Research Article
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Algal communities of the Mardan River in ecological assessment of water quality in district Mardan, Pakistan

Abstract

This paper represents the first results of algal species richness investigation in the Mardan River basin, the left tributary of the Kabul River, upper part of the Hindus River. Altogether 201 species and infraspecies of algae from six taxonomic Divisions were revealed for the communities of three sites in the Mardan River main channel and one site of its left tributary Kaltang. Diatom algae were prevailed with followed greens, charophytes and cyanobacteria. Species richness was higher in the lower part of studied river in site Mardan with 176 taxa, but community structure was similar in four studied sites. Water variables show changes with increasing by TDS, temperature and turbidity, but its dynamic demonstrated that water pollution is more correlated with organic matter than with dissolved inorganic ions in studied basin. Statistical analysis of species–environmental variables relationships with comparative floristics, diversity indices and 3D plots construction revealed that species richness was increased in high water temperature, Electrical conductivity and Total suspended solids but in lower water pH. These three parameters can be used for monitoring of the river ecosystem health because algal communities are responsible to the self–purification process in the studied Mardan River basin.

Keywords: algae, species composition, diversity indices, Mardan river, Pakistan

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Introduction

District Mardan is a part of the Peshawar valley and was a part of district Peshawar until 1937. It became an independent district in 1937. It is an important city of Khyber Pakhtunkhwa (KP), Pakistan. It lies between 34°05’ to 34°32’ north latitudes and 71°48’ to 72°25’ east longitudes. It is bounded on the northeast by Buner district, on north and north–west by Malakand Agency, on the southeast by Swabi district, on the south by Nowshera district and on the west by Charsadda district. Total area of the district Mardan is 1,632 square kilometers.[1] Generally, streams and rivers flow from north to the south and west to the east. Most of the streams fall into the River Kabul. An important stream (Kalpani) of the district comes out from Baizai and flows in southwards direction and falls into the River Kabul. The major problem of this settled and anthropogenically polluted area is the water quality decreasing during recent years. Algae represent virtually an unexplored, extensively diverse and heterogeneous group of photosynthetic organisms.[2] They play a very important role in our aquatic environment.[3] Environmental factors such as temperature, pH, climate etc. influence the algal growth and distribution.[4] The algal community study in aquatic environment gives signal about the pollution.[5] The diversity of algae was used with bioindication methods as a tool to monitor the biology of water resources in Israel,[6] in seasonal variation in the Santragachi Lake, West Bengal (India),[7] and in the Kabul River in Pakistan.[8–10] Ecological study of the algae plays a fundamental role in knowing the aquatic system and water quality.[11] Ecologically, the study of algae is one of the prime importance in their habitat.[12] Ecological study of the algal flora in the River Kunhar (Pakistan) was reported for the first time by Leghari et al.[13] Barinova et al.[9] explored the ecology and diversity of algae of the Qishon River (northern Israel).[14] Statistical and bioindication methods were used for the assessment of algal diversity and ecology in the Lower Jordan River.[15] Sarim et al.[16] reported freshwater algae from River Sardaryab, district Charsadda in Pakistan.[16] Filamentous blue–green algal diversity and ecology were studied in standing water basins of Bulgaria.[17] The interrelationship of algal biodiversity and environmental variables was investigated through various approaches.[18] The distribution of the algal species and its interrelationships to aquatic habitats on the altitude of the Hindu Cush Mountain were studied of the river valley of Swat.[19] Water from municipalities provides a continuous supply of nutrient for the growth of algae.[20] When pollution is in the initial stage, excessive growth and sudden change in the diversity of algae occurred.[5] In Pakistan, algae have been reported from various freshwater habitats to know their environmental role and ecological distribution.[21–25] Water from different sources will have its own impact on algal community.[26] The aim of present work is to reveal algal species diversity in the Mardan River and to assess environmental impact to the riverine communities.

Material and methods

To assess the water quality of district Mardan, four research sites (Sher Gharh, Takht Bhai, Mardan, and Katlang) were selected for sampling (Figure 1). Whereas Sher Gharh, Takht Bhai, and Mardan sites are placed in the Mardan River itself, the site Katlang is on the left tributary of the Mardan River. Water quality of these research sites become pollution with numerous pollutants from different sources as the water flow down the streams (north to south and north to west) across agriculturally used areas. During samples collection, water of Takht Bhai, Mardan and Katlang research sites are consider more polluted as there are areas that are more residential as compare to Sher Gharh research site. Algal and water samples were collected in different seasons for the year 2016. A total of 35 samples were collected from each the research sites at 120 meter radius. Algal specimens were collected regularly from water of floating habitat, attached with stones and submerged plants and on sidewalls of pond, stream and river. The collected specimens were kept in plastic bottles of 25 ml and brought to the Laboratory, Department of Botany, Islamia College University, Peshawar. The specimens were washed carefully and preserved in 4% formaldehyde solution. Morphology of different types of algal species was studied under microscope Nikon Lambda E2000 viewed at ×10, ×40 and ×100 microscope objectives. Images of the algal species were taken with the help of digital camera. Standard references of[27–30] were used for identification. Micrometric measurement (length and width) for each algal specimen has taken with the help of stage and ocular micrometers. Statistical analysis of the data for the species diversity and water quality parameters correlation was doing by 3D Surface plots using the Statistica 12.0 Program. Statistical significance of the data was design with the help of Pearson correlation method (wessa.net).

