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Bioindication of water quality by algal communities in the Mardan River, Pakistan

Abstract: The first results of ecological assessment of water quality in the Mardan River and its tributary Kaltang is representing as a results of implementation of bioindication methods and statistical approaches. Altogether 165 taxa-indicators of algae from six taxonomic Divisions were revealed for the communities of three sites in the Mardan River main stream and one site of its left tributary Kaltang. Diatom algae with subdominants of greens, charophytes and cyanobacteria mostly dominated algal communities. Species richness was higher in the lower part of studied river in site Mardan, but community structure was similar in all four studied sites. Water variables values were fluctuated in small range excluding temperature and turbidity, which dramatically increased down the river. Bioindicators distribution reflect pollution impact to the river ecosystem by toxicants and dissolved organic matters that start form the middle reaches of the river when it follow across the flatland. Statistical analysis of species-environmental variables relationships with 3D plots construction revealed that algal species grow is dependent mostly with water temperature, whereas impacted by turbidity. Nevertheless, the self-purification properties of the Mardan River ecosystem were in high level.
Key words: algae, bioindication, water quality, Mardan river, Pakistan.

Introduction

Pollution in the freshwater aquatic objects is complicated system. When water variables that reflect water quality can be measured directly, this need resources and expenses. Unfortunately, in the developing countries have not resources for full water quality monitoring whereas the water quality is decreasing year by year. In this situation can help the bioindication methods and indices that used for assessment of pollution impact on the natural water bodies and based on the ecological point of view to the water and biota relationships [1; 2]. The first level of the trophic pyramid, the algae, is define all processes in the aquatic ecosystems and therefore can be used for assessment of water properties with help of its community structure and species ecology [3]. Algae reflect all natural and anthropogenic processes occurring in water bodies with help of developed systems of indication [4]. A bioindication using algae community is inexpensive express-method as compared to chemical analysis. Up to now, the diversity of algae was used in bioindication methods as a tool to monitor water quality of the rivers and lakes in many countries of the southern Eurasia [5-17].

The major problem in the Mardan River as in all Pakistan rivers is of the water quality decreasing during recent years as a result of increasing of pollution in this settled area with increasing agriculture. There are water from municipalities and agriculture provides a continuous input of nutrient and suspended solids into the river water. In Pakistan, algae have been reported from various freshwater habitats to know their environmental role and ecological distribution [19-23] but bioindication methods were implemented effectively for only the Kabul River itself and its tributary Swat up to now [7-9; 24].

The aim of present work was to reveal algal species indicators in the Mardan River and its tributary and to assess water quality with bioindication methods and statistics.

District Mardan is a part of the Peshawar valley in Pakistan. It lies between 34° 05’ to 34° 32’ north latitudes and 71° 48’ to 72° 25’ east longitudes. It

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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 1632 square kilometers [25]. Generally, streams and rivers flow from north to the south and west to the east. Most of the streams falls into the River Kabul. An important stream (Kalpani) of the district comes out from Baizai and flows in northwards direction and falls into the River Kabul. The Mardan River start after narrow canal from the northern part of the Kabul River basin where the Swat River flow. So, practically the Mardan River is a second part of the lower reaches of the Swat River, the first part of it follow across the reservoir to the west and after it wriggles in the mountains with input to the Kabul River from the north. The river basin of the Mardan River is mostly placed on the flat territory with developed agriculture. The main city in the river basin is Mardan that very settled and take large place in the river basin surface. The left tributary of the Mardan River also start from foothill and later follow across the lowlands up to input to the River Mardan after the Mardan city and above the Mardan River input to the Kabul River (Figure 1).

Figure 1 – Sampling sites in the Mardan River basin (yellow buttons), the left tributary of the Kabul River (blue buttons) in Peshawar valley

Materials and methods

Four research sites in the Mardan River were selected for sampling (Figure 1) in purpose to assessment the water quality in the district Mardan. Sites Sher Gharh, Takht Bhai, and Mardan has been chosen in the Mardan River itself, but the site Katlang is represent upper part of the left tributary of the Mardan River. These sites were chosen as critical points of the river Mardan water quality changes in the results of pollution input of numerous pollutants from different sources to the water which flow down across agriculturally used areas. The sampling points were chosen during the field trips with help of visual assessment of pollution because sampling for ecological assessment of the Mardan River was doing in first time.

A total 35 algal and 35 water samples were collected from each the research sites at 120-meter radius in different seasons of 2016. Algal samples were collected from water by scooping, as well as by scratching of floating habitat, attached with stones, submerged plants, and on sidewalls of ponds, streams and river. The collected material was placed into plastic bottles of 25 ml and transported in icebox to the laboratory of Department of Botany, Islamia College, University of Peshawar. The specimens were preserved in 4% formaldehyde solution. Temperature and pH of the water were determine with the help of portable pH meter HANNA-8414 on the sampling point, while electrical conductivity (EC), turbidity, total dissolved solids (TDS) and total suspended solids (TSS) were measured in the laboratory by using standard techniques.

Algal species identification was doing with microscope Nikon Lambda E2000 viewed at ×10, ×40 and ×100 objectives. Images of the algal species were captured with help of digital camera. Micrometric measurement (length and width) for each algal species has taken with ocular micrometer. Standard references were used for algal taxonomical identification [26-31]. Modern taxonomy was adapted with algaebase.org [32]. Bioindication properties of each revealed species comes from our world database [33; 34]. Statistical analysis of the data for the species diversity, indicators and water variables relationships was doing by 3D Surface plots using the Statistica 12.0 Program.

Results and discussion

Water variables

Fluctuation of six physiochemical variables of the river water was revealed for four studied sites of the Mardan River basin in 2016 (Table 1). Water temperature 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 was dramatically increase in lower sites 3-Mardan and 4-Katlang up to 98 NTU and 58 NTU respectively. Electrical conductivity (EC) also increased from 260 µS cm^{-1} in 1-Sher Gharh to 607 µS cm^{-1} in 3-Mardan. Site 4-Katlang electrical conductivity was similar of it in site 2-Takht Bhai. Total dissolved (TDS) and suspended solids (TSS) values were increase from upper to lower stations and confirm the fluctuation trend of EC, which also demonstrated low influence of dissolved solids to the water quality. Comparison of environmental variables fluctuation have demonstrated strong influence of water turbidity to EC, dissolved and suspended solids. Increasing of water temperature and turbidity in the lower sites can be result of flattened the landscape in the river basin as well as increasing of agricultural effluents down the river.

Table 1 – Mean of measured variables of the water in studied sites of the Mardan River (1-3) and its tributary Katlang (4) in 2016

Variable	Sher Gharh (1)	Takht Bhai (2)	Mardan (3)	Katlang (4)
Temperature, C°	18	21	27.7	26.4
pH	7.5	7.8	8.34	8.84
Turbidity	3.2	9.2	98	58
Electrical conductivity, µS cm^{-1}	260	365	607	306
Total dissolved solids, mg l^{-1}	108	210	236	246
Total suspended solids, mg l^{-1}	220	230	225	290

Bioindication

We revealed 165 taxa with known ecological preferences from total 201 species of algae of the Mardan River communities [24] that can be used as indicators of nine environmental variables (Table 2). Its taxonomic Divisional distribution over the studied sites can see in Figure 2. Diatoms prevail in all sites with maximal diversity in the site 3-Mardan. It can give the best opportunity for bioindication because the diatoms is mostly studied in regards of species ecological properties and have most developed bioindication properties as can be seen in Table 2. So, algae indicators prefer benthic and plankto-benthic lifestyle in the Mardan River (Figure 2). They are indicators of temperate water temperature and middle oxygenated slow streaming low-alkaline and low saline water (Figure 2, 3). Organic pollution diatom indicators according Watanabe and species-indicators from all Divisions according Sládeček reflects middle level of pollution corresponds to Class 2 and 3 of water quality (Figure 3). Trophic state indicators are diverse and related to six from seven known trophic groups. Indicators of mesotrophic state are increased down the river whereas oligotrophes decrease with the same contain in the sites 3-Mardan and 4-Kaltang (Figure 4). Indicators of the nutrition type for algal species can show toxic impact if present. But no, distribution of indicator groups of autotrophy-heterotrophy in Figure 4 show strongly prevalence of autotrophic organisms with photosynthetic way of proteins creation and therefore survived without sufficient toxic impact.

