stickle & D.G.Mann	Planktonic	3a, (h)	19	–	–	16	–	–	–	20	9.37	1.31
9	*Sellaphora pseudopupula* (Krasske) Lange-Bertalot	Epiphytic	3a, (i)	–	18	14	–	–	–	16	20	28.12	1.62
10	*Sellaphora mutatoides* Lange-Bertalot & Metzeltin	Epiphytic	3a, (j)	18	–	13	–	–	–	16	–	21.8	1.12
	Family: Amphipleuraceae												
11	*Frustulia vulgaris* (Thwaites) De Toni	Benthic	3a, (k)	0	17	14	–	0	13	15	19	37.5	2.14
12	*Halamphora coffeiformis* (C.Agardh) Mereschkowsky	Benthic	3a, (l)	–	18	13	–	–	14	17	20	31.2	1.95
13	*Halamphora montana* (Krasske) Levkov	Benthic	3a, (m)	17	11	–	–	10	–	12	18	18.7	1.62
	Family: Diadesmidaceae												
14	*Diadesmis confervacea* Kützing	Benthic	3a, (n)	18	15	–	–	11	14	–	15	53.12	1.74
15	*Luticola saprophila* Levkov, Metzeltin & A. Pavlov	Epiphytic	3a, (o)	17	–	10	–	10	13	–	–	34.3	1.19
16	*Gyrosigma obtusatum* (Sullivant & Wormley) C.S. Boyer	Benthic	3a, (p)	16	12	9	–	–	12	–	18	59.37	1.59
	Family: Stauroneidaceae												
17	*Craticula cuspidata* (Kutzing) D.G.Mann	Benthic	3a, (q)	19	–	13	–	–	–	–	22	50	1.28
18	*Craticula ambigua* (Ehrenberg) D.G.Mann	Benthic	3a, (r)	18	–	15	10	12	–	18	20	28.12	2.21
	Family: Pleurosigmataceae												
19	*Pleurosigma salinarum* (Grunow) Grunow	Epiphytic	3a, (s)	–	17	13	–	–	12	0	19	37.5	1.45
	Family: Pinnulariaceae												
20	*Pinnularia amabilis* Krammer	Benthic	3a, (t)	18	13	–	–	10	–	13	18	21.8	1.71
21	*Pinnularia neomajor* Krammer	Benthic	3a, (u)	17	–	–	12	–	18	–	15	15.62	1.47
	Family: Diploneidaceae												
22	*Diploneis calcilacustris* Lange-Bertalot & A. Fuhrmann	Benthic	3a, (v)	18	–	–	–	–	13	17	–	43.75	1.44
	Order: Fragilariales												
	Family: Fragilariaceae												
23	*Ulnaria ulna* (Nitzsch) P. Compère	Epiphytic	3b, (a)	19	12	13	–	10	–	16	19	87.5	2.12

Table 3 (continued)

S. no.	Taxonomic assignment	Habit	Fig	Distribution and abundance								Evenness (%)	Relative abundance
				Sites									
				RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8		
24	*Ulnaria ulna* var. *repanda* (Q. X. Wang & Q.M. You) Williams	Epiphytic	3b, (b)	16	–	13	–	–	–	17	20	21.8	1.57
	Family: Staurosiraceae												
25	*Staurosira construens* Ehrenberg	Benthic	3b, (c)	16	12	11	–	–	12	–	–	37.5	1.21
26	*Staurosirella pinnata* (Ehrenberg) D. M. Williams & Round	Benthic	3b, (d)	–	–	–	10	12	13	14	16	18.7	1.55
	Order: Surirellales												
	Family: Surirellaceae												
27	*Iconella angusta* (Hustedt) D. Kapustin & Kulikovskiy	Benthic	3b, (e)	19	15	–	11	–	12	15	–	15.6	1.71
28	*Iconella capronii* (Brébisson & Kitton) Ruck & Nakov	Benthic	3b, (f)	–	–	13	–	–	–	14	18	21.8	1.07
29	*Surirella librile* Brébisson W. Smith (Brébisson) W. Smith	Benthic	3b, (g)	16	–	–	–	–	15	–	20	28.12	1.21
	Family: Entomoneidaceae												
30	*Entomoneis paludosa* (W. Smith) Reimer	Benthic	3b, (h)	12	–	–	–	–	–	08	10	12.5	0.97
	Order: Cymbellales												
	Family: Cymbellaceae												
31	*Cymbella tumida* (Brébisson) Van Heurck	Benthic	3b, (i)	19	–	12	–	10	12	–	20	90.62	1.74
32	*Cymbella hustedtii* Krasske	Benthic	3b, (j)	–	10	–	13	–	13	15	18	21.8	1.86
33	*Cymbella neoleptoceros* Krammer	Planktonic	3b, (k)	18	14	12	–	11	–	15	–	31.25	1.66
34	*Cymbella parva* (W. Smith) Kirchner	Planktonic	3b, (l)	–	18	–	12	11	12	–	15	40.62	1.62
35	*Cymbopleura frequens* Krammer	Benthic	3b, (m)	14	–	12	–	–	–	14	17	15.62	1.35
	Family: Gomphonemataceae												
36	*Gomphonema olivaceum* (Hornemann) Ehrenberg	Benthic	3b, (n)	16	–	14	–	–	13	–	18	43.7	1.45
37	*Gomphonema balticum* Cleve	Benthic	3b, (o)	16	10	12	–	–	16	–	–	40.62	1.28
38	*Gomphonema affine* Kützing	Benthic	3b, (p)	–	–	11	9	9	12	14	18	43.75	1.52
39	*Gomphonema clavatum* Ehrenberg	Benthic	3b, (q)	–	16	–	9	0	12	14	18	53.12	1.64
40	*Encyonema lacustre* (C. Agardh) F.W. Mills	Benthic	3b, (r)	15	–	12	–	–	–	12	17	18.75	1.33
41	*Placoneis clementispronina* Lange–Bertalot & Wojtal	Benthic	3b, (s)	–	15	–	–	–	14	–	18	31.25	1.12
	Order: Bacillariales												
	Family: Bacillariaceae												
42	*Nitzschia obtusa* W. Smith	Planktonic	3b, (t)	15	–	11	–	12	–	–	15	56.25	1.28
43	*Nitzschia solgensis* A.Cleve	Benthic	3b, (u)	17	–	12	–	–	–	–	17	34.37	1.09
44	*Nitzschia tabellaria* (Grunow) Grunow	Benthic	3b, (v)	15	–	13	10	–	–	12	–	37.5	1.19
45	*Nitzschia clausii* Hantzsch	Benthic	3b, (w)	17	–	–	12	10	–	15	17	21.8	1.69
46	*Hantzschia calcifuga* E.Reichardt & Lange-Bertalot	Benthic	3b, (x)	–	12	–	–	–	11	15	17	37.5	1.31
47	*Hantzschia amphioxys* (Ehrenberg) Grunow	Planktonic	3c, (a)	–	–	13	–	–	16	16	19	21.8	1.14