Figure 1 Sampling sites in the Mardan river basin, the left tributary of the Kabul river in Peshawar valley.

Ecological diversity of the algal species (species richness, species evenness, species dominance and combine index) in the research sites communities were calculated for different seasons with the help of biodiversity indices such as:

I. Margalef index: The Margalef index was used for measurement of species richness.

Margalef index (d) = (S–1) / ln N,

Where:

S = number of recorded species

N = total recorded individuals in the sample, and

In = natural logarithm.

II. Pielou's evenness index: The Pielou's evenness index was used for measurement of species evenness.

Pielou's evenness index (J′) = H′ (observed) / H′max,

Where:

H′max and H′ is Shannon–Wiener index

H′max = ln (S)

S = number of recorded species.

Value for J' ranges between 0 and 1. The higher the value for J, there will be less variation in communities between the species.

III. Simpson's index: The Simpson's index (D) was used for measurement of species dominance.

Simpson's index of dominance $D = 1 - \left[\Sigma\left(n-1\right) / N\left(N-1\right)\right]$

Where:

n = the total number of individuals of a particular species,

N = the total number of individuals of all species.

Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases. The value of D ranges between 0 and 1.

IV. Shannon–Wiener index (H′): Combined diversity was commonly measured with the help of Shannon–Wiener index (H′).

Shannon–Wiener index $H' = \Sigma p_i \left(\ln^* p_i\right)$ or $H = -\Sigma p_i \left(\ln^* p_i\right)$

Where:

p_i is the proportion of relative species to the total number of species.

Water temperature and pH were measured with the help of portable pH meter–8414 on the sampling point, while electrical conductivity, turbidity, total dissolved solids (TDS) and total suspended solids (TSS) were determined in the laboratory by using standard techniques.

Results and discussion

Water chemistry variables

In this study, six variables related to the water chemistry across the studied sites were measured through available standard methods. Fluctuation in the physiochemical properties of the river water in the research sites were recorded (Table 1). Water temperature was increased from 18°C in site 1–Sher Gharh to 27.7°C in 3–Mardan. Water pH also increased down the river from 7.5 to 8.84. Turbidity demonstrated dramatically increasing in lower sites 3–Mardan and 4–Katlang to 98 NTU and 58 NTU respectively. In the same direction was increase Electrical conductivity (EC) from 260 µS cm^{-1} in 1–Sher Gharh to 607 µS cm^{-1} in 3–Mardan. Remarkable that EC in site 4–Katlang was comparable with EC in site 2–Takht Bhai that can assume that water pollution is more correlated with organic matter than with dissolved inorganic ions. Total dissolved (TDS) and suspended solids (TSS) values were increased from upper to lower stations and confirm the fluctuation trend of EC, which also demonstrated low influence of dissolved solids to the water quality.

Algal species diversity

A total of 201 species and infraspecies of algae were revealed in the Mardan River basin research sites (Table 2). Species richness was varied between sites with increasing from 122 in Sher Gharh to 176 in Mardan down the Mardan River channel. The tributary site 4–Katlang has 161 algal taxa that comparable to site 2–Takht Bhai. Table 3 and Figure 2 show that Bacillariophyta prevail in each studied community. Chlorophyta and Charophyta species richness were followed, while Cyanobacteria were on the fourth of the taxonomical position. Euglenoids and yellow–green algae were minimal diverse. These results are similar to species richness distribution in the Kabul River basin algal communities.[9,10] We revealed species of algae that indifferent to the environmental change in the studied sites and can see (Table 2) that common presented taxa overall sites were mostly diatoms (24), and greens (16), while charophytes and cyanobacteria have 12 and 11 taxa respectively. Only one species of Ochrophyta and Euglenozoa were participating in all studied communities. In other hand, the unique taxa that developed in only one community of studied sites can show individual properties of the site. They are *Oedogonium calcareum* from Chlorophyta, *Euglena deses* from Euglenozoa, and *Vaucheria longipes* from Ochrophyta which were found in the 4–Katlang community. Therefore, these three species can be marked as unique for studied sites as peculiarity of the tributary Katlang algal community. We compare taxonomic species richness with comparative floristics program and Figure 3 show two floristic clusters one of them combined upper sites of the Mardan River (Sher Gharh and Takht Bhai) while second cluster included lower part of the Mardan River and community of its tributary (Mardan and Katlang). We combine with yellow line the hydrologically relevant sites to the main stream of the Mardan River, can be seen that yellow communities are related to different clusters. In Dendrogram can be seen also that clusters were divided on so small percent of similarity like 17% for cluster 1 and 33% for cluster 2. It can characterize each studied community as rather individual nevertheless its species richness looks like similar in Table 2. Species richness overlapping can clarify this picture and show (Figure 4) that community of the site Mardan is floristic core for all studied sites. We combine with yellow line the hydrologically relevant sites to the main stream of the Mardan River and with blue line the most overlapped communities. Dendrite show very large percent of overlapping (more than 80%) for the lower polluted sites of the Mardan River (2,3) and its tributary (4) which marked by blue line. Only upper site of the Mardan River (1) have 71% of overlapping and therefore can be marked as reference site for studied communities.