Table 2 – Algae indicator species in communities of the Mardan River basin sites, 2016. Sampling sites: (1) Sher Gharh; (2) Takht Bhai; (3) Mardan; (4) Katlang. Substrate preferences (P – planktonic, P-B – plankto-benthic, B – benthic, Ep – epiphyte, S – soil); Temperature preferences (cool – cool-water, temp – temperate, eterm – eurythermic, warm – warm-water); Oxygenation and streaming (st – standing water, str – streaming water, st-str – low streaming water, aer – aerophiles); Salinity ecological groups (hb – oligohalobes-halophobes, i – oligohalobes-indifferents, mh – mesohalobes, hl – halophiles); Saprobity groups of diatoms (sx – saproxenes, es – eurysaprobes, sp – saprophiles); pH preferences range (alb – alkalibiontes; alf – alkaliphiles, ind – indifferents; acf – acidophiles; neu – neutrophiles as a part of indifferents); Nitrogen uptake metabolism preferences (ats – nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; ate – nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen; hne – facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen; hce – obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen); Trophic state indicators (ot – oligotraphentic; o-m – oligo-mesotraphentic; m – mesotraphentic; me – meso-eutraphentic; e – eutraphentic; o-e – oligo- to eutraphentic (hypereutraphentic)); S – Index saprobity S.

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Cyanobacteria														
Anabaena cylindrica Lemmermann	1	1	1	1	P-B,S	-	aer	-	-	-	b-o	1.7	-	-
Aphanocapsa grevillei (Berkeley) Rabenhorst	0	1	1	1	P	-	-	-	hb	-	o-b	1.4	-	-
Chroococcus turgidus (Kützing) Nägeli	0	1	1	1	P-B,S	-	aer	alf	hl	-	x-b	0.8	-	-
Chroococcus prescottii Drouet & Daily	1	1	0	1	P	-	-	-	-	-	-	-	o	-
Dolichospermum sigmoideum (Nygaard) Wacklin, L.Hoffmann & Komárek	1	1	1	1	P	-	-	-	i	-	o-a	2	e	-
Gloeocapsa alpina Nägeli	0	0	1	1	Ep,S	-	aer	-	-	-	-	-	-	-
Gloeocapsa rupestris Kützing	1	1	1	1	Ep,S	-	aer	-	-	-	-	-	-	-
Kamptonema formosum (Bory ex Gomont) Strunecký, Komárek & J.Smarda	1	1	1	1	P-B,S	-	st	-	-	-	a	3.1	me	-
Limnococcus limneticus (Lemmermann) Komárková, Jezberová, O.Komárek & Zapomelová	1	1	1	0	P	-	-	-	i	-	b-o	1.7	om	-
Limnoraphis birgei (G.M.Smith) J.Komárek, E.Zapomelová, J.Smarda, J.Kopecky, E.Rejmánková, J.Woodhouse, B.A.Neilan & J.Komárková	0	1	0	1	P-B	-	st	-	-	-	-	-	-	-
Lyngbya lutea Gomont ex Gomont	0	1	1	1	P-B	-	-	-	mh	-	-	-	-	-
Merismopedia convoluta Brébisson ex Kützing	1	0	1	1	P-B	-	-	-	-	-	b-a	2.5	om	-
Merismopedia tenuissima Lemmermann	1	1	1	1	P-B	-	-	-	hl	-	b-a	2.4	e	-
Microcystis aeruginosa (Kützing) Kützing	1	1	0	0	P	-	-	-	hl	-	b	2.1	e	-
Nostoc paludosum Kützing ex Bornet & Flahault	0	1	1	1	P-B,S	-	st	-	-	-	b-o	1.6	m	-
Oscillatoria curviceps C.Agardh ex Gomont	1	1	1	1	P-B	-	st-str	-	i	-	x-a	1.6	me	-

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Oscillatoria limosa C.Agardh ex Gomont	1	1	1	1	P-B	-	st-str	-	hl	-	a-o	2.6	e	-
Oscillatoria major Vaucher ex Forti	1	1	1	1	B,Ep	-	-	-	-	-	b	2.3	m	-
Oscillatoria ornata Kützing ex Gomont	0	0	1	1	P-B,S	-	st-str	-	i	-	o-b	1.5	om	-
Oscillatoria princeps Vaucher ex Gomont	1	1	1	0	P-B,S	-	st-str	-	-	-	a-o	2.8	om	-
Oscillatoria tenuis C.Agardh ex Gomont	1	1	1	1	P-B,S	-	st-str	-	hl	-	a-o	2.6	me	-
Phormidium ambiguum Gomont	1	1	0	1	B,S	eterm	st-str	ind	i	-	b	2.3	me	-
Phormidium irriguum (Kützing ex Gomont) Anagnostidis & Komárek	0	1	1	1	B,Ep	-	aer	-	-	-	-	-	me	-
Phormidium puteale (Montagne ex Gomont) Anagnostidis & Komárek	1	0	1	0	B,S	-	st-str	-	-	-	-	-	-	-
Phormidium retzii Kützing ex Gomont	1	1	1	1	B,S	-	st-str	-	-	-	o-b	1.4	o	-
Phormidium stagninum Anagnostidis	0	1	1	1	B,Ep	-	-	-	-	-	-	-	om	-
Scytonema ocellatum Lyngbye ex Bornet & Flahault	0	0	1	1	S	-	-	-	-	-	-	-	-	-
Spirulina major Kützing ex Gomont	1	1	1	0	P-B,S	warm	st	-	hl	-	a	3.4	-	-
Bacillariophyta														
Amphora ovalis (Kützing) Kützing	1	0	1	1	B	temp	st-str	alf	i	sx	o-b	1.5	me	ate
Asterionella formosa Hassall	1	1	1	1	P	-	st-str	alf	i	sx	o	1.4	om	ate
Aulacoseira granulata (Ehrenberg) Simonsen	0	1	1	0	P-B	temp	st-str	ind	i	es	b	2	me	ate
Brachysira vitrea (Grunow) R.Ross	1	1	1	1	B	-	st-str	alb	i	es	x-o	0.5	om	ats
Caloneis bacillum (Grunow) Cleve	1	1	1	1	B	temp	st-str	ind	i	es	o	1.3	me	ats
Cocconeis pediculus Ehrenberg	0	1	1	1	B	-	st-str	alf	i	sx	o-a	1.8	me	ate
Cocconeis placentula Ehrenberg	1	1	1	1	P-B	temp	st-str	alf	i	es	o	1.4	me	ate
Cocconeis scutellum Ehrenberg	1	1	1	1	B	-	-	-	hl	-	-	-	-	-
Craticula ambigua (Ehrenberg) D.G.Mann	1	1	1	1	B	warm	st	alf	i	es	b	2.3	me	-
Craticula cuspidata (Kutzing) D.G.Mann	0	1	1	1	B	temp	st-str	alf	i	es	b-a	2.5	me	-
Cymatopleura solea var. *vulgaris* Meister	0	1	1	1	B	-	-	ind	i	-	-	-	-	-
Cymbella affinis Kützing	1	1	1	1	B	temp	st-str	alf	i	sx	o	1.1	ot	ats

