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Original Research

Effect of mining site seepage and copper plant waste water on the water quality and epilithic diatom communities in Maden Stream (Elazığ-Turkey)

Vesile Yıldırım[1*], Okan Külköylüoğlu[2]

[1] Department of Biology, Fırat University, Elazığ, Turkey
[2] Department of Biology, Abant İzzet Baysal University, Gölköy, Bolu, Turkey

Correspondence to: vyildirim@firat.edu.tr

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Abstract: The present study investigated the effect of pollution caused by mining site seepage, copper plant flotation and domestic wastewaters on the water quality and epilithic diatom communities in the Maden Stream, Elazığ (Turkey). Maden Stream's epilithic diatoms, water chemistry and physical variables were examined between January 2008- December 2008 which identified 4 stream sites taken the samples of montly periods. During the study, a total of 77 diatom taxa belonging to 24 genera were identified. Three of which *Cymbella, Navicula*, and *Nitzschia* included the highest number of species. Species dominancy was changed among the stations where the most common species found from first, second, third, and fourth stations were *Cymbella affinis, Ulnaria ulna, Achnanthes minutissima* and *Surirella angustata*, and *Gomphonema parvulum*, respectively. Canonical correspondence analysis (CCA) explained 82.6% of the correlation between 66 species and 12 environmental variables among which EC, pH, DO, and Mn, were the most explanatory variables for species occurrence. Individual species showed different ecological tolerance and optimum levels. Among the species with cosmopolitan characteristics, eight of them (*C. cistula, U. ulna, Nitzscia palea, N. sigmoida, G. parvulum, Achnanthes laceolatum, Navicula pupula,* and *Diatoma tenuis*) were the most common species with relatively high tolerance levels to those environmental variables measured.

Key words: Epilithic diatoms; Water quality; Heavy metals; Diversity; Pollution.

Introduction

Benthic algae including benthic diatoms are one of the most important primary producers in aquatic ecosystems. One of their important characteristics is that their biomass and species compositions show a great diversity (1). The fluvial systems are affected by complex contamination factors as a result of organic and inorganic waste discharges from inadequately treated sewage and metal-related industries. Like many other organisms, benthic diatoms are negatively affected by such process. Most of the epilithic diatom species were known to be extremely susceptible to physical and chemical changes and that were good biological indicators (2,3). In determining water quality and long-term changes in waters, bioindicator species can provide better information than physicochemical analyses. For example, using bioindicator species is also the cheapest way of determining water quality alterations. As primary producers in fresh waters and with their responses to environmental changes, diatoms are used as determinants of ecological conditions when investigating environmental changes in streams from around the world (4). The main purpose of the present study was to analyze possible relationships between epilithic communities and environmental changes caused by changes in water qualities of Maden Stream.

Materials and Methods

Ergani-Maden Copper deposit is the oldest and the most significant mineral deposit in Turkey. This copper deposit site is known to be operated since 2000 B.C. (5). Since 1939, Maden copper deposite has been operated with modern techniques and is enriched by flotation. However, floatation waste water, slags and metallic waters have been flowing into the Maden stream for years. Maden Stream flows throughout from Maden mountains at an average height of 2500-3000 m within the South-eastern Taurus Range in the east of Turkey (38°-26'-32" N, 39°-37'-32" E). The length of the stream is about 46 km, including various spring waters embodies the source of the Dicle River.

In order to investigate the relationships between epilithic diatoms and effect of waste water discharges in Maden Stream, samples were collected monthly from four stations between January 2008 and December 2008. First station was located in cold water region in the flow direction of the Maden Stream. It represents the region before both domestic wastewater and the heavy metal ions flow into the stream. Second station is the site where domestic wastewaters of Maden district discharge into the stream. Station three was the region where the flotation wastewaters flow directly into the stream and where the contamination is extensive. Station four was located at about 800 m away from the discharge point of the flotation wastewaters. This station was the region where the effects of the contamination caused by the flow of the floatation wastewaters into the stream can be observed.

The water temperature, pH, electrical conductivity and dissolved oxygen were measured *in situ* with a multi-parameter probe (Hach-Lange HQ40d). Other chemical variables (Nitrate, alkalinity, and heavy metals) were analysed in the laboratory by using standard methods (6).

Epilithic diatoms were collected monthly by scraping 5 to 8 rocks with a sharpe knife into plastic containers. To prepare permanent diatoms slides, sub-samples were taken and strong acidic solution (50:50 nitric/sulphuric acid) was added to digest organic material. These samples were boiled up on a hot plate for 15 min to expedite the digestion process, and subsequently left to cool. Then samples were neutralized by rinsing with distilled water, and left to dry out on cover-slips, mounted on the slides using Canada balsam. Individual numbers were obtained by counting at least two hundred valves on each slide and results were expressed as (%) relative abundance. Species were identified according to Krammer and Lange-Bertalot (7-10).