Table 1 Physicochemical parameters of the water in different localities of district Mardan

No	Parameter	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
1	Temperature	18	21	27.7	26.4
2	pH	7.5	7.8	8.34	8.84
3	Turbidity	3.2	9.2	98	58
4	Electrical conductivity	260	365	607	306
5	Total dissolved solids	108	210	236	246
6	Total suspended solids	220	230	225	290

Table 2 Taxonomical content of algae in algal communities of the Mardan River basin sites, mean of 2016 four season sampling

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
Cyanobacteria					
1	*Anabaena cylindrica* Lemmermann	1	1	1	1
2	*Aphanocapsa grevillei* (Berkeley) Rabenhorst	0	1	1	1
3	*Chroococcus turgidus* (Kützing) Nägeli	0	1	1	1
4	*Chroococcus prescottii* Drouet & Daily	1	1	0	1
5	*Dolichospermum sigmoideum* (Nygaard) Wacklin, Hoffmann L & Komárek	1	1	1	1
6	*Gloeocapsa alpina* Nägeli	0	0	1	1
7	*Gloeocapsa rupestris* Kützing	1	1	1	1
8	*Kamptonema formosum* (Boryex Gomont) Strunecký, Komárek & Smarda J	1	1	1	1
9	*Limnococcus limneticus* (Lemmermann) Komárková, Jezberová, Komárek O & Zapomelová	1	1	1	0
10	*Limnoraphis birgei* (Smith GM) Komárek J, Zapomelová E, Smarda J, Kopecky J, Rejmánková E, Woodhouse J, Neilan BA & Komárková J	0	1	0	1
11	*Lyngbya lutea* Gomont ex Gomont	0	1	1	1
12	*Merismopedia convoluta* Brébisson ex Kützing	1	0	1	1
13	*Merismopedia tenuissima* Lemmermann	1	1	1	1
14	*Microcystis aeruginosa* (Kützing) Kützing	1	1	0	0
15	*Nostoc paludosum* Kützing ex Bornet & Flahault	0	1	1	1
16	*Oscillatoria curviceps* Agardh C ex Gomont	1	1	1	1
17	*Oscillatoria limosa* Agardh C ex Gomont	1	1	1	1
18	*Oscillatoria major* Vaucher ex Forti	1	1	1	1