Table 3 (continued)

S. no.	Taxonomic assignment	Fig	Habit	Distribution and abundance										Evenness (%)	Relative abundance
				Sites											
				RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8				
48	*Tryblionella constricta* (Kützing) M.Poulin	3c, (b)	Benthic	19	15	–	–	10	–	–	20			46.8	1.52
49	*Tryblionella hungarica* (Grunow) Frenguelli	3c, (c)	Benthic	16	–	–	10	11	15	–	18			43.75	1.66
	Order: Tabellariales														
	Family: Tabellariaceae														
50	*Diatoma vulgaris* Bory	3c, (d)	Benthic	–	17	–	–	–	–	18	20			56.25	1.31
	Order: Stephanodiscales														
	Family: Stephanodiscaceae														
51	*Cyclotella meneghiniana* Kützing	3c, (e)	Planktonic	18	14	0	11	14	16	18	20			78.12	2.64
52	*Cyclotella ocellata* Pantocsek	3c, (f)	Planktonic	20	16	–	15	–	–	–	20			62.5	1.69
53	*Spicaticribra kodaikanaliana* B. Karthick & Kociolek	3c, (g)	Benthic	18	15	–	–	12	15	–	20			9.37	1.90
	Order: Thalassiophysales														
	Family: Catenulaceae														
54	*Amphora copulata* (Kützing) Schoeman & R.E.M. Archibald	3c, (h)	Benthic	–	–	12	–	10	15	16	19			37.5	1.71
	Order: Aulacoseirales														
	Family: Aulacoseiraceae														
55	*Aulacoseira granulata* (Ehrenberg) Simonsen	3c, (i)	Planktonic	–	18	15	–	–	–	15	20			40.6	1.62
	Order: Rhopalodiales														
	Family: Rhopalodiaceae														
56	*Epithemia gibba* (Ehrenberg) Kützing	3c, (j)	Benthic	–	17	–	11	–	–	–	17			15.6	1.07
	Order: Mastogloiales														
	Family: Achnanthaceae														
57	*Achnanthes inflata* (Kützing) Grunow	3c, (k)	Epiphytic	21	19	–	9	10	–	–	22			40.6	1.93
	Order: Cocconeidales														
	Family: Cocconeidaceae														
58	*Cocconeis placentula* Ehrenberg	3c, (l)	Epilithic	21	18	–	15	14	–	20	23			56.25	2.64
59	*Cocconeis pediculus* Ehrenberg	3c, (m)	Epiphytic	22	20	15	–	16	17	20	24			53.12	3.19
	Family: Achnanthidiaceae														
60	*Lemnicola hungarica* (Grunow) Round & Basson	3c, (n)	Epilithic	–	19	15	–	–	14	16	18			43.75	1.95
61	*Planothidium biporomum* (M.H. Hohn & Hellerman) Lange-Bertalot	3c, (o)	Epilithic	–	16	12	–	10	–	–	–			28.12	0.90
	Order: Melosirales														
	Family: Melosiraceae														
62	*Melosira varians* C. Agardh	3c, (p)	Benthic	17	–	–	–	8	–	14	20			15.62	1.50

Table 3 (continued)

S. no.	Taxonomic assignment	Fig	Habit	Distribution and abundance									Evenness (%)	Relative abundance
				Sites										
				RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8			
	Order: Eupodiscales													
	Family: Eupodiscaceae													
63	*Pleurosira laevis* (Ehrenberg) Compère	3c, (q)	Benthic	21	15	12	–	–	–	15	20		18.7	1.97

Tryblionella etc.), followed by araphids (viz. *Ulnaria, Diatoma, Staurosira* and *Staurosirella*) and centric (*Cyclotella, Melosira*). In terms of number of species, the genus *Navicula* with 05 species dominates this wetland followed by the *Cymbella, Nitzschia* and *Gomphonema* with 4 species each. The highest relative abundance was achieved by *Cocconeis pediculus* (Ehrenberg) 3.19% which had evenness value of 53.12% followed by *Cocconeis placentula* 'Ehrenberg' in Murobuse (RA 2.64%, evenness 56.25%), *Cyclotella meneghiniana* Kützing (RA 2.64%, evenness 78.12%), *Craticula ambigua* (Ehrenberg) (RA 2.21%, evenness 28.12%), *Frustulia vulgaris* (Thwaites) De Toni (RA 2.14%, evenness 37.5%) (Table 3). The least dominant taxa were *Planothidium biporomum* (M.H. Hohn & Hellerman) Lange-Bertalot (RA 0.90%, evenness 28.12%), *Navicula witkowskii* (Lange-Bertalot, Iserentant & Metzeltin) (RA 0.93%, evenness 53.12%), *Entomoneis paludosa* (W. Smith) Reimerss (RA 0.97%, evenness 12.5%), *Nitzschia solgensis* Cleve-Euler 34.37 (RA 1.09%, evenness 34.37%) (Table 3). The diatom species that are found to be frequent in over 50% of the sampling sites includes taxa like *Navicula rostellata* (Kützing), *Navicula capitatoradiata* (Germain), *Navicula erifuga* (Lange-Bertalot), *Sellaphora pseudopupula* (Krasske) Lange-Bertalot, *Sellaphora mutatoides* (Lange-Bertalot & Metzeltin), *Diadesmis confervacea* (Kützing), *Diploneis calcilacustris* (Lange-Bertalot & A. Fuhrmann), *Staurosirella pinnata* (Ehrenberg) D. M. Williams & Round, *Cymbella parva* (W. Smith) Kirchner (Table 3).