The diversity (*H'*) was estimated with the Shannon-Wiener index (11). Canonical Correspondence Analyses (CCA) was used to display relationships between 66 species and 12 environmental variables. Before CCA, we run Detrended Correspondence Analyses (DCA) to see suitability of our data for CCA. During which, rare species were eliminated from the data to eliminate the influence of multicolinearity and arc-effect. Besides, both species and ecological data were log-transformed and tested with the Monte Carlo test (499 permutations).

The C2 program was used to measure ecological tolerance and optimum estimates of each species for different environmental variables after applying a transfer function of weight averaging (WA) regression (12). Application of C2 analyses consists of 64 species occurred at least 16 times from the sampling sites where the data on environmental variables were available. During WA, optimum values for each species are considered as the mean of all sites where the species occurs, it is assumed that all species express unimodal responses to environmental variables selected. Thus, a species can be most abundant in sampling sites where the values were close to their optimum estimates (13).

Results

During the research, surface water temperature was between 0°C and 26.5°C, and maximum water temperature was observed in September (26.5°C) and minimum water temperature was observed in January (0°C) in the first station. During the sampling period, pH values varied between 7.35 and 8.97 among stations and sampling periods. Maximum pH (8.97) was observed in the second station in October, while minimum pH was observed in the fourth station in October. Dissolved oxygen levels differed slightly among stations; maximum dissolved oxygen level was observed in the first station in February (13.5 mg/L) and minimum dissolved oxygen level was observed in the fourth station in October (5.8 mg/L). Chemical oxygen requirement reached its maximum value (132 mg/L) in the third station, whereas its minimum values were observed in different months and in different stations (in March and April in the first station, in April in the second station, and in January in the fourth station). Electrical conductivity in the Stream varied depending on the sampling stations and seasons. The lowest electrical conductivity was observed in the first station in April (250 Mmhos/cm) and the highest electrical conductivity was recorded in the third station in October. Metal concentrations of affected and non-affected sites were significantly different from each other (Table 1).

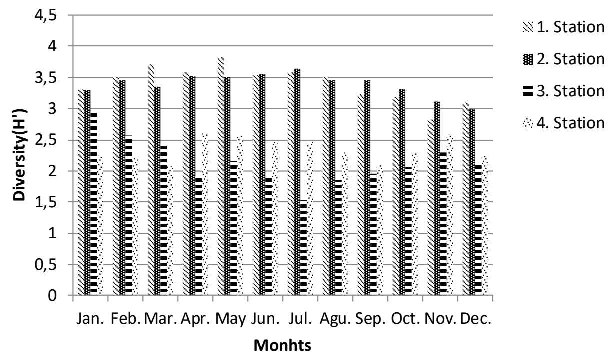

Figure 1. Diversities (*H'*) of epilithic diatom communities.

The physicochemical data obtained from each sampling station are shown in Table 1. During the present study, it seems that water temperature and pH did not show significant changes among the stations when dissolved oxygen levels differed slightly. In contrast, electrical conductivity displayed significant changes both among the stations and the seasons. The minimum and maximum EC values were observed at the first and third

Table 1. Variations in concentrations of some physical and chemical parameters in the stream.

Parameters	Station 1	Station 2	Station 3	Station 4
Water temperature (°C)	13.14±9.57	13.09±9.10	14.30±9.02	13.60±9.20
pH	8.46±0.32	8.44±0.26	8.16±0.39	8.01±0.38
Conductivity (µmhos/cm)	351.33±44.74	360.00±53.55	558.16±247.27	443.33±88.27
Dissolved oxygen(mgl^{-1})	10.37±2.27	10.05±2.21	8.38±2.55	9.28±2.46
Chemical oxygen (mgl^{-1})	58.16±15.71	58.00±22.25	92.92±22.23	66.58±18.97
Alkalinity ($CaCO_3$ mgl^{-1})	150.08±16.57	144.75±16.81	138.75±15.32	135.75±17.56
Cu (mgl^{-1})	0.02±0.02	0.03±0.02	0.07±0.00	0.04±0.00
Fe (mgl^{-1})	0.24±0.10	0.30±0.18	0.32±0.31	0.19±0.07
Mn (mgl^{-1})	0.00±0.01	0.01±0.00	0.74±0.06	0.28±0.03
Co (mgl^{-1})	0.00±0.00	0.00±0.00	0.00±0.00	0.07±0.01
Zn (mgl^{-1})	0.16±0.06	0.15±0.05	0.23±0.21	0.22±0.12
Ni (mgl^{-1})	0.01±0.01	0.01±0.01	3.69±0.03	0.02±0.02

stations, respectively. Besides, metal concentrations of affected and non-affected sites were significantly different from each other (Table 1).