Table Continued

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
19	*Oscillatoria ornata* Kützing ex Gomont	0	0	1	1
20	*Oscillatoria princeps* Vaucher ex Gomont	1	1	1	0
21	*Oscillatoria tenuis* C.Agardh ex Gomont	1	1	1	1
22	*Phormidium ambiguum* Gomont	1	1	0	1
23	*Phormidium diguetii* (Gomont) Anagnostidis & Komárek	1	1	1	1
24	*Phormidium irriguum* (Kützing ex Gomont) Anagnostidis & Komárek	0	1	1	1
25	*Phormidium puteale* (Montagne ex Gomont) Anagnostidis & Komárek	1	0	1	0
26	*Phormidium retzii* Kützing ex Gomont	1	1	1	1
27	*Phormidium stagninum* Anagnostidis	0	1	1	1
28	*Scytonema ocellatum* Lyngbye ex Bornet & Flahault	0	0	1	1
29	*Spirulina major* Kützing ex Gomont	1	1	1	0
Bacillariophyta					
30	*Amphora ovalis* (Kützing) Kützing	1	0	1	1
31	*Asterionella formosa* Hassall	1	1	1	1
32	*Aulacoseira granulata* (Ehrenberg) Simonsen	0	1	1	0
33	*Brachysira vitrea* (Grunow) R.Ross	1	1	1	1
34	*Caloneis bacillum* (Grunow) Cleve	1	1	1	1
35	*Chaetoceros radicans* Schütt F	0	1	0	1
36	*Cocconeis pediculus* Ehrenberg	0	1	1	1
37	*Cocconeis placentula* Ehrenberg	1	1	1	1
38	*Cocconeis scutellum* Ehrenberg	1	1	1	1
39	*Craticula ambigua* (Ehrenberg) Mann DG	1	1	1	1
40	*Craticula cuspidata* (Kutzing) Mann DG	0	1	1	1
41	*Cyclotella quillensis* Bailey LW	1	1	0	0
42	*Cymatopleura solea* var. vulgaris Meister	0	1	1	1
43	*Cymbella affinis* Kützing	1	1	1	1
44	*Cymbella tumida* (Brébisson) Van Heurck	1	1	0	1
45	*Cymbella vulgata* Krammer	1	1	1	0
46	*Cymbopleura cuspidata* (Kützing) Krammer	1	1	1	1
47	*Diatoma vulgaris* Bory	0	1	1	0
48	*Encyonema leibleinii* (Agardh C) Silva WJ, Jahn R, Veiga Ludwig TA & Menezes M	0	1	1	0
49	*Fragilaria acus* (Kützing) Lange–Bertalot	0	1	0	0
50	*Fragilaria capucina* Desmazières	0	1	1	1
51	*Fragilaria crotonensis* Kitton	1	0	1	1
52	*Frustulia rhomboides* (Ehrenberg) De Toni	1	1	1	1
53	*Frustulia vulgaris* (Thwaites) De Toni	1	1	1	1
54	*Gomphonema angustum* Agardh C	1	1	1	1
55	*Gomphonema olivaceum* (Hornemann) Brébisson	1	1	1	1
56	*Gomphonema parvulum* (Kützing) Kützing	1	0	1	0
57	*Gomphonema truncatum* Ehrenberg	0	0	1	1

Table Continued

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
58	*Gyrosigma acuminatum* (Kützing) Rabenhorst	1	1	1	0
59	*Gyrosigma attenuatum* (Kützing) Rabenhorst	1	1	1	1
60	*Gyrosigma kuetzingii* (Grunow) Cleve	0	1	1	1
61	*Gyrosigma wormleyi* (Sullivant) Boyer	1	1	0	1
62	*Halamphora normanii* (Rabenhorst) Levkov	0	1	1	1
63	*Iconella robusta* (Ehrenberg) Ruck & Nakov	1	1	1	0
64	*Lindavia comta* (Kützing) Nakov, Gullory, Julius, Theriot & Alverson	1	1	1	1
65	*Mastogloia danseyi* (Thwaites) Thwaites ex Smith W	1	1	1	1
66	*Mastogloia smithii* Thwaites ex W Smith	0	0	1	1
67	*Melosira varians* Agardh C	0	0	1	1
68	*Meridion circulare* (Greville) Agardh C	1	1	0	1
69	*Navicula cryptocephala* Kützing	1	1	1	0
70	*Navicula exilis* Kützing	1	1	1	1
71	*Navicula radiosa* Kützing	1	0	1	1
72	*Navicula rhynchocephala* Kützing	1	1	0	1
73	*Navicula tripunctata* (Müller OF) Bory	1	1	1	1
74	*Navicula veneta* Kützing	0	1	1	1
75	*Neidium ampliatum* (Ehrenberg) Krammer	0	1	1	1
76	*Neidium dubium* (Ehenberg) Cleve	1	1	1	1
77	*Nitzschia commutata* Grunow	0	1	1	1
78	*Nitzschia filiformis* (Smith W) Van Heurck	1	1	1	1
79	*Nitzschia linearis* Smith W	1	1	1	1
80	*Nitzschia paleacea* (Grunow) Grunow	1	1	1	1
81	*Nitzschia scalpelliformis* Grunow	0	0	1	1
82	*Nitzschia sigmoidea* (Nitzsch) Smith W	1	1	0	1
83	*Odontidium anceps* (Ehrenberg) Ralfs	1	1	1	1
84	*Pinnularia globiceps* Gregory W	0	0	1	1
85	*Pinnularia major* (Kützing) Rabenhorst	0	1	1	0
86	*Pinnularia microstauron* (Ehrenberg) Cleve	1	1	0	1
87	*Pinnularia viridis* (Nitzsch) Ehrenberg	1	1	1	1
88	*Placoneis gastrum* (Ehrenberg) Mereschkowsky	1	1	1	1
89	*Sellaphora pupula* (Kützing) Mereschkovsky	0	1	1	1
90	*Stauroneis acuta* Smith W	1	0	1	1
91	*Stauroneis anceps* Ehrenberg	0	1	1	1
92	*Stenopterobia sigmatella* (Gregory W) Ross R	1	1	0	1
93	*Surirella cruciata* Schmidt AWF	0	1	1	1
94	*Surirella librile* (Ehrenberg) Ehrenberg	1	1	1	0
95	*Surirella ovalis* Brébisson	1	0	1	1
96	*Tryblionella hungarica* (Grunow) Frenguelli	1	1	0	0
97	*Ulnaria danica* (Kützing) Compère & Bukhtiyarova	1	1	1	1