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Cymbella tumida (Brébisson) Van Heurck	1	1	0	1	B	temp	str	alf	i	sx	b	2.2	me	ats
Cymbella vulgata Krammer	1	1	1	0	B	-	-	ind	-	-	o	1	ot	-
Cymbopleura cuspidata (Kützing) Krammer	1	1	1	1	P-B	temp	-	ind	i	-	o-a	1.8	om	-
Diatoma vulgaris Bory	0	1	1	0	P-B	-	st-str	ind	i	sx	b	2.2	me	ate
Fragilaria acus (Kützing) Lange-Bertalot	0	1	0	0	P	-	st-str	alb	i	es	o-a	1.8	-	-
Fragilaria capucina Desmazières	0	1	1	1	P-B	-	-	ind	i	es	b-o	1.6	m	-
Fragilaria crotonensis Kitton	1	0	1	1	P	-	st-str	alf	I	es	o-b	1.5	m	ate
Frustulia rhomboides (Ehrenberg) De Toni	1	1	1	1	B	-	st	acf	hb	es	x	0.3	ot	ats
Frustulia vulgaris (Thwaites) De Toni	1	1	1	1	P-B	-	st	alf	i	es	o-a	1.8	me	ate
Gomphonema angustum C.Agardh	1	1	1	1	B	-	st-str	ind	i	es	o	1.1	ot	ats
Gomphonema olivaceum (Hornemann) Brébisson	1	1	1	1	B	-	st-str	alf	i	es	o-b	1.5	e	ate
Gomphonema parvulum (Kützing) Kützing	1	0	1	0	B	temp	str	ind	i	es	b	2.4	om	hne
Gomphonema truncatum Ehrenberg	0	0	1	1	B	-	st-str	ind	i	es	o-b	1.4	me	ats
Gyrosigma acuminatum (Kützing) Rabenhorst	1	1	1	0	B	cool	st-str	alf	i	es	o-a	2	me	ate
Gyrosigma attenuatum (Kützing) Rabenhorst	1	1	1	1	P-B	-	st	alf	i	-	o-a	1.8	om	ate
Gyrosigma wormleyi (Sullivant) Boyer	1	1	0	1	B	-	-	alf	hl	-	b	2	om	-
Halamphora normanii (Rabenhorst) Levkov	0	1	1	1	B	-	ae	alf	hb	-	x	0.1	m	ats
Iconella robusta (Ehrenberg) Ruck & Nakov	1	1	1	0	P-B	-	st-str	ind	I	es	x-o	0.5	ot	-
Lindavia comta (Kützing) Nakov, Gullory, Julius, Theriot & Alverson	1	1	1	1	P	-	st	alf	i	sx	o	1.2	om	-
Mastogloia danseyi (Thwaites) Thwaites ex W.Smith	1	1	1	1	B	-	-	alf	mh	-	o	1	-	-
Mastogloia smithii Thwaites ex W.Smith	0	0	1	1	B	-	-	alf	mh	sx	o	1.3	me	-
Melosira varians C.Agardh	0	0	1	1	P-B	temp	st-str	ind	hl	es	b	2.1	me	hne
Meridion circulare (Greville) C.Agardh	1	1	0	1	B	-	str	ind	i	es	o	1.1	om	ate
Navicula cryptocephala Kützing	1	1	1	0	P-B	temp	st-str	ind	i	es	b	2.1	oe	ate
Navicula exilis Kützing	1	1	1	1	B	-	-	alb	hl	es	x-b	0.8	ot	-
Navicula radiosa Kützing	1	0	1	1	B	temp	st-str	ind	i	es	o	1.3	me	ate

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Navicula rhynchocephala Kützing	1	1	0	1	B	-	-	alf	hl	-	o-a	2	om	ate
Navicula tripunctata (O.F.Müller) Bory	1	1	1	1	P-B	-	st-str	ind	i	es	b-o	1.7	e	ate
Navicula veneta Kützing	0	1	1	1	B	-	-	alf	hl	es	a-o	2.7	-	-
Neidium ampliatum (Ehrenberg) Krammer	0	1	1	1	B	-	st	ind	I	es	o-x	0.6	ot	-
Neidium dubium (Ehenberg) Cleve	1	1	1	1	B	-	str	alf	i	-	b-o	1.7	me	ats
Nitzschia commutata Grunow	0	1	1	1	P-B	-	-	alf	mh	-	b	2	-	-
Nitzschia filiformis (W.Smith) Van Heurck	1	1	1	1	P-B	-	st-str	alf	hl	es	b-a	2.5	e	hne
Nitzschia linearis W.Smith	1	1	1	1	B	temp	st-str	alf	i	es	b-o	1.7	me	ate
Nitzschia paleacea (Grunow) Grunow	1	1	1	1	P-B	-	st-str	alf	i	es	b	2.2	e	hce
Nitzschia scalpelliformis Grunow	0	0	1	1	B	-	-	alf	hl	sp	b	2	me	-
Nitzschia sigmoidea (Nitzsch) W.Smith	1	1	0	1	P-B	-	st-str	alf	i	-	b-a	2.5	e	ate
Odontidium anceps (Ehrenberg) Ralfs	1	1	1	1	P-B	cool	st-str	neu	hb	sx	o-x	0.6	ot	-
Pinnularia globiceps W.Gregory	0	0	1	1	B	-	-	acf	i	-	x	0.2	om	-
Pinnularia major (Kützing) Rabenhorst	0	1	1	0	B	temp	st-str	ind	i	-	o-x	0.6	me	ate
Pinnularia microstauron (Ehrenberg) Cleve	1	1	0	1	P-B	temp	st-str	ind	i	sp	o-x	0.7	ot	ate
Pinnularia viridis (Nitzsch) Ehrenberg	1	1	1	1	P-B	temp	st-str	ind	i	es	x	0.3	oe	ate
Placoneis gastrum (Ehrenberg) Mereschkowsky	1	1	1	1	B	-	st-str	ind	i	sx	o-b	1.4	e	ate
Sellaphora pupula (Kützing) Mereschkovsky	0	1	1	1	B	eterm	st	ind	hl	sx	o-a	1.9	me	ate
Stauroneis acuta W.Smith	1	0	1	1	B	-	st-str	alf	i	-	o	1	om	-
Stauroneis anceps Ehrenberg	0	1	1	1	P-B	-	st-str	ind	i	sx	o	1.3	om	ate
Surirella librile (Ehrenberg) Ehrenberg	1	1	1	0	B	-	st-str	alf	i	-	b	2.1	e	ate
Surirella ovalis Brébisson	1	0	1	1	P-B	-	st-str	alf	I	es	a	3	me	ate
Tryblionella hungarica (Grunow) Frenguelli	1	1	0	0	P-B	-	-	alf	mh	sp	a-o	2.9	e	ate
Ulnaria danica (Kützing) Compère & Bukhtiyarova	1	1	1	1	P-B	temp	-	alf	i	es	b-o	1.7	om	-
Ulnaria ulna (Nitzsch) Compère	0	1	1	1	P-B	temp	st-str	ind	i	es	b	2.3	oe	ate
Urosolenia longiseta (O.Zacharias) Edlund & Stoermer	1	0	1	1	P	-	-	-	hl	-	x-b	0.9	-	-