Effect of spatial variation in water chemistry on diatom diversity – Canonical correspondence analysis (CCA) revealed that the spatial variation in water chemistry of the study area influence the diatom community structure. The first two axes (Axis 1 & 2) of CCA biplot ($\lambda 1 = 0.19$, $\lambda 2 = 0.15$) explained 56.11% of the total variance (Table 4, Fig. 4). Axis 1 is negatively correlated to pH (−0.04) and sites include RW1, RW2, RW4-RW6 while positively correlated with TDS (0.14), WT (0.15), PO_4 (0.06), NO_3 (0.07) Na (0.38) and sites viz. RW3, RW7 and RW8. Diatom taxa including *Surirella capronioides* (0.95), *Hantzschia amphioxys* (0.95), *Aulacoseira granulata* (0.68), *Sellaphora pseudopupula* (0.68), *Halamphora coffeiformis* (0.51), *Ulnaria ulna* var. *repanda* (0.49), *Navicula rostellata* (0.46) showed positive correlation with the axis 1, whereas *Fallacia pygmea* (−0.99), *Cyclotella ocellata* (−0.77), *Tryblionella hungarica* (−0.76), *Achnanthes inflata* (−0.71) etc. showed negative correlation. However, axis 2 showed positive loadings with pH (0.10), NO_3 (0.007), sites such as RW1, RW3, RW5 and RW7, whereas had negative loadings with TDS (−0.10), WT (−0.08), Na (−0.08), PO_4 (−0.03), sites RW2, RW4, RW6 and RW8. The highly positive correlated taxa on the same axis were *Halamphora montana* (0.48), *Pinnularia amabilis* (0.47), *Tryblionella constricta* (0.41), *Navicula rostellata*
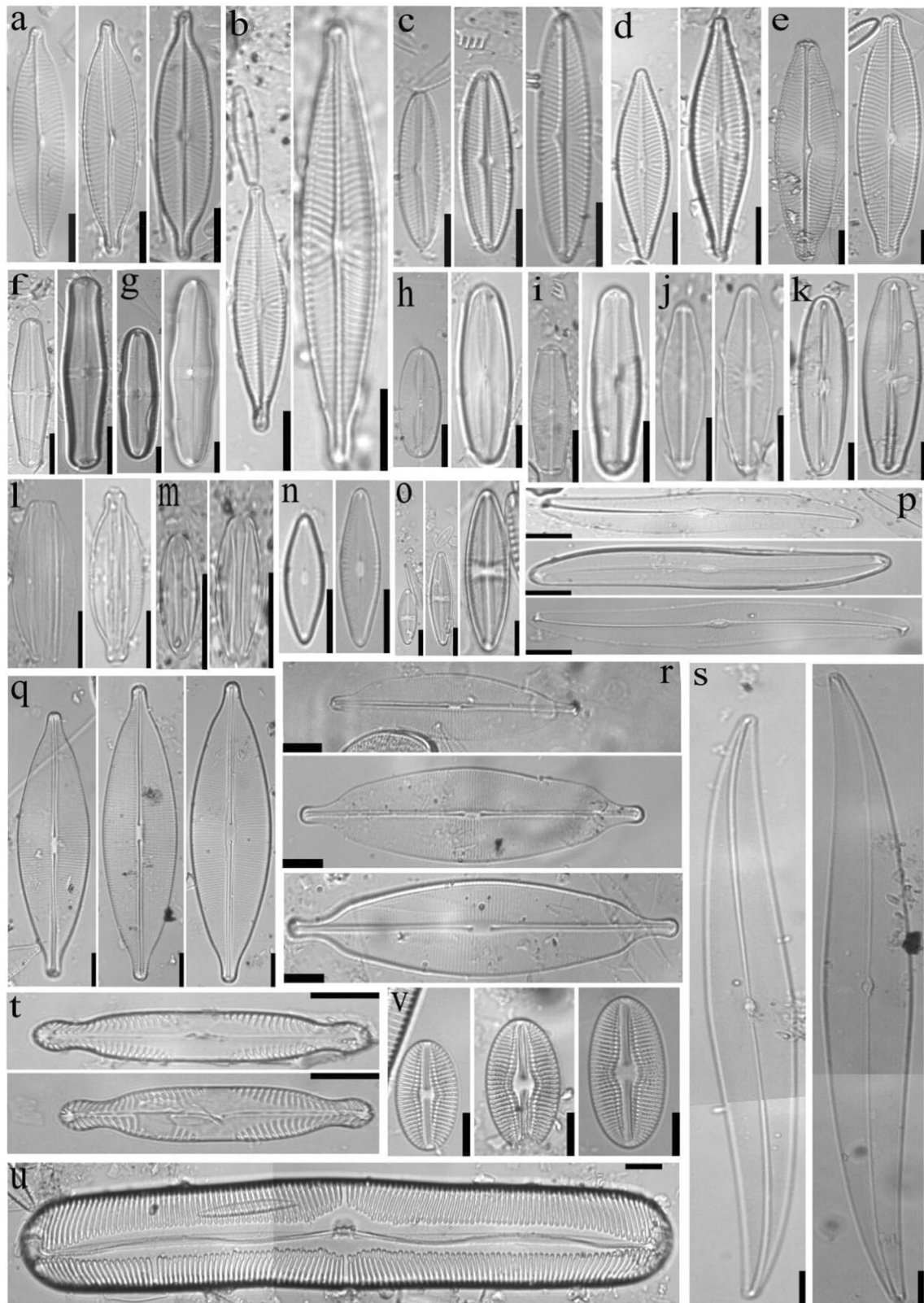
◄ **Fig. 3 a** Micro-photograph of diatom species identified from study area. (a): *Navicula rostellata*; (b): *Navicula capitatoradiata*; (c): *Navicula erifuga*; (d): *Navicula witkowskii*; (e): *Navicula viridula*; (f): *Caloneis aequatorialis;* (g): *Caloneis silicula*; (h): *Fallacia pygmea*; (i): *Sellaphora pseudopupula*; (j): *Sellaphora mutatoides*; (k): *Frustulia vulgaris*; (l): *Halamphora coffeiformis*; (m): *Halamphora montana*; (n): *Diadesmis confervacea*; (o): *Luticola saprophila*; (p): *Gyrosigma obtusatum*; (q): *Craticula cuspidata;* (r): *Craticula ambigua*; (s): *Pleurosigma salinarum*; (t): *Pinnularia amabilis*; (u): *Pinnularia neomajor*; (v): *Diploneis calcilacustris*. (Scale = 10 μm). **b** Micro-photograph of diatom species identified from study area. (a): *Ulnaria ulna*: (b): *Ulnaria ulna* var. *repanda*; (c): *Staurosira construens*; (d): *Staurosirella pinnata*; (e): *Iconella angusta*; (f): *Iconella capronii*; (g): *Surirella librile*; (h): *Entomoneis paludosa*; (i): *Cymbella tumida*; (j): *Cymbella hustedtii*; (k): *Cymbella neoleptoceros*; (l): *Cymbella parva*; (m): *Cymbopleura frequens*; (n): *Gomphonema olivaceum*; (o): *Gomphonema balticum*; (p): *Gomphonema affine*; (q): *Gomphonema clavatum*; (r): *Encyonema lacustre*; (s): *Placoneis clementispronina*; (t): *Nitzschia obtusa*; (u): *Nitzschia solgensis*; (v): *Nitzschia tabellaria*; (w): *Nitzschia clausii*; (x): *Hantzschia calcifug*a. (Scale = 10 μm). **c** Micro-photograph of diatom species identified from study area. (a): *Hantzschia amphioxys*; (b): *Tryblionella constricta*; (c): *Tryblionella hungarica*; (d): *Diatoma vulgaris*; (e): *Cyclotella meneghiniana*; (f): *Cyclotella ocellata*; (g): *Spicaticribra kodaikanaliana*; (h): *Amphora copulata*; (i): *Aulacoseira granulata*; (j): *Epithemia gibba*; (k): *Achnanthes inflata*; (l): *Cocconeis placentula*; (m): *Cocconeis pediculus*; (n): *Lemnicola hungarica*; (o): *Planothidium biporomum*; (p): *Melosira varians*; (q): *Pleurosira laevis*. (Scale = 10 μm)