A total of 77 diatom taxa were observed in the epilithic samples (Table 2). Of which, members of Pennales were more dominant than the members of Centrales both in taxon richness and the abundance (i.e. number of individuals). During the present work, both the number of species and community structure greatly varied among the stations. This variation was also observed in the dominant algae groups: *Cretoneis arcus, Didymosphenia geminata, Epitemia turgidus, Neidium iridis,* and *Stauroneis anceps* were only observed at the first station; *C. affinis, D. tennuis, D. vulgare,* and *Gomphonema olivaceum* were the dominant diatoms of the benthic flora at the 1. station; *U. ulna* and *N. palea* at the 2. station, *A. minutissima N. palea* and *Surirella angustata* were the dominant diatoms of the benthic flora at the 3.

Table 2. List of epilithic taxa in Maden Stream and relative abundance (%) at sampling stations.

		Mean relative abundance (%)			
Taxa	**Code**	**Station 1**	**Station 2**	**Station 3**	**Station 4**
Cyclotella meneghiniana Kützing	CM	2.78	2.78	-	-
Achnanthes minutissima Kützing	AM	2.47	1.55	22.24	21.31
A. lanceolate (Brebisson) Grunow	AL	2.09	2.84	11.98	6.53
Melosira varians Agardh	MV	1.66	3.40	-	2.66
Amphora ovalis (Kützing) Kützing	AO	0.35	0.52	-	-
Cocconeis placentula Ehrenberg	CP	3.19	1.78	-	-
Cymatopleura elliptica (Brebisson) W. Smith	CE	0.23	0.08	2.01	-
C. solea (Brebisson) W. Smith	CS	0.31	0.17	-	0.17
Cymbella affinis Kützing	CA	5.64	1.79	0.57	2.24
C. amphicephala Naegeli	CAM	0.22	0.10	-	-
C. aspera (Ehrenberg) Cleve	CAS	0.36	0.97	-	-
C. caespitosa Kützing	CCA	-	0.81	-	-
C. lanceolata (Ehrenberg) Kirchner	*CL*	0.64	1.74	-	-
C. prostrata (Berkely) Cleve	CPR	3.80	1.93	-	-
C.helvetica Kützing	CH	3.12	4.00	0.34	3.98
C. cistula (Ehrenberg) Kirchner	CC	2.85	3.06	3.04	6.98
C. angustata (W. Smith) Cleve	CAN	0.71	0.18	-	-
C. ventricosa (C. Agardh)	CV	2.40	4.11	-	-
C.gracilis (Ehrenberg) Kützing	CG	0.44	0.81	-	0.39
C.minuta Hilse ex Robh	CM	2.50	6.06	1.96	-
C.cuspidata Kützing	CCU	1.18	0.61	-	-
Cretoneis arcus (Ehrenberg) Kützing	CAR	0.26	-	-	-
Diatoma tenuis Agardh	DT	4.78	3.15	1.31	3.50
D. vulgaris Bory	DV	4.76	1.78	-	0.28
D.moliformis Kützing	DM	2.77	1.17	-	-
Didymosphenia geminata (Lyngbya) M. Schimidt	DG	0.03	-		-
Diploneis ovalis (Hilse) Cleve	DO	0.67	0.06	-	-