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Ochrophyta														
Tribonema elegans Pascher	0	1	1	1	B	-	-	-	-	-	x	1	-	-
Tribonema minus (Wille) Hazen	0	1	1	1	B	-	-	-	i	-	x-b	0.9	-	-
Euglenozoa														
Euglena deses Ehrenberg	0	0	0	1	P-B,S	warm	st-str	ind	mh	-	b	2.2	-	-
Euglena elastica Prescott	1	0	1	0	P-B	-	st-str	-	-	-	b-a	2.5	-	-
Euglena gracilis G.A.Klebs	1	1	1	1	P-B	eterm	st	ind	oh	-	b	2.3	-	-
Euglena oblonga F.Schmitz	0	1	1	0	P	eterm	st-str	ind	-	-	b	2.1	-	-
Euglenaformis proxima (Dangeard) M.S.Bennett & Triemer	0	1	1	1	P-B	eterm	st-str	ind	mh	-	p-a	3.5	-	-
Monomorphina pyrum (Ehrenberg) Mereschkowsky	1	1	1	0	P-B	eterm	st-str	ind	mh	-	b	2.4	-	-
Phacus acuminatus Stokes	0	1	1	1	P-B	eterm	st-str	-	i	-	b-a	2.5	-	-
Phacus elegans Pochmann	0	1	1	0	-	-	-	-	-	-	o-a	1.9	-	-
Phacus triqueter (Ehrenberg) Perty	0	0	1	1	P-B	-	st-str	-	i	-	b-a	2.5	-	-
Trachelomonas superba Svirenko	1	0	1	1	P-B	-	st-str	-	-	-	o-a	1.8	-	-
Chlorophyta														
Acutodesmus acutiformis (Schröder) Tsarenko & D.M.John	0	1	1	1	P-B	-	st-str	-	-	-	o-a	1.8	-	-
Ankistrodesmus falcatus (Corda) Ralfs	1	1	1	1	P-B	-	st-str	-	hb	-	b	2.3	-	-
Chaetophora pisiformis (Roth) C.Agardh	1	1	1	1	B	-	-	-	-	-	o	1.3	-	-
Chlamydomonas angulosa O.Dill	1	1	1	1	P	-	st	-	-	-	o-a	1.8	-	-
Chlamydomonas debaryana Goroschankin	0	1	1	0	P	-	-	-	-	-	a	3	-	-
Chlamydomonas ehrenbergii Gorozhankin	1	1	1	1	P	-	-	-	-	-	p-a	3.5	-	-
Chlamydomonas globosa J.W.Snow	0	1	1	1	P,S	-	-	-	-	-	o-a	1.9	-	-
Chlorella vulgaris Beyerinck	1	1	1	1	P-B, pb,S	-	-	-	hl	-	a	3.1	-	-
Cladophora glomerata (Linnaeus) Kützing	1	1	1	1	P-B	-	st-str	alf	i	-	o-a	1.9	-	-
Coelastrum astroideum De Notaris	1	0	1	1	P	-	st-str	-	-	-	b	2.2	-	-
Coelastrum sphaericum Nägeli	1	1	1	1	P-B	-	st-str	-	i	-	o-b	1.4	-	-
Desmodesmus opoliensis (P.G.Richter) E.Hegewald	1	1	1	1	P-B	-	st-str	-	-	-	b	2.2	-	-

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Geminella minor (Nägeli) Heering	1	1	1	1	-	-	-	-	-	-	o-a	1.8	-	-
Haematococcus lacustris (Girod-Chantrans) Rostafinski	1	0	1	1	P	-	st	-	-	-	o	1.3	-	-
Hydrodictyon reticulatum (Linnaeus) Bory	1	1	1	1	P-B	-	st	-	-	-	o-a	1.8	-	-
Kirchneriella obesa (West) West & G.S.West	1	1	1	1	P-B	-	st-str	-	i	-	o-a	1.8	-	-
Monactinus simplex (Meyen) Corda	1	1	1	1	P-B	-	st-str	-	-	-	b	2	-	-
Monoraphidium mirabile (West & G.S.West) Pankow	0	0	1	1	P-B	-	st	-	oh	-	b-a	2.5	-	-
Oedogonium cardiacum Wittrock ex Hirn	1	1	1	1	B	-	-	-	-	-	o-b	1.5	-	-
Pandorina morum (O.F.Müller) Bory	0	1	0	1	P	-	st	-	i	-	b	2.3	-	-
Protosiphon botryoides (Kützing) Klebs	0	1	1	1	S	-	-	-	-	-	o	1.1	-	-
Scenedesmus obtusus Meyen	0	1	1	0	P-B	-	st-str	-	-	-	o-a	1.8	-	-
Scenedesmus parisiensis Chodat	0	1	1	1	-	-	-	-	-	-	o-a	1.9	-	-
Schizomeris leibleinii Kützing	1	1	0	1	-	-	-	-	-	-	b-a	2.4	-	-
Selenastrum capricornutum Printz	1	1	1	1	-	-	-	-	-	-	o-b	1.5	-	-
Sphaerellocystis ampla (Kützing) Nováková	1	1	1	0	P-B	-	-	alf	-	-	b-o	1.7	-	-
Stigeoclonium lubricum (Dillwyn) Kützing	0	1	1	0	-	-	-	-	-	-	b-a	2.5	-	-
Tetradesmus dimorphus (Turpin) M.J.Wynne	1	1	1	0	-	-	-	-	-	-	b	2.3	-	-
Tetradesmus obliquus (Turpin) M.J.Wynne	1	0	0	1	P-B	-	st-str	ind	i	-	b	2.1	-	-
Ulothrix tenerrima (Kützing) Kützing	1	0	1	1	B	-	st	-	i	-	o-a	1.8	-	-
Ulothrix zonata (F.Weber & Mohr) Kützing	1	1	1	0	P-B	-	st-str	ind	i	-	o-a	1.8	-	-
Charophyta														
Chara aspera C.L.Willdenow	0	1	1	0	B	-	-	-	-	-	o	1.2	-	-
Chara braunii var. *schweinitzii* (A.Braun) Zaneveld	0	0	1	1	B	-	-	-	-	-	o	1.2	-	-
Chara globularis Thuiller	0	1	1	1	B	-	st	-	-	-	o	1.2	-	-
Chara vulgaris Linnaeus	1	1	1	1	B	-	st-str	-	-	-	o	1.1	-	-
Closterium acerosum Ehrenberg ex Ralfs	1	1	1	1	P-B	-	st-str	ind	i	-	a-o	2.6	e	-
Closterium angustatum Kützing ex Ralfs	0	1	1	1	B	-	-	acf	-	-	-	-	om	-
Closterium attenuatum Ralfs	0	1	1	1	B	-	-	ind	-	-	-	-	m	-