Table Continued

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
98	*Ulnaria ulna* (Nitzsch) Compère	0	1	1	1
99	*Urosolenia longiseta* (Zacharias O) Edlund & Stoermer	1	0	1	1
Ochrophyta					
100	*Tribonema elegans* Pascher	0	1	1	1
101	*Tribonema minus* (Wille) Hazen	0	1	1	1
102	*Vaucheria longipes* Collins	0	0	0	1
103	*Vaucheria undulata C* –Jao C	1	1	1	1
Euglenozoa					
104	*Euglena deses* Ehrenberg	0	0	0	1
105	*Euglena elastica* Prescott	1	0	1	0
106	*Euglena gracilis* Klebs GA	1	1	1	1
107	*Euglena oblonga* Schmitz F	0	1	1	0
108	*Euglenaformis proxima* (Dangeard) Bennett MS & Triemer	0	1	1	1
109	*Monomorphina pyrum* (Ehrenberg) Mereschkowsky	1	1	1	0
110	*Phacus acuminatus* Stokes	0	1	1	1
111	*Phacus elegans* Pochmann	0	1	1	0
112	*Phacus triqueter* (Ehrenberg) Perty	0	0	1	1
113	*Trachelomonas superba* Svirenko	1	0	1	1
Chlorophyta					
114	*Acutodesmus acutiformis* (Schröder) Tsarenko & John DM	0	1	1	1
115	*Ankistrodesmus falcatus* (Corda) Ralfs	1	1	1	1
116	*Chaetophora elegans* (Roth) Agardh C	1	0	1	1
117	*Chaetophora pisiformis* (Roth)Agardh C	1	1	1	1
118	*Chlamydomonas angulosa* Dill O	1	1	1	1
119	*Chlamydomonas debaryana* Goroschankin	0	1	1	0
120	*Chlamydomonas ehrenbergii* Gorozhankin	1	1	1	1
121	*Chlamydomonas globosa* Snow JW	0	1	1	1
122	*Chlorella vulgaris* Beyerinck	1	1	1	1
123	*Cladophora glomerata* (Linnaeus) Kützing	1	1	1	1
124	*Coelastrum astroideum* De Notaris	1	0	1	1
125	*Coelastrum sphaericum* Nägeli	1	1	1	1
126	*Desmodesmus opoliensis* (Richter PG) Hegewald E	1	1	1	1
127	*Geminella minor* (Nägeli) Heering	1	1	1	1
128	*Gloeocystis major* Gerneck ex Lemmermann	0	0	1	1
129	*Haematococcus lacustris* (Girod–Chantrans) Rostafinski	1	0	1	1
130	*Hydrodictyon reticulatum* (Linnaeus) Bory	1	1	1	1
131	*Kirchneriella cornuta* Korshikov	1	1	1	0
132	*Kirchneriella obesa* (West) West & West GS	1	1	1	1
133	*Lychaete dotyana* (Gilbert WJ) Wynne MJ	1	1	1	1