(0.40), *Craticula ambigua* (0.40), *Navicula capitatoradiata* (0.40) etc. while some of the taxa revealed highly negative correlation on axis 2 including *Placoneis clementispronina* (−0.98), *Caloneis silicula* (−0.73) and *Gomphonema clavatum* (−0.61) etc.

4 Discussion

The wetlands are generally considered as sink for pollutant and have potential to purify water but at the same time they are susceptible to nutrient enrich environment. The present and previous studies on aquatic sampling indicate that Ropar wetland is currently under high natural and anthropogenic pressure (Akhter and Brraich 2020a, b; Brraich et al. 2021; Komal et al. 2021; Singh et al. 2022). Due to this high nutrient load increasing day by day on this wetland may lead to water quality degradation. The diatoms are recognized as bioindicator of water quality, due to their sensitivity and quick response to change in water chemistry of an aquatic ecosystem. Many diatom species are known to grow well in high nutrient concentration and their presence in water indicates degraded water quality. Few diatom species including *Navicula rostellata, Melosira varians, Cyclotella meneghiniana, Gomphonema olivaceum* and *Entomoneis paludosa* reported from around the world from nutrient rich eutrophic water were also recorded in current study from Roper wetland.

In present study, the diatoms and water samples were collected from selected sites of Ropar wetland to investigate the diversity of diatoms as well as their response to the spatial variation in water chemistry. The physico-chemical analysis of selected parameters revealed significant spatial variation in water chemistry of Ropar wetland (Table 1). The water of Ropar wetland was found alkaline in nature with significant variation in pH and water temperature of selected sites at time of sample collection. The alkaline nature of water promotes the growth of the phytoplanktons which generally helps to increase in the primary productivity of an aquatic ecosystem (Kumar and Prabhahar 2012; Sharma et al. 2013). However, all the sampling sites showed variation in EC and TDS values. Electrical conductivity and TDS have a direct correlation as more is the EC, greater will be the TDS of water body (Rusydi 2018). The higher values of EC and TDS were observed at sampling site RW8 may be due to accumulation of the dissolved salts, chlorides, sulphate, sodium and potassium from wastewater, agricultural runoff, and anthropogenic activities (household waste, organic matters, agricultural and industrial run off) (Mahananda et al. 2010; Kataria et al. 2011; Reyes-Toscano et al. 2020; Singh et al. 2020). However, the weathering of rocks, suspension of deposited salts, wastewater and agricultural runoff may be responsible for the higher content of chloride. The gypsum, sulphate-containing fertilizers and other minerals in agricultural runoff are the main sources of sulphate in water bodies with agriculture catchment area (Pande and Moharir 2018). Moreover, the high content of nitrate and phosphate in aquatic ecosystems results in eutrophication which favours the luxuriant growth of phytoplankton. The phosphate and nitrate content in water is mainly increased with the addition of untreated sewage, industrial effluent and runoff from adjoining agricultural field in to the water bodies (Singh 2013; Singh and Ahluwalia 2013; Jindal et al. 2015). The overall trend of physico-chemical parameters in the study area revealed that water of sampling site RW8 is most degraded followed by site RW1 which may be due to the high pollution load from natural as well as anthropogenic processes.