Prolongation of Tables 2

Taxa	1	2	3	4	Hab	T	Oxy	pH	Sal	D	Sap	S	Tro	Aut-Het
Closterium baillyanum (Brébisson ex Ralfs) Brébisson	0	1	1	1	B	-	-	ind	-	-	-	-	om	-
Closterium lunula Ehrenberg & Hemprich ex Ralfs	1	0	1	1	B	-	-	ind	-	-	x-b	0.8	m	-
Closterium parvulum Nägeli	1	0	1	0	P-B	-	-	ind	i	-	b	2	m	-
Closterium turgidum Ehrenberg ex Ralfs	1	1	1	1	B	-	-	acf	-	-	-	-	m	-
Cosmarium biretum Brébisson ex Ralfs	1	1	1	1	P-B	-	-	ind	-	-	-	-	me	-
Cosmarium botrytis Meneghini ex Ralfs	0	0	1	1	P-B	-	st-str	ind	i	-	o-a	1.9	m	-
Cosmarium formosulum Hoff	1	1	1	1	P-B	-	-	ind	-	-	o-a	1.8	me	-
Cosmarium granatum Brébisson ex Ralfs	1	1	1	1	B	-	st-str	ind	i	-	o	1.2	m	-
Cosmarium nitidulum De Notaris	1	0	1	1	-	-	-	acf	-	-	-	-	m	-
Cosmarium reniforme (Ralfs) W.Archer	0	1	0	1	P-B	-	st-str	ind	hb	-	o	1	me	-
Cosmarium subcrenatum Hantzsch	1	1	1	1	B,aer	-	aer	acf	-	-	o	1.1	m	-
Cosmarium undulatum Corda ex Ralfs	0	1	1	1	P-B	-	-	acf	i	-	-	-	m	-
Mougeotia robusta (De Bary) Wittrock	1	1	1	1	B	-	-	-	-	-	o	1	-	-
Mougeotia scalaris Hassall	1	1	1	0	B	-	-	-	i	-	o-b	1.5	-	-
Spirogyra crassa (Kützing) Kützing	0	1	1	0	B	-	-	-	-	-	o-b	1.5	-	-
Spirogyra daedalea Lagerheim	0	1	1	1	B	-	st-str	-	-	-	-	-	-	-
Spirogyra inflata (Vaucher) Dumortier	0	1	1	1	B	-	-	-	-	-	o	1.1	-	-
Spirogyra maxima (Hassall) Wittrock	1	1	1	1	B	-	-	-	-	-	o	1.1	-	-
Spirogyra parvula (Transeau) Czurda	0	1	1	1	B	-	st-str	-	-	-	-	-	-	-
Spirogyra porticalis (O.F.Müller) Dumortier	1	1	1	1	B	-	-	-	-	-	o-b	1.4	-	-
Spirogyra varians (Hassall) Kützing	1	1	1	1	P-B	-	-	-	oh	-	b	2.1	-	-
Spirogyra weberi var. *grevilleana* (Hassal) O.Kirchner	1	0	1	1	B	-	st	-	-	-	-	-	-	-
Zygnema vaginatum Klebs	0	1	1	0	B	-	-	-	-	-	o	1	-	-

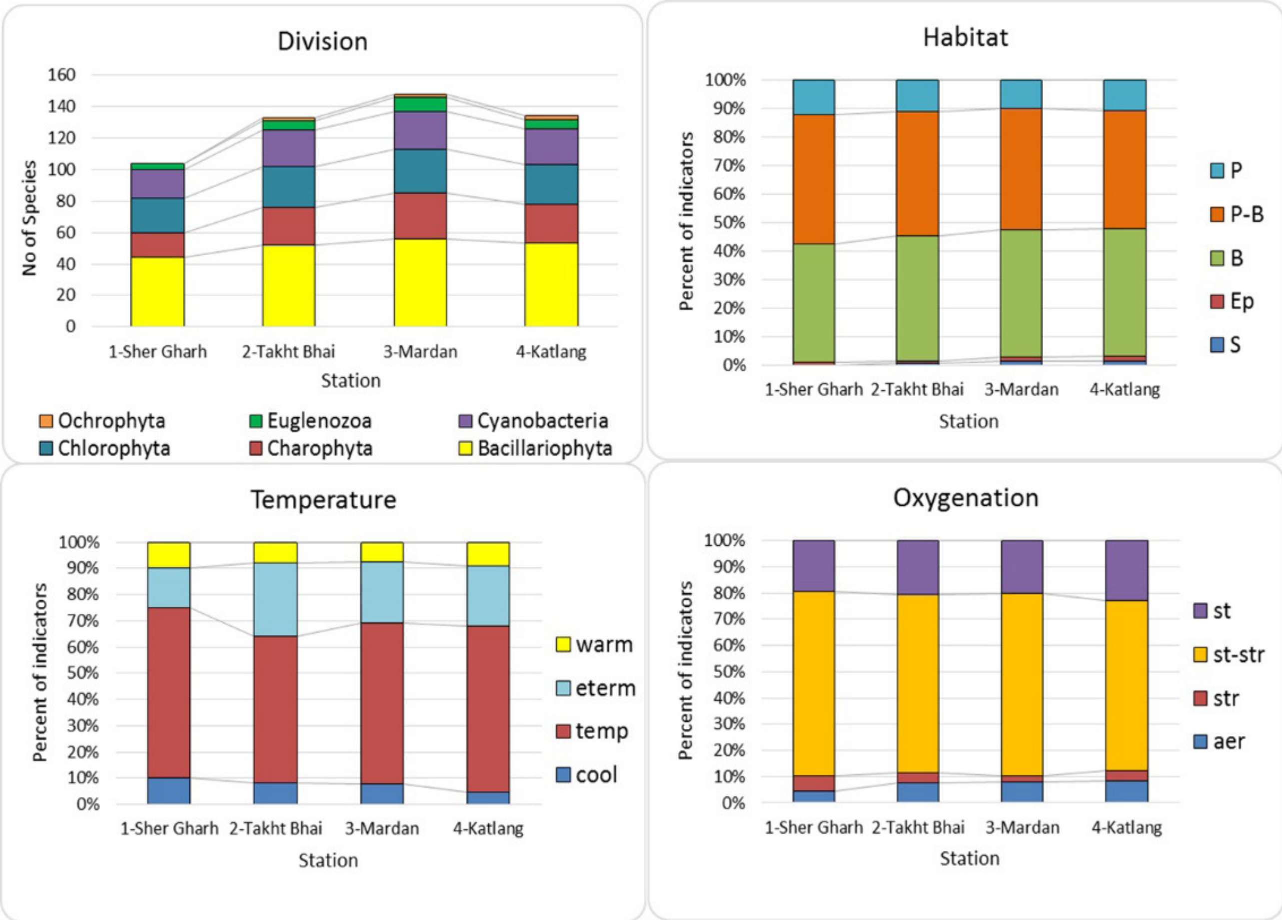

Figure 2 – Distribution of indicator species in Taxonomic divisions and in the ecological groups of habitat preferences, Water temperature, and Water streaming and oxygenation over the sampling sites of the Mardan River basin, 2016

Bioindicators give us great possibility to reveal the environmental variables that important to algal community grows because the primary producers are responsible o the self-purification process in the river ecosystem. By this, the 3D surface plots were constructed for revealing relationships between species groups and major environmental variables, which influenced it.

For this analysis, we choose the most fluctuated in the Mardan River environmental variables such as water pH, TDS, turbidity, and temperature for construction of 3D plots. Figure 5 show bioindicators and these variables relationships. The indicators of the lifestyle of algae in the Mardan River communities have two important groups of substrate preferences that defined self-purification process in the ecosystem of large rivers: planktonic and benthic species. Can be seen that planktonic group is preferred lower turbidity but indifferent to fluctuation of water temperature and TDS, and therefore, have better environment in the upper part of the river (Figure 5a, b). Benthic species preferred high temperature and TDS but indifferent to suspended solids (Figure 5c, d), and therefore can survive over all sites of studied river. Indicators of water fluidity and oxygenation distribution show preferences of high turbidity, pH and water temperature that are peculiarities of the lower sites of the river (Figure 5e, f). This distribution also demonstrate that turbidity is impacted factor for algal grows and indicators of this group are mostly reflected oxygenation than fluidity of water in the Mardan River.