Table Continued

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
134	*Monactinus simplex* (Meyen) Corda	1	1	1	1
135	*Monoraphidium mirabile* (West & West GS) Pankow	0	0	1	1
136	*Oedogonium angustistomum* Hoffman	1	1	1	1
137	*Oedogonium anomalum* Hirn	1	1	1	1
138	*Oedogonium calcareum* Cleve & Wittrock	0	0	0	1
139	*Oedogonium cardiacum* Wittrock ex Hirn	1	1	1	1
140	*Oedogonium punctatum* Wittrock ex Hirn	0	1	1	1
141	*Oedogonium tyrolicum* Wittrock ex Hirn	0	1	1	0
142	*Pandorina morum* (Müller OF) Bory	0	1	0	1
143	*Protosiphon botryoides* (Kützing) Klebs	0	1	1	1
144	*Rhizoclonium fontanum* Kützing	0	1	1	0
145	*Scenedesmus obtusus* Meyen	0	1	1	0
146	*Scenedesmus parisiensis* Chodat	0	1	1	1
147	*Schizomeris leibleinii* Kützing	1	1	0	1
148	*Selenastrum capricornutum* Printz	1	1	1	1
149	*Sphaerellocystis ampla* (Kützing) Nováková	1	1	1	0
150	*Sphaerocystis schroeteri* Chodat	0	0	1	1
151	*Stigeoclonium attenuatum* (Hazen) Collins	0	1	0	1
152	*Stigeoclonium helveticum* Vischer	1	1	1	0
153	*Stigeoclonium lubricum* (Dillwyn) Kützing	0	1	1	0
154	*Stigeoclonium nanum* (Dillwyn) Kützing	1	0	1	1
155	*Tetradesmus dimorphus* (Turpin) Wynne MJ	1	1	1	0
156	*Tetradesmus obliquus* (Turpin) Wynne MJ	1	0	0	1
157	*Ulothrix cylindrica* Prescott	0	0	1	1
158	*Ulothrix tenerrima* (Kützing) Kützing	1	0	1	1
159	*Ulothrix zonata* (Weber F & Mohr) Kützing	1	1	1	0
Charophyta					
160	*Chara aspera* Willdenow CL	0	1	1	0
161	*Chara braunii* var. schweinitzii (Braun A) Zaneveld	0	0	1	1
162	*Chara globularis* Thuiller	0	1	1	1
163	*Chara vulgaris* Linnaeus	1	1	1	1
164	*Closterium acerosum* Ehrenberg ex Ralfs	1	1	1	1
165	*Closterium angustatum* Kützing ex Ralfs	0	1	1	1
166	*Closterium attenuatum* Ralfs	0	1	1	1
167	*Closterium baillyanum* (Brébisson ex Ralfs) Brébisson	0	1	1	1
168	*Closterium lunula* Ehrenberg & Hemprich ex Ralfs	1	0	1	1
169	*Closterium parvulum* Nägeli	1	0	1	0
170	*Closterium turgidum* Ehrenberg ex Ralfs	1	1	1	1
171	*Cosmarium biretum* Brébisson ex Ralfs	1	1	1	1

Table Continued

No	Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
172	*Cosmarium botrytis* Meneghini ex Ralfs	0	0	1	1
173	*Cosmarium formosulum* Hoff	1	1	1	1
174	*Cosmarium granatum* Brébisson ex Ralfs	1	1	1	1
175	*Cosmarium nitidulum* De Notaris	1	0	1	1
176	*Cosmarium reniforme* (Ralfs) Archer W	0	1	0	1
177	*Cosmarium subcrenatum* Hantzsch	1	1	1	1
178	*Cosmarium undulatum* Corda ex Ralfs	0	1	1	1
179	*Mougeotia robusta* (De Bary) Wittrock	1	1	1	1
180	*Mougeotia scalaris* Hassall	1	1	1	0
181	*Spirogyra bellis* (Hassall) Crouan P & Crouan H	0	0	1	1
182	*Spirogyra borgeana* Transeau	1	1	1	1
183	*Spirogyra condensata* (Vaucher) Dumortier	1	0	1	1
184	*Spirogyra crassa* (Kützing) Kützing	0	1	1	0
185	*Spirogyra daedalea* Lagerheim	0	1	1	1
186	*Spirogyra formosa* (Transeau) Czurda	1	1	1	1
187	*Spirogyra groenlandica* Rosenvinge	1	0	1	1
188	*Spirogyra inflata* (Vaucher) Dumortier	0	1	1	1
189	*Spirogyra jugalis* (Dillwyn) Kützing	0	1	1	0
190	*Spirogyra maxima* (Hassall) Wittrock	1	1	1	1
191	*Spirogyra parvula* (Transeau) Czurda	0	1	1	1
192	*Spirogyra porticalis* (Müller OF) Dumortier	1	1	1	1
193	*Spirogyra pratensis* Transeau	0	1	1	0
194	*Spirogyra ternata* Ripart	1	1	1	1
195	*Spirogyra varians* (Hassall) Kützing	1	1	1	1
196	*Spirogyra weberi* Kützing var. weberi	0	1	0	1
197	*Spirogyra weberi* var. grevilleana (Hassal) O.Kirchner	1	0	1	1
198	*Zygnema giganteum* Randhawa	0	1	1	0
199	*Zygnema parvulum* (Kützing) Cooke	1	1	0	1
200	*Zygnema vaginatum* Klebs	0	1	1	0
201	*Zygogonium ericetorum* Kützing	1	1	1	1
Total taxa		**122**	**159**	**176**	**161**