Principal component analysis (PCA) has been employed to find out the variation patterns in water chemistry on the basis of analyzed physico-chemical parameters. PCA differentiated the data set into three groups on the basis of spatial variation in water chemistry of selected sites of Ropar wetland (Table 2; Fig. 2). Group I includes sites RW1, RW7 and RW8 with higher content of EC, TA and TDS and PO_4, NO_3, SO_4, Mg, NH_4, and Cl may be due to their exposure to pollutants from domestic waste, siltation, fishing and industrial effluents (Kour et al. 2022; Pratiwi et al. 2023). Group II is formed by sampling sites RW2 and RW6 with high content of sodium and potassium. Accumulation of sodium
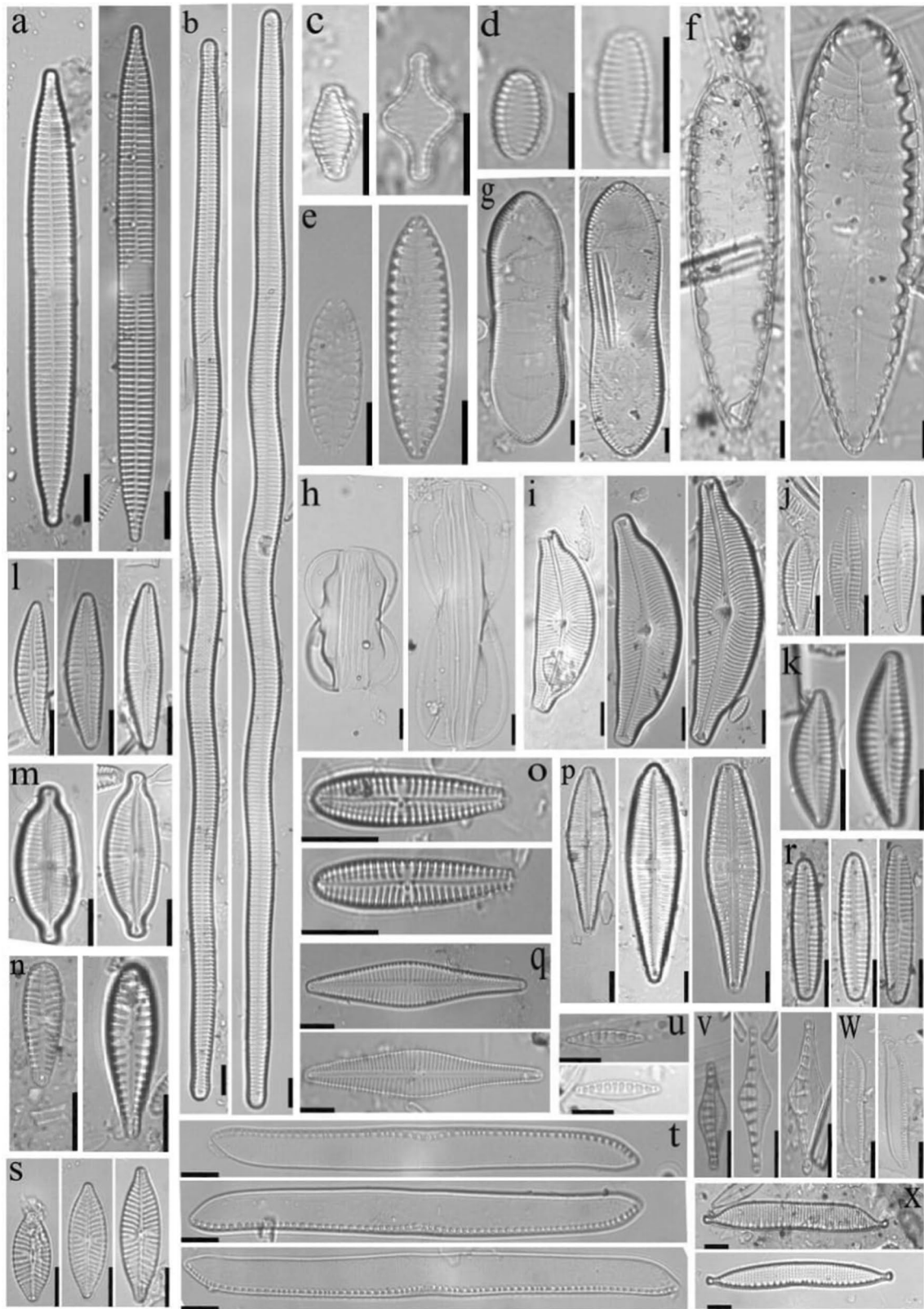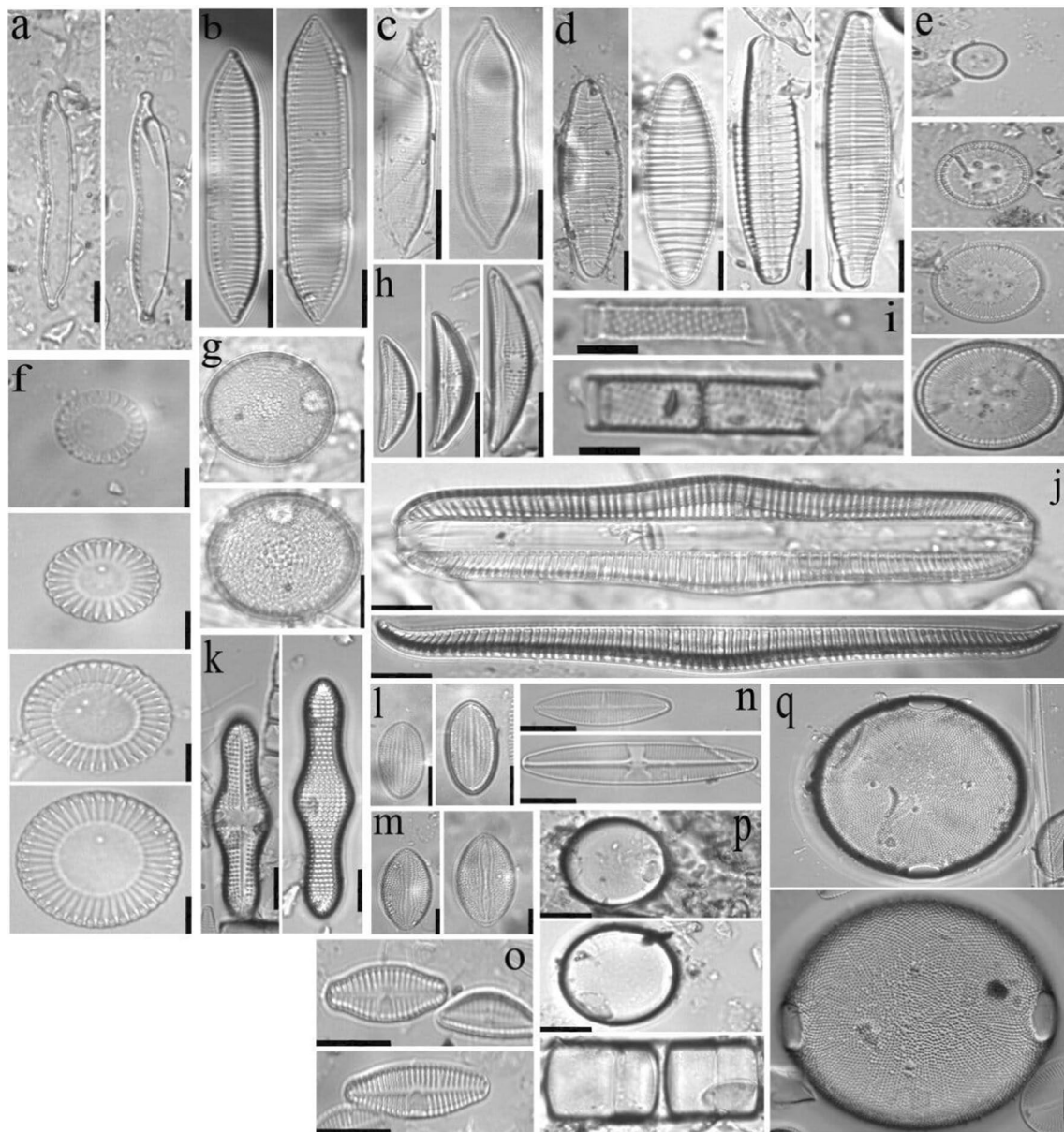
Fig. 3 (continued)