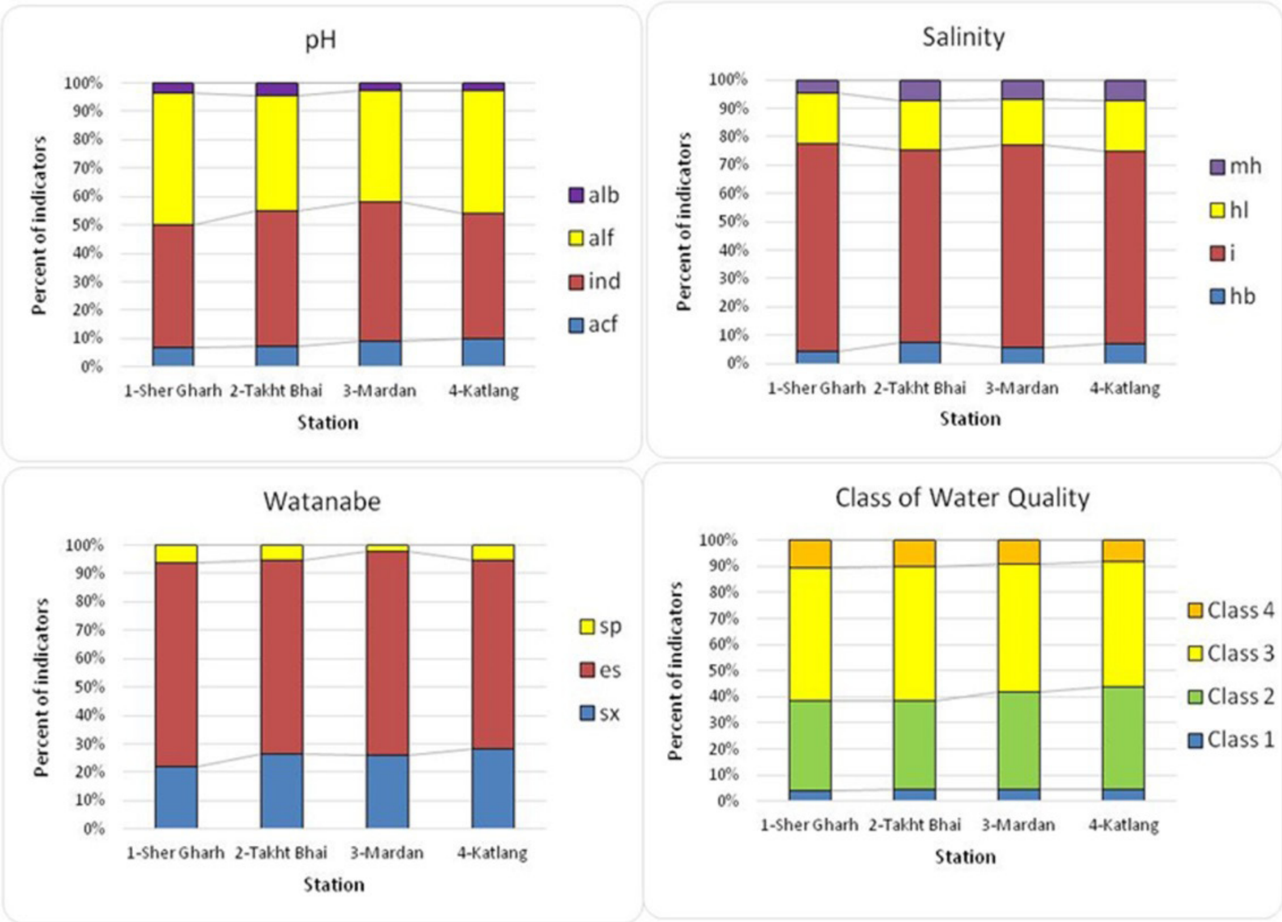

Figure 3 – Distribution of indicator species in the ecological groups of Water pH, Salinity, Organic pollution according Watanabe, and Class of Water quality according Sládeček self-purification ranks over the sampling sites of the Mardan River basin, 2016. Classes of Water Quality are in EU color code

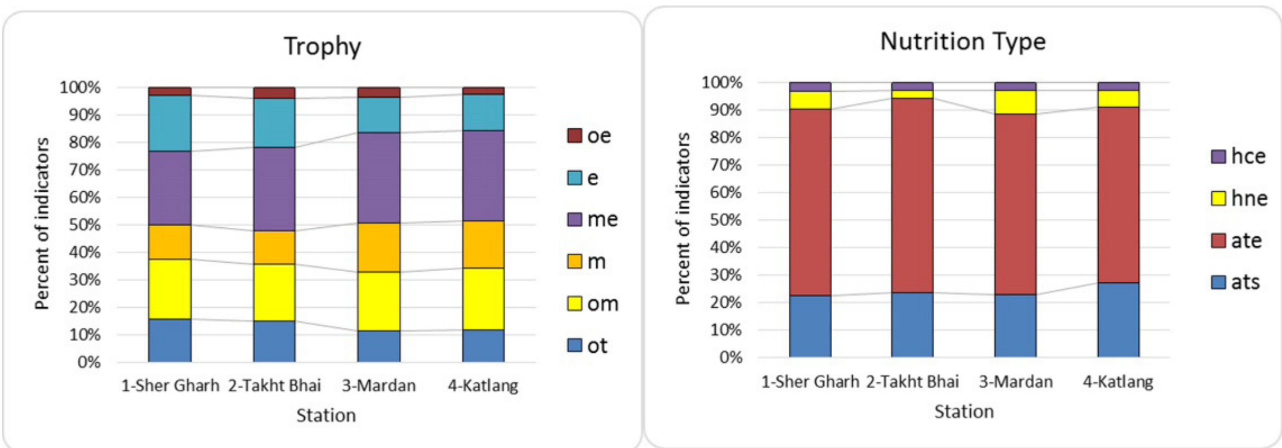

Figure 4 – Distribution of indicator species in the ecological groups of Trophic state and Type of nutrition over the sampling sites of the Mardan River basin, 2016