Epithemia adnata (Kützing) Brebisson	EA	0.46	0.08	-	0.24
E.turgida Ehrenberg	ET	0.73	-	-	-
Frustulia vulgaris (Thwaiter)	FV	0.04	-	-	0.14
Fragilaria ulna (Nitzsch) Lange-Bertalot	UU	2.17	6.28	5.08	4.38
F.arcus (Ehrenberg) Cleve	FC	2.44	4.24	-	-
Gomphonema acuminatum Ehrenberg	GA	1.28	1.00	-	-
G.angustatum Agardh	GAN	2.06	0.94	-	2.44
G.constrictum Ehrenberg	GC	2.00	0.92	-	0.32
G. truncatum Ehrenberg	GT	-	0.20	-	-
G. parvulum (Kützing) Grun	GP	0.66	3.05	20.50	2.87
G. olivaceum (Hornemann) Brebisson	GO	4.24	0.59	-	-
Gyrosigma acuminatum (Kützing) Rabenhorst	GAC	1.20	0.05	-	-
Hantzschia amphioxys (Ehrenberg Grunow.	HA	0.33	0.14	-	-
Meridion circulare (Greville) Agardh	MC	0.29	0.92	-	-
Navicula cryptocephala Kützing	NC	2.95	4.54	0.21	0.12
N.cari Ehrenberg	NCA	-	0.11	-	-
N. cuspidata Kützing	NCU	0.40	0.83	0.11	-
N. gracilis Ehrenberg	NG	0.28	0.21	-	-
N. pupula Kützing	NP	2.64	2.87	3.89	4.92
N. radiosa Kützing	NR	2.01	1.50	-	0.16
N. lanceolata (Agardh) Ehrenberg	NL	0.22	0.73	-	-
N. rhyncocephala Kützing	NRH	0.58	0.10	1.01	-
N. viridula (Kützing) Ehrenberg	NV	1.21	0.04	-	-
N. tripunctata (O. F. Müller) Bory	NT	2.20	0.96	-	-
N. menisculus Schuman	NM	0.29	0.07	-	-
N.tuscula (Ehrenberg) Grunow	NTU	0.08	0.12	-	-
N.trivialis Lange-Bertalot	NTR	1.85	3.20	3.20	-
N.praeterita Hustedt	NPR	1.22	0.12	0.54	3.65
N.salinarum Grunow	NS	0.99	2.09	-	-
N.reinhardtii Grunow	NRE	1.24	0.04	-	-
N.bacillum Ehrenberg	NB	-	0.05	-	-
Neidium dubium (Ehrenberg) Cleve	NED	0.07	0.04	-	-
N. iridis (Ehrenberg) Cleve	NEI	0.03	-	-	-
Nitzschia amphibia Grunow	NIA	0.33	3.51	4.22	1.86
N. angustata Grunow	NIG	0.56	0.13	-	-
N. hantzschiana Rabenhorst	NIH	0.06	0.16	-	-
N. linearis (Agardh) W. Smith	NIL	3.71	1.57	-	2.34
N. palea (Kütz.) W. Smith	NIP	2.21	5.05	10.68	13.66
N. sigmoidea (Ehr.) W. Smith	NIS	1.46	2.23	1.35	5.77
N. gracilis Hantzsch	NIG	0.14	1.18	-	-
N. hungarica Grunow	NIU	0.43	0.07	-	-
N. thermalis Kützing	NIT	1.47	1.16	0.29	7.95
Pinnularia viridis (Nitzsch.) Ehrenberg	*PV*	-	0.14	-	-
Rhopalodia gibba (Ehrenberg) O. Müller	RG	1.06	0.35	-	0.47
Stauroneis anceps Ehrenberg	STA	0.04	-	-	-
Surirella angustata Kützing	SA	0.61	0.99	5.15	-
S. ovata Kützing	SO	0.15	0.47	-	-
S. linearis W. smith	SL	0.40	0.54	-	-
S. ovalis Brebisson	SOV	0.23	0.02	-	0.30
S. robusta Ehrenberg	SR	0.06	0.02	-	-