Fig. 3 (continued)

Table 4 Total variance and Eigen values explained by CCA biplot

	F1	F2	F3	F4	F5	F6
Eigenvalue	0.19	0.15	0.11	0.07	0.05	0.02
Constrained inertia (%)	31.24	24.86	19.23	11.96	8.97	3.72
Cumulative (%)	31.24	56.10	75.34	87.30	96.27	100.00
Total inertia	28.25	22.48	17.39	10.81	8.11	3.36
Cumulative (%)	28.25	50.73	68.13	78.94	87.06	90.42

and potassium content into these sites of wetland may due to surface runoff, weathering of rocks, minerals and sewage discharges from adjoining areas into the water (Bhateria and Jain 2016; Akhtar et al. 2021). While rest of the sampling sites (RW3, RW4 and RW5) represents group III which showed somewhat less content of nutrients in comparison

(axes F1 and F2: 56.11 %)
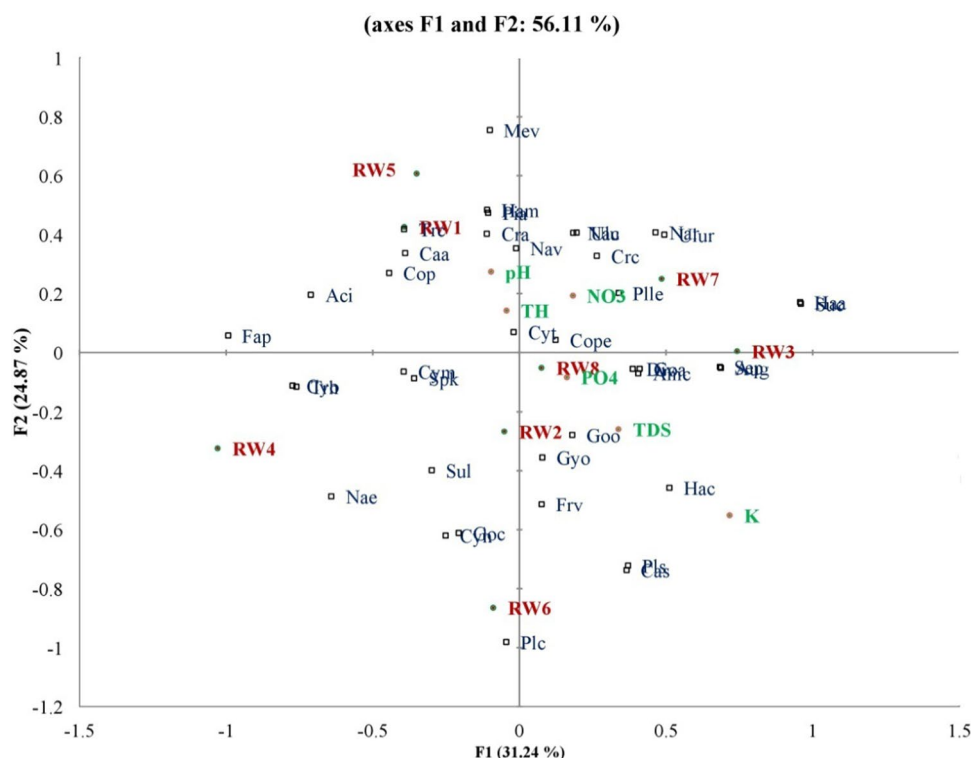
Fig. 4 CCA biplot showing relationship between physico–chemical parameters and occurrence of diatom taxa at different sampling sites. RW1: Roper wetland site 1, RW2: Roper wetland site 2, RW3: Roper wetland site 3, RW4: Roper wetland site 4, RW5: Roper wetland site 5, RW6: Roper wetland site 6, RW7: Roper wetland site 7, RW8: Roper wetland site 8. Aci: *Achnanthes inflata*, Amc: *Amphora copulata*, Aug: *Aulacoseira granulata*, Caa: *Caloneis aequatorialis*, Cas: *Caloneis silicula*, Cop: *Cocconeis placentula*, Cope: *Cocconeis pediculus*, Cra: *Craticula ambigua*, Crc: *Craticula cuspidata*, Cyh: *Cymbella hustedtii*, Cym: *Cyclotella meneghiniana*, Cyo: *Cyclotella ocellata*, Cyt: *Cymbella tumida*, Div: *Diatoma vulgaris*, Fap: *Fallacia pygmea*, Frv: *Frustulia vulgaris*, Goa: *Gomphonema affine*, Gocc: *Gomphonema clavatum*, Goo: *Gomphonema olivaceum*, Gyo: *Gyrosigma obtusatum*, Haa: *Hantzschia amphioxys*, Hac: *Halamphora coffeiformis*, Ham: *Halamphora montana*, Mev: *Melosira varians*, Nac: *Navicula capitatoradiata*, Nae: *Navicula erifuga*, Nar: *Navicula rostellata*, Nav: *Navicula viridula*, Pia: *Pinnularia amabilis*, Plc: *Placoneis clementispronina*, Plle: *Pleurosira laevis*, Pls: *Pleurosigma salinarum*, Sep: *Sellaphora pseudopupula*, Spk: *Spicaticribra kodaikanaliana*, Suc: *Surirella capronioides*, Sul: *Cymatopleura solea*, Trc: *Tryblionella constricta*, Trh: *Tryblionella hungarica*, Ulu: *Ulnaria ulna*, Ulur: *Ulnaria ulna* var. repanda. NO_3: nitrate, PO_4: phosphate, TDS: total dissolved salts, TH: total hardness, K: potassium

to other sites may be due to less anthropogenic activities and entries of fresh waters near these sites which may dilute the concentration of nutrient contents. Different magnitude of anthropogenic pressure on these selected sites may be the reason for their different water quality (Akhtar et al. 2021; Singh et al. 2022; de Almeida et al. 2023). Water quality at these sites may be mainly influences by agricultural runoff, industrial effluents, and discharges through anthropogenic activities from the catchment areas (Singh et al. 2020, 2022; Siriwardhana et al. 2023).

In present study, the morpho-taxonomic analysis of selected diatom samples revealed that the study area exhibit significant of diatom diversity. However, among 63 diatom taxa identified during current study, earlier only five species have been reported from Punjab (*Diatoma vulgaris* Bory, *Cocconeis placentula* Ehrenberg, *Craticula cuspidata* (Kutzing) D.G.Mann, *Gomphonema olivaceum* (Hornemann) Ehrenberg and *Ulnaria ulna* (Nitzsch) P. Compère (Thakar

and Singh 2010) (Table 3). While analyzing the diversity of phytoplankton in relation to physico-chemical parameters of water or for the forensic purpose's taxa such as *Achnanthes, Ulnaria, Navicula, Gyrosigma, Pinnularia, Nitzschia, Cymbella, Gomphonema, Amphora, Cavinula, Neidium, Cyclotella, Surirella, Melosira, Cocconeis* etc. were previously recorded from the different parts of Punjab but only at genus level (Thakar and Singh 2010; Brraich and Kaur 2015; Brraich and Saini 2015; Marbaniang and Paul 2015). Thus, during present study 58 taxa are reported for the first time from Ropar Wetland as well as from Punjab state of India.

In present study, *Cymbella, Navicula, Ulnaria, Nitzschia, Cocconeis, Halamphora* and *Cyclotella* were observed as the most frequent taxa, while *Amphora* and *Diatoma* as rare diatom taxa from the study area. Similar observations have also been reported by Sharma et al. (2013) from River Sutlej, Punjab state of India. The present investigation also indicated that, biraphid diatoms (viz. *Navicula, Nitzschia,*