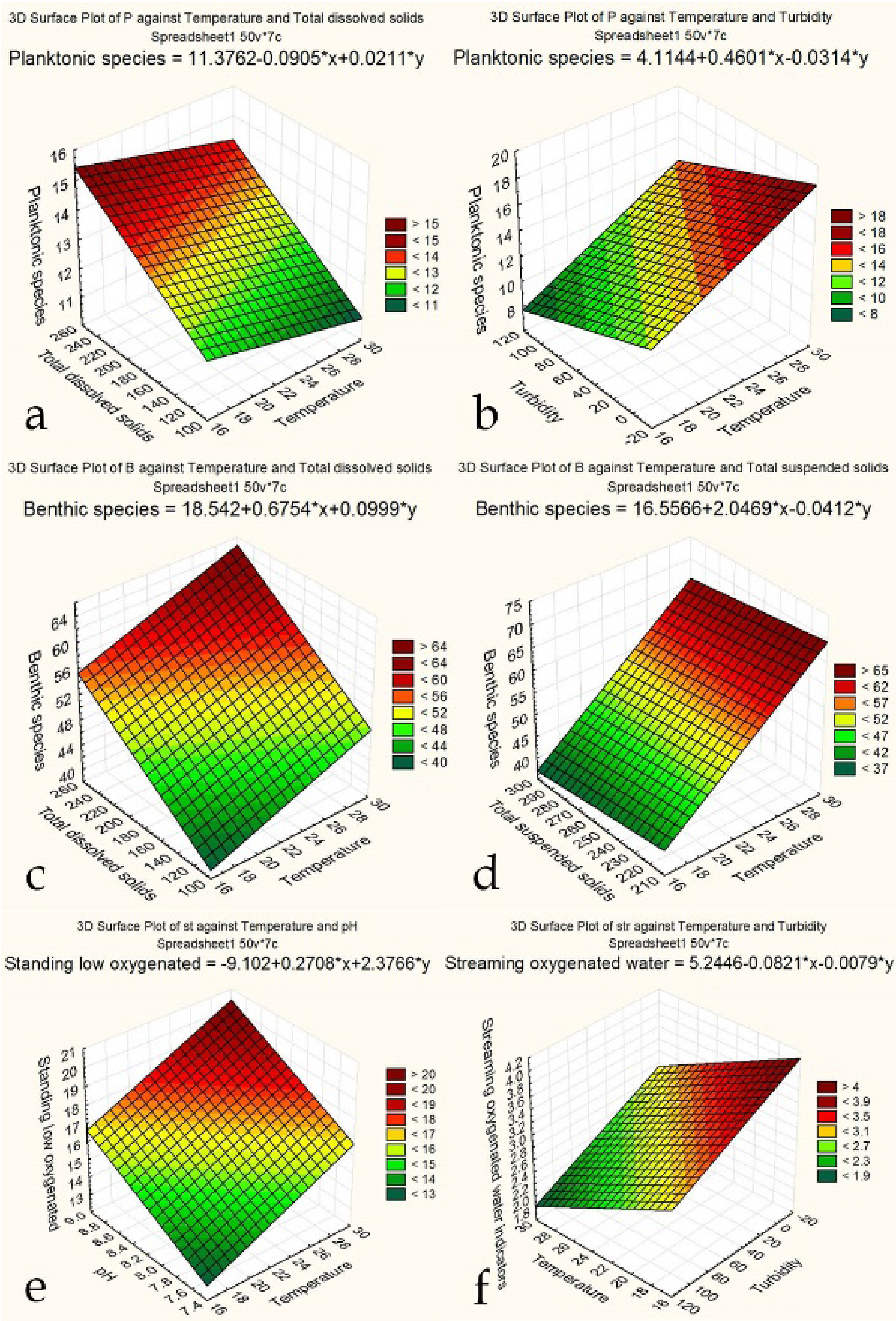

Figure 5 – Relationships of indicator species in the ecological groups of algal community habitat (a-d), water moving and oxygenation (e, f) and environmental variables: TDS, turbidity, temperature, and pH in the Mardan River basin, 2016

Distribution of salinity indicators show preference of its major groups of species for high water TDS but indifferent to water temperature (Figure 6a, b) and therefore marked the lower sites as source of salinity input. Indicators of acidification distribution (Figure 6c, d) demonstrated preference of high temperature but indifferent to turbidity that are water properties of the lower sites. Group of alkalibiontes, the indicators of high water pH, preferred lower temperature and high TDS that are in the upper site.

Figure 6e demonstrated organic pollution indicators preference of high temperature and TDS that are characteristics of lower sites, and marked it as polluted. The same preference can be recognized in Figure 6f where eutrophic state indicators mostly grows in the waters with high temperature and TDS that also marks lower sites 3-Mardam and 4-Kaltang as stay under eutrophication impact with organic pollution.

Indicators of nutrition type of algal species can clarify situation with toxic substances pollution [35]. So, Figure 7a show preference of autotrophic species the waters with high TDS but lower temperature (Figure 7a) which are in the upper part of the river. The facultative heterortophes, that used both types of nutrition, with chlorophyll and dissolved organics and can be a markers of some toxic influence, preferred wat

ers with high temperature and lower TDS (Figure 7b) that are the characteristic properties of water in the middle sites. Both this distributions (Figure 7a, b) can demonstrate that some pollution toxicants input is started from the middle part of the studied river, but ecosystem processes of self-purification still as rather high. Indicators of water quality of Class 2 preferred high temperature but water TDS was not so important for they grows (Figure 7c) that can be in the middle part of the river. The indicators of organically polluted waters of Class 4 preferred low temperature waters with high TDS (Figure 7d) that also is characteristics of the middle sites. It let us to conclude that organic pollution input start in the middle part of the Mardan River.

Our bioindication results demonstrated the similarity of studied Mardan River with the Swat River with differences of prevailing of autotrophic species and indicators of mesotrophic state in the Mardan River [14]. Similar distribution of species has been found for the Kabul River [9] but self-purification was mostly doing by charophytic algae in Kabul River. In any case, bioindication approach demonstrated peculiarities of the rivers in the Kabul River basin with prevailing of autotrophic algal species that preferred fresh middle oxygenated mesotrophic waters. These results are over than chemical analysis data [9] and can be received with help of bioindication only.

Conclusion

Bioindication of the Mardan River and its left tributary Katlang in 2016 was doing on the base of 165 species that were indicators of nine environmental variables. Bioindication methods were choose for the water quality assessment because the environmental variables were studied in the small quantity, only six due to limited opportunities for chemical analysis. In any case, the measured chemical water properties help us to reveal the water quality is fluctuated down the river with sharply increasing of temperature and turbidity in the lower site of the main river Mardan and its tributary Katlang. Water pH, dissolved and suspended solids were fluctuated in small range. We cannot define any other environmental variables but our aims were to describe situation with water pollution in the Mardan River basin because the water quality is very important for Pakistan. Biondication helps us to reveal that in self-purification processes in the studied river are mostly participated diatoms with followed by charophytes, greens and cyanobacteria. Temperature impact start from the site 2-Takht Bhai, whereas the measured variable show sharp increasing of this parameter only on the lower site 3-Mardan. Indicators are characterize the studied river as low saline, low alkaline and middle organically polluted where algae grows in plankton and periphyton and preferred low flowing middle oxygenated waters. More precision characteristics of water properties give us the statistical analysis of indicator species distribution over most fluctuated water variables – temperature, turbidity and pH. With helps of 3D surface plots, we revealed that turbidity is impacted factor for algal grows. Water temperature stimulated algal development in sites from middle reaches in site Takht Bhai and in the same site were started pollution effluents with organic and toxic components up to lower site Mardan and in tributary Katlang. Bioindication show also that this fluctuation of ecosystem properties can be related with flowing the river across the flatland with high agricultural activity. Nevertheless, algal community of the river is purify the river water mostly with help of photosynthetic processes. Therefore, we can to conclude that bioindication methods can help not only for characterize the water quality but also reveal early changes in pollution input and ecosystem trophic state when opportunities for chemical analysis is limited.