Table 3. Optima (O) and tolerance (T) values are calculated for the pH. electrical conductivity (EC). dissolved oxygen (DO). water temperature (Tw). calcium carbonate ($CaCO_3$). N_2 shows Hill's coefficient (measure of effective number of occurrence). Count and maximum represent numbers of the species occurrence and numbers of individuals.

Species Code	Count	Max	N_2	pH		EC		DO		Tw		$CaCO_3$	
				O	T	O	T	O	T	O	T	O	T
CM	24	1	24	8.11	1.75	357.17	47.46	9.70	1.93	13.40	9.66	148.54	15.34
AM	38	1	38	7.82	1.91	459.26	190.77	9.38	2.07	12.68	9.14	142.61	19.89
AL	41	1	41	7.91	1.85	464.83	195.76	9.03	2.07	14.54	9.45	144.49	18.05
MV	32	1	32	8.09	1.52	409.69	111.51	9.38	1.86	12.61	9.06	146.94	16.49
AO	11	1	11	7.70	2.57	339.73	48.36	9.31	2.04	16.09	9.30	143.64	18.68
CP	24	1	24	8.11	1.75	357.17	47.46	9.70	1.93	13.40	9.66	148.54	15.34
CE	12	1	12	7.62	2.42	378.17	143.70	10.03	1.54	11.96	7.92	146.75	19.19
CS	6	1	6	8.38	0.50	379.50	133.68	9.53	1.77	16.67	9.35	140.17	25.90
CA	37	1	37	8.03	1.42	485.27	204.40	9.02	2.11	13.82	9.34	141.84	19.64
CAM	5	1	5	8.32	0.37	356.00	44.84	10.06	1.82	11.00	7.31	148.00	7.58
CAS	15	1	15	7.88	2.19	351.27	56.09	9.61	1.66	12.73	9.22	145.80	17.05
CCA	9	1	9	8.39	0.18	348.67	56.76	9.03	1.72	15.89	9.69	146.67	17.67
CL	16	1	16	7.94	2.14	356.25	54.63	9.91	2.01	11.97	9.34	146.94	17.92
CPR	24	1	24	8.11	1.75	357.17	47.46	9.70	1.93	13.40	9.66	148.54	15.34
CH	38	1	38	7.90	1.92	442.50	164.06	9.24	1.95	13.07	9.41	144.42	17.54
CC	46	1	46	7.93	1.74	457.85	179.65	9.17	2.00	13.13	9.05	143.50	18.87
CAN	6	1	6	7.28	3.57	341.67	56.46	11.17	1.69	7.42	6.71	149.50	21.29
CV	24	1	24	8.11	1.75	357.17	47.46	9.70	1.93	13.40	9.66	148.54	15.34
CG	18	1	18	7.98	2.01	418.44	139.49	9.61	2.08	12.56	9.63	147.39	16.37
CM1	28	1	28	7.80	2.22	383.57	84.20	9.92	1.89	12.04	9.54	149.11	14.68
CCU	15	1	15	7.87	2.20	361.87	38.44	9.89	2.20	13.23	10.67	152.13	14.41
CAR	4	1	4	8.30	0.37	357.50	25.68	9.70	2.29	15.88	10.18	153.50	7.23
DT	40	1	40	7.88	1.87	451.33	190.26	9.14	1.93	13.11	8.98	141.68	19.34
DV	25	1	25	8.13	1.71	361.48	51.75	9.46	2.05	14.20	9.39	149.52	15.27
DM	21	1	21	8.45	0.28	349.10	44.38	9.76	2.05	14.38	9.80	149.52	16.13
DG	2	1	2	8.55	0.35	352.00	52.33	10.50	3.54	15.00	16.97	164.00	15.56
DO	8	1	8	7.39	3.00	357.63	49.99	10.73	2.03	9.88	9.57	150.13	18.10
EA	9	1	9	8.53	0.34	360.00	54.12	10.39	2.36	11.39	9.49	147.00	23.78
ET	11	1	11	8.46	0.34	351.46	44.53	9.78	2.02	14.82	9.13	149.73	16.38
FV	1	1	1	7.90	1.43	391.00	97.07	13.00	1.94	2.50	8.99	150.00	17.14
UU	45	1	45	7.90	1.77	467.02	189.37	9.22	1.98	13.20	9.33	142.31	19.02
FC	23	1	23	8.08	1.78	356.35	48.36	9.56	1.83	14.02	9.37	148.13	15.55
GA	20	1	20	8.03	1.91	359.60	50.93	10.17	1.76	10.93	8.59	148.95	16.48
GAN	31	1	31	8.08	1.54	434.65	173.09	9.32	2.07	13.50	9.20	144.84	19.15