Algal diversity fluctuation in four studied sites was measured by Margalef index used for species richness, Pielou's evenness index used for species evenness, Simpson's index used for species dominance and Shannon–Wiener index used as a combine Index of ecological diversity (Table 4). Values for Margalef index in Mardan research site was (27.052), followed by Katlang (26.098) and Takht Bhai (25.696) research sites. Minimum species richness (21.740) was found in Sher Gharh site. Values for Pielou′s index of species evenness was maximum (0.864) in Sher Gharh research site followed by Katlang (0.860) and Mardan (0.855) research sites. Minimum species evenness (0.854) was found in Takht Bhai research site. Species dominance was high in Mardan (0.983) research site followed by Katlang (0.9826) and Takht Bhai (0.980) research sites. Minimum species dominance (0.978) was found in Sher Gharh research site. Highest valve (5.00) was recorded for combine Index of ecological diversity Shannon–Wiener in Mardan research site followed by Katlang (4.98) and Takht Bhai (4.931) research sites. Minimum value (4.809) was recorded for combine Index of ecological diversity in Sher Gharh research site. It let us to conclude that Margalef index of species richness and Shannon–Wiener index of community structure complication can be used for assessment of the ecological state of the River Mardan because reflect the difference between reference and polluted sites, whereas Pielou's evenness index and Simpson's index of species dominance show very close values in the studied communities. These results are similar to our calculation for the Kabul River communities.[9,10] The correlations between environmental variables and species richness for the studied sites of The Mardan River were calculated on the base of Table 1 and Table 3. So, Pearson coefficients of positive correlation were significant for the pair TDS and Species Richness (0.94, $p<0.03$), TDS and Bacillariophyta (0.95, $p<0.02$), TDS and Cyanobacteria (0.97, $p<0.02$), TDS and Charophyta (0.93, $p<0.03$). In the same time, the Temperature have positive correlation with Chlorophyta (0.91, $p<0.04$), and with Charophyta species number (0.90, $p<0.05$). Given the Pearson correlation coefficients, the major environmental variables that influenced algal communities in the Mardan River can be water temperature and TDS. We then decided to construct the surface plots for these and other water variables (Table 1) and species richness in algal communities on the Divisional level (Table 3). Figure 5 shows that species richness is preferred high water temperature, Electrical conductivity and Total suspended solids but lower water pH. Similar set of variables that influenced algal communities was revealed during investigation of close placed rivers Swat and Kabul of the same Kabul River basin[9,10] with using statistical methods.

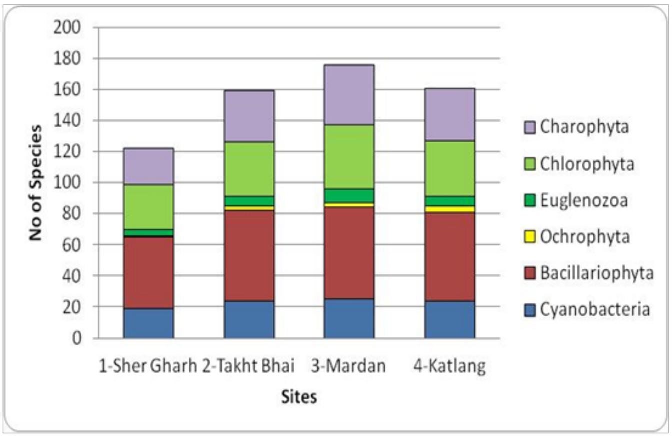

Figure 2 Taxonomical diversity fluctuations over the studied sites of the Mardan River in 2016.

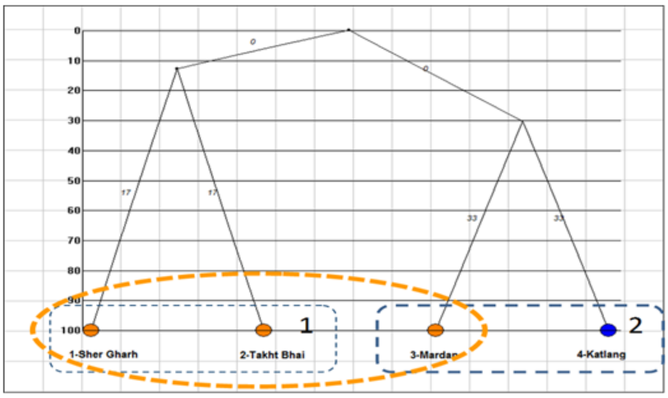

Figure 3 Taxonomical diversity comparison with Euclidean distance dendrogram for algal communities in studied sites of the Mardan River 2016.

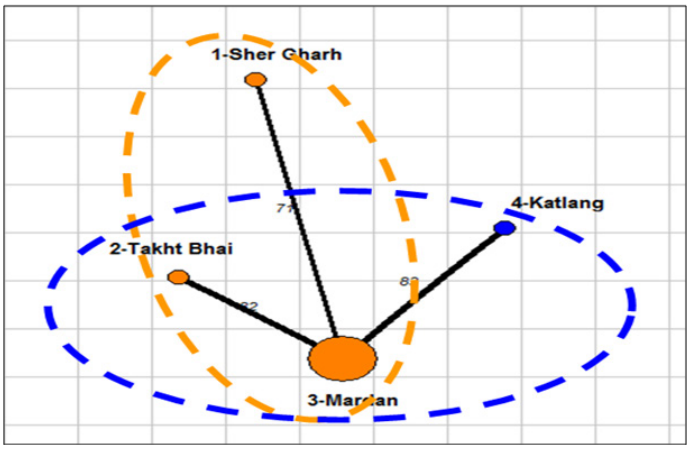

Figure 4 Taxonomical diversity overlapping dendrite for algal communities of the studied sites in the Mardan River 2016.