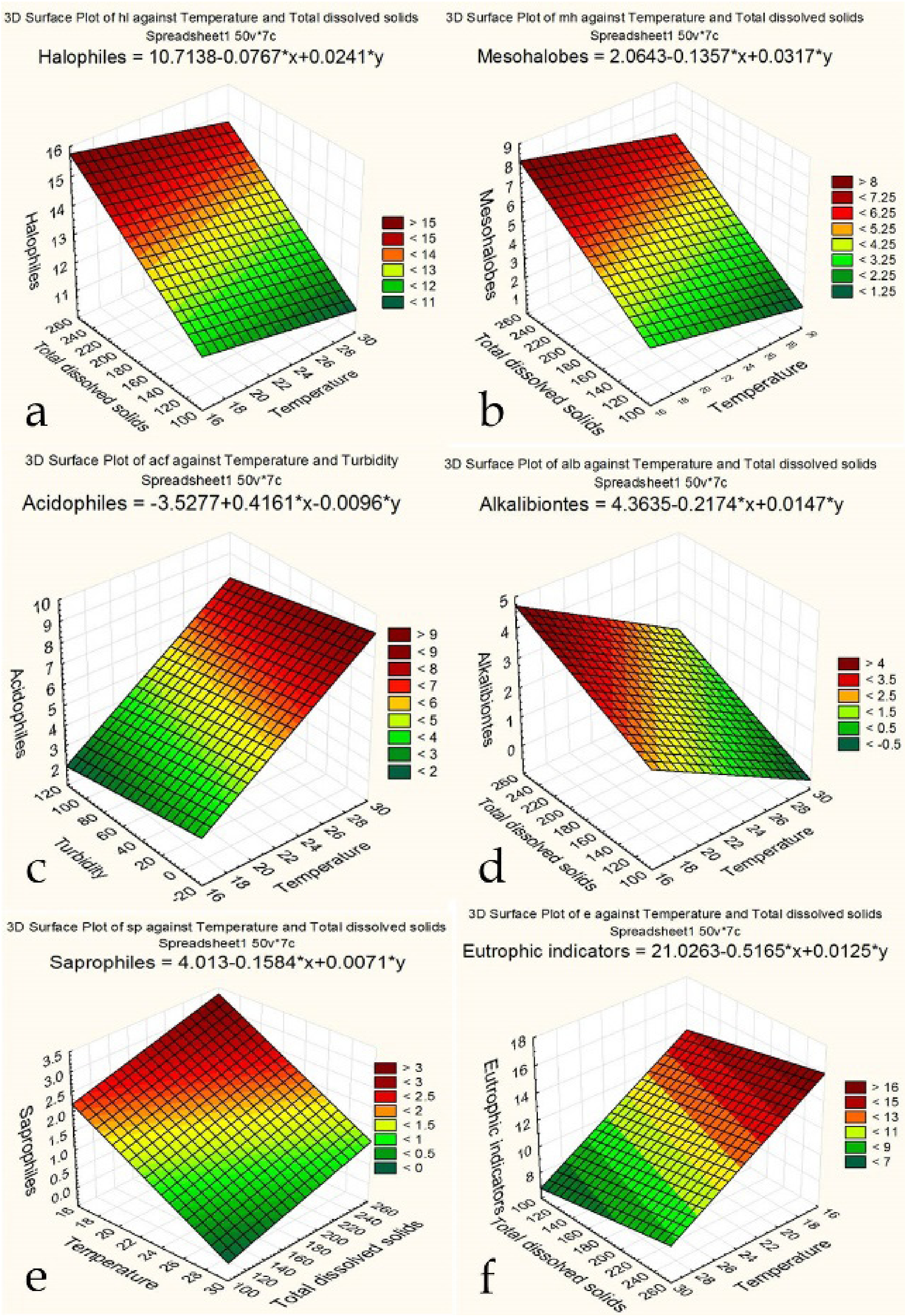

Figure 6 – Relationships of indicator species in the ecological groups of salinity (a, b), pH (c, d), organic pollution (e), and eutrophic state (f) and environmental variables: TDS, turbidity, temperature, and pH in the Mardan River basin, 2016

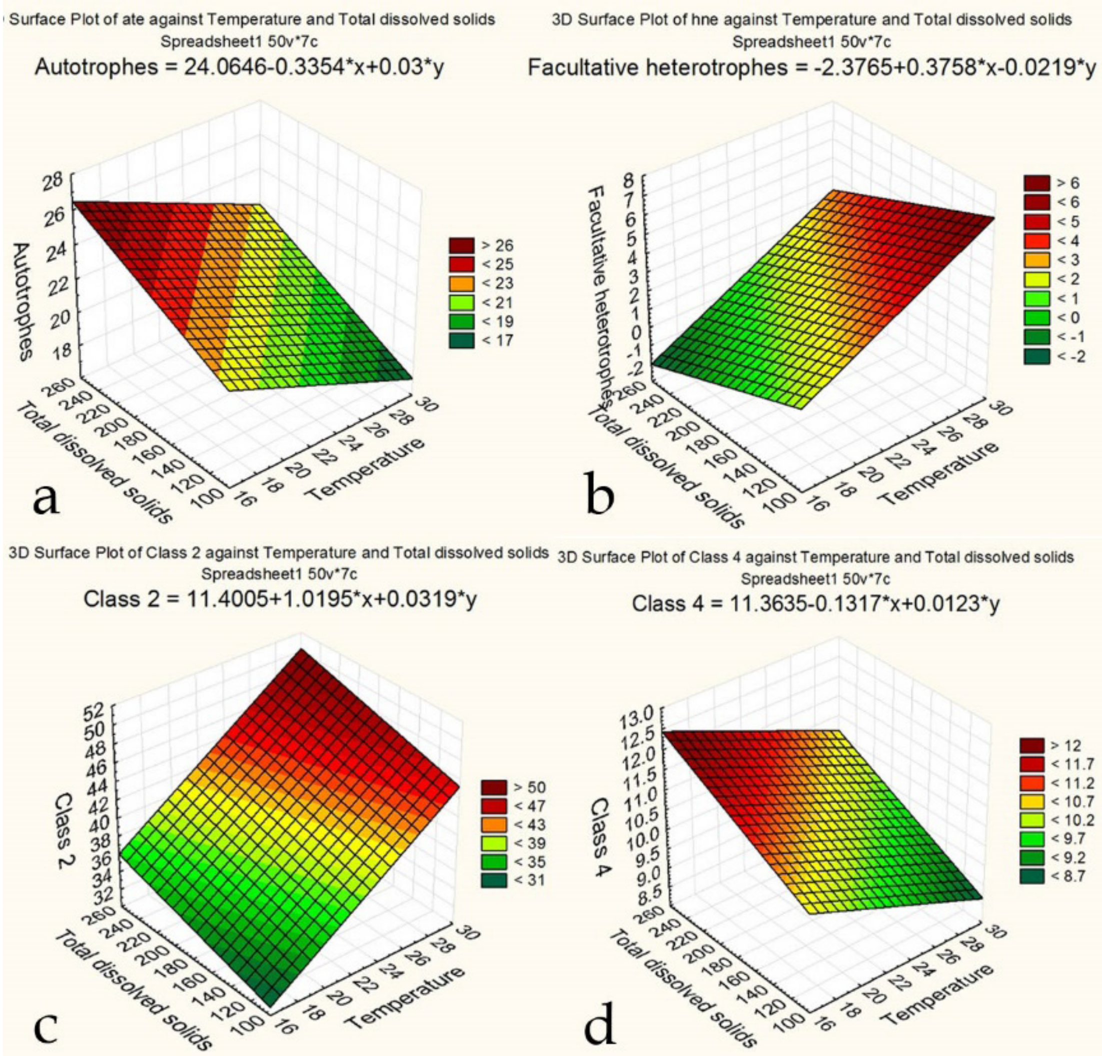

Figure 7 – Relationships of indicator species in the ecological groups of autotrophes (a), facultative heterotrophes (b), organic pollution indicators of Class 2 (c), and Class 4 (d), and environmental variables TDS and temperature in the Mardan River basin, 2016

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