GC	30	1	30	8.11	1.56	428.47	175.34	9.21	2.08	14.38	9.57	146.53	16.07
GT	2	1	2	4.20	5.94	396.00	97.07	11.00	1.41	1.75	2.47	150.00	4.24
GP	43	1	43	7.86	1.80	486.00	192.25	9.17	2.09	12.67	9.21	141.37	19.07
GO	19	1	19	8.01	1.96	362.79	43.96	9.91	1.98	12.39	10.00	151.53	13.36
GAC	8	1	8	8.51	0.32	346.88	45.86	9.78	1.86	13.81	9.09	150.50	17.16
HA	5	1	5	8.46	0.23	324.40	44.75	9.24	1.18	17.60	6.66	150.40	23.82
MC	9	1	9	8.55	0.29	323.11	49.99	10.58	1.76	11.06	6.98	144.22	20.98
NCA	2	1	2	8.65	0.21	355.00	63.64	9.20	0.42	14.50	2.12	150.00	14.14
NC	26	1	26	8.14	1.68	375.23	151.41	9.54	1.99	13.71	9.46	147.50	15.30
NCU	18	1	18	7.98	2.01	345.67	45.86	10.10	1.98	13.22	10.09	151.17	16.94
NG	9	1	9	8.56	0.32	354.56	50.43	11.49	1.58	7.06	7.06	153.22	17.75
NP	41	2	40	7.90	1.83	454.05	191.81	9.12	1.96	13.98	9.61	144.67	17.66
NR	24	1	24	8.11	1.75	357.17	47.46	9.70	1.93	13.40	9.66	148.54	15.34
NL	9	1	9	7.57	2.85	330.44	57.68	10.69	1.35	9.33	6.29	142.22	19.79
NRH	8	1	8	8.57	0.35	343.25	47.14	10.96	1.98	10.19	8.01	153.00	18.87
NV	11	1	11	8.43	0.32	344.27	44.24	9.46	1.71	16.00	8.24	148.36	14.59
NT	22	1	22	8.04	1.82	354.86	48.96	9.40	1.71	14.52	9.27	146.91	14.74
NM	7	1	7	8.49	0.33	357.14	54.06	10.99	1.62	8.64	6.87	147.00	17.37
NTU	3	1	3	8.10	0.26	365.00	22.61	9.67	2.89	16.50	12.62	156.67	5.77
NTR	33	1	33	7.83	2.05	422.91	167.68	9.51	2.04	13.67	9.88	146.88	17.44
NPR	25	1	25	8.33	0.39	491.92	196.21	8.99	2.12	14.08	9.32	142.28	18.98
NS	21	1	21	8.04	1.86	359.19	49.61	9.73	1.82	12.93	9.05	148.29	16.17
NRE	14	1	14	8.48	0.31	350.14	41.26	9.86	2.04	14.14	9.22	151.79	14.94
NIA	33	1	33	7.72	2.02	452.24	167.03	9.25	2.10	12.56	9.02	141.58	20.64
NIL	36	1	36	8.12	1.43	441.03	168.50	9.17	1.98	13.60	9.38	144.08	17.88
NIP	45	1	45	7.89	1.76	475.24	192.18	9.17	2.01	13.44	9.58	141.62	18.74
NIS	44	1	44	7.89	1.78	459.00	184.95	9.12	1.97	13.27	9.17	143.14	18.79
NIG	28	1	28	7.69	2.20	440.96	179.62	9.29	2.01	13.68	9.48	143.36	19.36
NIU	6	1	6	8.38	0.34	332.50	48.15	9.80	2.19	16.58	9.79	146.50	17.81
NIT	34	1	34	8.12	1.47	440.62	173.05	9.09	1.97	14.31	9.15	143.79	18.35
RG	18	1	18	8.48	0.31	353.67	51.14	9.67	1.97	13.94	9.37	146.06	16.84
SA	30	1	30	7.73	2.13	440.30	172.50	9.61	2.14	12.07	9.46	143.80	18.83
SO	9	1	9	8.26	0.31	362.33	73.01	10.26	1.76	10.78	9.08	147.22	15.14
SL	9	1	9	8.46	0.33	336.44	60.75	11.03	1.83	8.44	7.00	145.33	22.43
SOV	6	1	6	8.33	0.41	444.17	159.65	9.15	2.29	13.92	9.67	146.67	17.51
SR	3	1	3	8.38	0.44	317.00	70.76	11.50	1.80	9.17	6.75	140.67	25.32
Mean				8.05	1.43	386.23	97.07	9.80	1.94	12.76	8.99	147.15	17.14
Max				8.65	5.94	491.92	204.40	13.00	3.54	17.60	16.97	164.00	25.90
Min				**4.20**	**0.18**	**317.00**	**22.61**	**8.99**	**0.42**	**1.75**	**2.12**	**140.17**	**4.24**