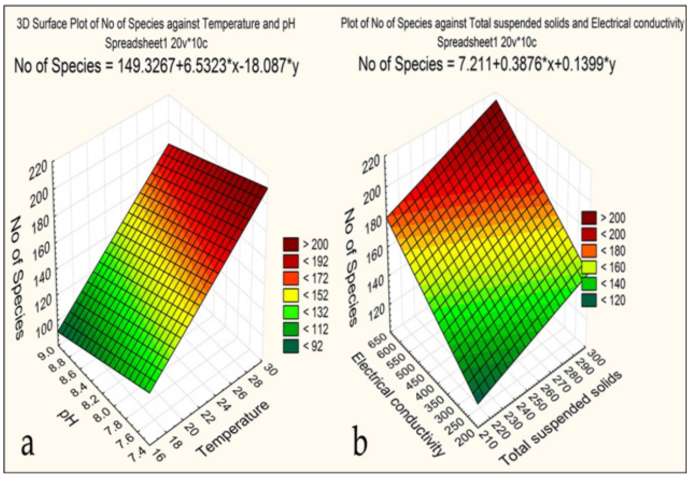

Figure 5 Surface plots for algal communities and environmental variables of the studied sites in the Mardan River 2016.

a. Distribution of algal species richness over water pH and Temperature,

b. over electrical conductivity and total suspended solids.

Table 3 Taxonomical composition of algal communities in the Mardan River in four sampling sites in 2016

Taxa	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
Cyanobacteria	19	24	25	24
Bacillariophyta	46	58	59	57
Ochrophyta	1	3	3	4
Euglenozoa	4	6	9	6
Chlorophyta	29	35	41	36
Charophyta	23	33	39	34
Total taxa	**122**	**159**	**176**	**161**

Table 4 Algal diversity indices estimation for the Mardan River algal communities, 2016

No	Index	1-Sher Gharh	2-Takht Bhai	3-Mardan	4-Katlang
1	Margalef index (D)	21.740	25.696	27.051	26.098
2	Pielou's index (J')	0.864	0.854	0.855	0.860
3	Simpson's index (D)	0.978	0.980	0.983	0.982
4	Shannon-Wiener index (H')	4.809	4.931	5.00	4.98

Conclusion

Our investigation in the Mardan River basin shows that water variables fluctuated dramatically with increasing of temperature and TDS in the lower part of the river and its tributary. Nevertheless, water pollution is more correlated with organic matter than with dissolved inorganic ions as can be seen in analysis of relationships between chemical and biological variables. Altogether 201 species and infraspecies of algae were revealed in first time in the Mardan River basin in which Bacillariophyta is prevailing in each studied community. Chlorophyta and Charophyta species richness were the next, while Cyanobacteria were on the fourth position from six revealed taxonomic Divisions. Species richness distribution over studied sites was very similar in the most of the Mardan sites and demonstrated that algae were indifferent to the environmental change in the studied river basin. Only three species can be marked as unique for studied sites as peculiarity of the tributary Katlang algal community. Comparative floristics reveals two floristic clusters in which species of communities were divided on small percent of similarity about 17%. This can characterize each studied community as rather individual nevertheless its species richness looks like similar in Divisional level. As a result of comparison, the Mardan site is floristic core of studied algal diversity that overlapped more than 80% between sites and the Sher Gharh site can be named as the referenced site for the Mardan River algal communities. Calculation of diversity indices for studied communities shows that Margalef index of species richness and Shannon–Wiener index of community structure compliance can be used for assessment of the ecological state of the Mardan River. Investigation of algal community response to the environmental variables by Pearson coefficients demonstrated positive correlation between TDS and species richness, Bacillariophyta, Cyanobacteria, and Charophyta species number, whereas water temperature stimulated Chlorophyta and Charophyta species richness. Therefore, the major variables that influenced algal communities in the Mardan River basin were water temperature and TDS. Statistically constructed 3D Surface plots also confirm that species richness increased in high water temperature, Electrical conductivity and Total suspended solids but preferred lower water pH. These three parameters can be used for monitoring of the river's ecosystem health because they are influenced algal communities responsible for the self–purification process in the studied Mardan River basin.

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Conflict of interest

None.

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