Gomphonema, Cymbella, Tryblionella etc.) dominated the study area, which was followed by araphids (viz. *Ulnaria, Diatoma, Staurosira* and *Staurosirella*) and rare one was centric diatoms (*Cyclotella* and *Melosira*). Biraphids have also been recorded earlier from Himalayan Rivers (Nautiyal et al. 2004; Sharma et al. 2007) and Kumaun region (Verma and Nautiyal 2009) as dominant diatom taxa. Biraphid diatoms (*Navicula, Nitzschia, Cymbella* and *Achnanthidium*) were also observed as dominant genera in Western Ghats and peninsular regions of India (Karthick et al. 2013). Nautiyal and Verma (2009) have recorded 293 diatom species from two different biogeographic regions of India, the Himalaya and the Central Highlands (Vindhya region) and observed that the number of diatom species in Vindhya (293 taxa) region was more than the Himalaya (189 taxa). On the basis of number of species, the genus *Navicula* was found to be the dominant genera with maximum number of species (05) followed by the *Cymbella, Nitzschia* and *Gomphonema* with 4 species each (Table 3). In present study, most of the reported diatom taxa were benthic (39) followed by epiphytic (12), planktonic (09), and epilithic (03) in nature. The dominance of benthic forms over planktonic may be due to the flowing nature of water and absence of deep stagnant parts of this wetland. Similar observations have been made by different workers from different parts of India as well as from other countries (Bella et al. 2007; Paul et al. 2016). The *Synedra ulna* var. *repanda* which was earlier reported from China (Qingmin et al. 2008) has been reported for the first time from India during this study. Taxon *Ulnaria ulna* var. *repanda* is quite similar to *Ulnaria ulna* in terms of density of striae and frustules, the main characteristic feature which makes it distinct from other species of *Ulnaria* is the undulate valves having a straight pseudoraphe. The length of the *Ulnaria ulna* var. *repanda* was 350.2–371.2 µm with 8–8.12 µm breadth, striae are parallel in the middle with density varies from 8 to 9 µm and radiate in the apices (Fig. 3b).

Canonical correspondence analysis (CCA) has been used to analyze the effect of spatial variation in water chemistry on distribution of diatoms in Ropar Wetland. The resultant CCA biplot showed distribution of diatom taxa, physicochemical parameters and sampling sites into two groups along both the axes of biplot on the basis different nutrient requirements of different diatom taxa (Fig. 4). Group I include *Cocconeis pediculus, Cyclotella meneghiniana, Pleurosigma salinarum, Cymbella tumida, Navicula viridula, Ulnaria ulna, Nitzschia obtusa* and *Caloneis silicula* which shows their close relationships with mesotrophic or nutrient rich conditions (high TDS, TH, NO_3 and PO_4 content). Kennedy and Buckley (2021) have also reported similar observation from Irish lakes. These diatom taxa represent Group I may be the nutrient tolerant taxa and act as indicator of change in the content of TDS, TH, NO_3 and

PO_4 in water of Ropar wetland and other similar aquatic habitats (Barinova and Mamanazarova 2021). The high contents of TDS, TH, NO_3 and PO_4 in water of Ropar wetland may attributed to the addition of various salts resultant of untreated discharge of industrial effluent and agricultural runoff etc. (Singh et al. 2017, 2022; Reyes-Toscano et al. 2020). The Group II is represented by the diatom taxa having high abundance in sampling sites with oligotrophic water conditions. From CCA plot, it is evident that the abundance of diatom taxa in Ropar wetland depends on the availability of nutrients. From CCA biplot, it is clear that the majority of dominant species have high affinity to TDS, TH, PO_4 and NO_3 (Fig. 4). This reveals that these parameters influence the distribution and occurrence of diatoms in this wetland. Kock et al. (2019) also observed the influence of environmental variables on the distribution and occurrence of diatoms in lake ecosystem. The different environmental factors like pH, EC, alkalinity, total hardness, phosphate and nitrate in any aquatic ecosystem play an important role in the distribution of diatom community structure (Dibong and Ndjouondo 2014; Dimowo et al. 2018; Chintapenta et al. 2018; Silva-Lehmkuhl et al. 2019; Maraşlıoğlu et al. 2020).

In present study, *Navicula rostellata* was abundantly found on the sites RW1, RW7 and RW8 having high nutrient concentration than other selected sampling sites. *Melosira varians* in case of our study was mainly observed on the sites RW1, RW7 and RW8. *Melosira varians* has been reported to found in eutrophic water conditions and can be an indicator of high trophic level (Dimowo et al. 2018). According to Lacerda et al. (2004) *Cyclotella meneghiniana* had known to be significantly correlated with total alkalinity, hardness and phosphate. The abundance of *Gomphonema olivaceum* increases with the increase in concentration of phosphate and can be act as good indicator of high phosphate content in water (Maraşlıoğlu et al. 2020). The species of genera like *Amphora, Cyclotella, Cocconeis, Cymbella, Navicula, Cymatopleura* and *Nitzschia* are known to occur in calcareous and alkaline water (Kivrak and Uygun 2012; Cantonati et al. 2017). *Entomoneis paludosa* observed during the present study is strictly found in saline water as well as salt-contaminated water. The higher abundance this taxon in water indicates the high salinity in aquatic ecosystem (Cantonati et al. 2017). These taxa have also been commonly recorded from the nutrient rich water with high electrical conductivity and considered as an indicator of oligo-eutrophic status of water. Although, the concentration of physico-chemical parameters measured during present study are lower but the presence of these high nutrient tolerant diatom taxa indicates that this wetland is under the threat of eutrophication.

Our study concludes that water chemistry of Ropar wetland showed spatial variations which also affect the diversity and distribution of diatoms. This wetland harbors unique assemblage of benthic, epiphytic, planktonic and epilithic

diatom taxa with varied distributional pattern and occurrence. One of the features of this study is that, among 63 identified diatom taxa, 58 taxa of which are new records for Punjab (India), whereas *Ulnaria ulna* var. *repanda* is the first report from India. The CCA depict that the TDS, TH, PO_4 and NO_3 are the key physico–chemical parameters mainly influencing the occurrence and distribution of diatom taxa in Ropar wetland. This study highlights the unexplored diatom diversity, their relationships with the current physico–chemical condition and provides information, to use diatoms in the biomonitoring studies in similar habitats. Further, recommend that there is an urgent need to develop programs, taking into account the diatoms and all other aquatic communities, for conservation and management of biodiversity of this Ramsar site (Ropar wetland) and all other aquatic ecosystems of this region.

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Declarations

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