station; *G. parvulum* was the dominant diatom of the benthic flora in the 4. station. *Navicula cari, Navicula bacillum* and *Pinnularia viridis* were only determined at the 2. station. Similar numbers of taxa were observed in all four stations but species diversity and abundance were poor at the last two (3. and 4.) stations. Along the contamination inputs, some species decreased while relative abundance of other species increased as well (Table 2).

Ecological tolerance and optimum values applied to the benthic diatoms for the first time in this stream showed variation among the species. Some of those common species showed relatively higher tolerance and optimum estimation values than the mean values of the

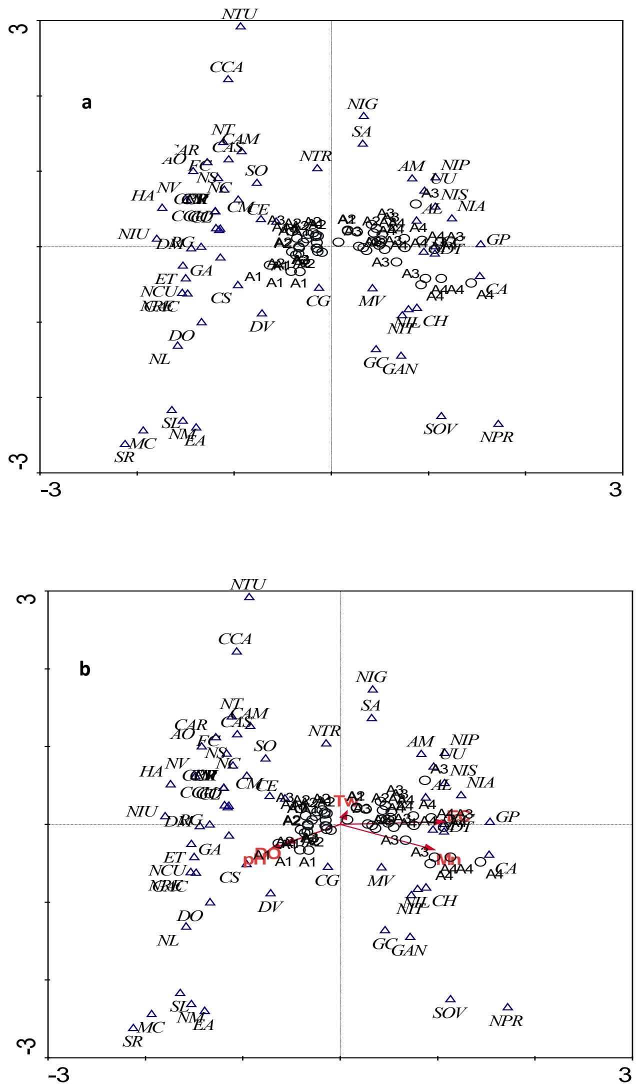

Figure 2. CCA diagrams of all data and species with variables in (a) sampling site and species in (b) environmental variables and species. In all figures, pay attention to the different scales of the axes (1-0.5 etc.). This is because of different distribution of the variables and species. DO dissolved oxygen (mg/l), EC electrical conductivity (MS/cm), TW water temperature (˚C), Mn (mg/l), pH.

total. The most common species was *C. cistula* with 46 occurrences while *U. ulna* and *N. palea* were collected 45 times and *N. sigmoide*, *G. parvulum, A. lanceplata, N. pupula,* and *D. tenuis* were collected 44, 43, 41, and 40 times, respectively (Table 3). Accordingly, species with cosmopolitan characteristics seem to have high tolerance levels and low optimum values to different environmental variables (14). The first two axes of CCA results displayed 82.6 % of the correlation between 66 species occurred three or more times during the study and 12 environmental variables (Water temperature, pH, EC, DO, CO, $CaCO_3$, Cu, Fe, Mn, Co, Zn, Ni). The five most effective variables were electrical conductivity (EC), pH, dissolved oxygen (DO), water temperature (TW), and Mn (Figure 2, Table 4). Among the stations, pH and DO were more influential at the first and second stations while Mn and EC were more effective on the species occurrence at the third and fourth stations.

The diversity of epilithic diatoms also varied significantly among the stations. The diversity of species was particularly higher at the first and second stations compared to the third and fourth stations. Our results revealed that diatoms in polluted waters responded to environmental impairment both at the community and individual levels changing the dominant taxa and species diversity and, frustule morphology of some certain species, respectively. Hence, the results displayed that increasing levels of pollution corresponds to the diatom species with high tolerance levels to the pollution.

Discussion

The first station in the stream is the headwater source and apparently includes clean water where there was relatively low amount of metallic pollution although the flow rate was relatively low. The site receives a sufficient amount of light due to its open surface area in which four species (*C. affinis*, *D. tennuis, D. vulgare* and *G. olivaceum*) exhibited dominancy over others. This also corresponds with some of those previous studies that underlined the dominancy of these species closer to the clean headwater sources (15). The second station is the discharge point of domestic wastewaters and the species with significant relative densities were *U.ulna, N. palea, N. cryptocephala, C. cistula,* and *C. minuta*. These diatoms are known to be common in different aquatic polluted habitats of the world along with the other taxa (e.g. algae) (16). Kelly *et al*. (17) reported that *C. minuta* was tolerant to organic pollution and prevalent in organically-polluted waters. High numbers of these diatoms were found in the samples collected from the second station, which is the location receiving domestic wastewater discharge. The third and fourth stations were those with lowest diversity compared to the first and second stations. Numbers of certain species such as *A. minuttisima* and *G. parvulum* were increased at the first two stations. In the regions exposed to long-term metal pollution. pollution may have contributed to

Table 4. Summary of CCA result. First two axes explained 82.6% of relationships between 66 species (occurred 3 or more times) and 12 environmental variables.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.174	0.034	0.022	0.013	0.872
Lengths of gradient	2.119	1.276	0.844	1.216	
Species-environment correlations	0.864	0.618	0.549	0.617	
Cumulative percentage variance					
of species data	20.0	23.9	26.4	27.9	
of species-environment relation	69.1	82.6	91.5	96.6	
Sum of all eigenvalues				0.872	
Sum of all canonical eigenvalues					0.252

increase tolerance levels of the species. In their studies Deniseger *et al*. (18) and Medly and Clements (19) reported that *A. minuttisima* was tolerant to toxic compounds. Similarly Nakanishi *et al.* (20) reported that *A. minuttisuma* and *S. anqustata* were tolerant to Cu pollution in rivers and in conclusion. *A. minuttissim*a was suggested to be used as an indicator of heavy metal pollution. In this study, in the third station where metal pollution was the highest the density of *A. minuttisima* was significantly higher compared to the other sampling stations. *N. palea* is a heavy metal-tolerant species and it is described as the characteristic species of heavy metal-contaminated streams and rivers (21). Duong *et al*. (22) reported that increases in Cd concentration significantly increased the growth of *N. palea* supporting the idea of Rushforth *et al*. (23) who also stated that *N. palea* was tolerant to copper. In the metal pollution-exposed third and fourth stations, the density of *N. palea* was significantly higher than in the other two stations (Table 2). In our case at the third and fourth stations with the intense pressure of metal pollution the presence of these species seems to reduce diversity. Moreover it was reported that in eutrophic waters with high nitrate concentrations *N. palea* showed a prevalent growth (24). In this study the high relative abundance of this species have both in stations with metal and organic pollution. Besides our data is supportive of this view (Table 3) that the species is also tolerant to EC. High metal concentration may have inhibited the development of individuals with low ecological tolerance and therefore, may have contributed to the dominance of metal and nutrient-tolerant species in the flora.

During the sampling in the Maden Stream significant differences in diversity were determined among the sampling stations (Figure 1). In the third sampling station with toxic pollution diversity values were lower than in the other stations and the high diversity values in the first station are noteworthy. The third and fourth stations of the Maden Stream are the sampling regions in which organic pollution and metal pollution were both clearly presented with the current data. In these stations, pollution-tolerant taxa were determined while the growth of the rest was either limited or completely inhibited (Table 2). The pollution caused by the release of non-degradable toxic and acidic wastes into the environment may have caused the disappearance of susceptible organisms, which in turn may have led to the low species diversity observed in these stations. Different ecological conditions (water quality) and geographic status and a combination of these two can affect species richness and diversity. In the third station with high levels of pollution, only 16 different species were determined and only a small fraction of these species reached a significant relative density. As seen in Table 2. these species are *A. minutisima. A. lanceolate, C. cistula, U. ulna, G. parvulum, N. amphibia, N. palea, N. sigmoidea* and *N. gracilis*. Diatom species have specific properties and each species seems to have species-specific tolerance and optimum values for different environmental variables. Among these species cosmopolitan species are more advantageous than non-cosmopolitan species (Table 3). Indeed, 36 of 64 species occurred 16 times as cosmopolitan species, they were found more frequently than the other species. *C. meneghiniana, M. varians, C. placentula, D. vulgaris, D. moliformis* and *F. capucina* are among the species with high pH tolerance. In their study, Yun *et al*. (25) reported that *D. tenuis* and *F. capucina* were observed in samples with high nutrient content and pH and *D. vulgaris* was also observed in stations with high pH and DO values. Similarly, our study showed supportive evidence that *D. vulgaris* was highly tolerant to pH and DO (Table 3). Besides, pH and EC values of the cosmopolitan species were relatively higher than those of the other species. Actually, the CCA diagram (Figure 2) showed that most of the species were concentrated around pH, EC and DO (Figure 2, Table 4) suggesting the fact that these variables significantly affected the distribution and frequencies of the species. In conclusion, diatoms determined in Maden Stream differed greatly in diversity, relative density and in species composition among sampling stations across the stream. Along the contamination inputs the number of some species have decreased while the relative density of other species increased. Community structure also well reflected the changes in the chemical structure of water. This study revealed that species composition of diatoms also shifted depending on changing ecological conditions. During the study, the pressure of both organic and metal pollution and the resultant changes in diatom diversity along with the changes in community structure were observed in the selected stations. An advantage was observed in favor of cosmopolitan species and their distribution. This study shows that diatoms, clearly respond to metal contamination through taxonomic shifts. As a result of their short generation times, they are capable of detecting the recovery of impacted sites earlier than other biological indicators. This is so called “ecological succession” (14).

This study is a useful contribution to the literature regarding use of epilithic diatoms in the ecological evaluation of heavy-metal pollution in freshwater streams.

In field studies, it is challenging to distinguish the effects of environmental factors on biological communities in relation to each other. Experimental studies are necessary to determine the causal connections and eventually protect aquatic life and develop better guidelines.

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