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ECOLOGY

# Taxonomic composition of epilithic diatoms and indicator role in freshwater pools and the effect of pollution in the Keban Dam lake, Turkey

**Vesile Yildirim*** **and Selda Demirkapu**

Depertman of Biology, Univrsity of Firat, Elazig 231119, Turkey. *Author for correspondence. E-mail: vyildirim@firat.edu.tr

**ABSTRACT.** The aim of this study is to determine the epilithic diatom flora of stations exposed to pollutants of different characteristics, to test the relationships of these diatoms with water quality and the suitability of environmental quality indicators, and to determine different indicators of various quality pollutants for the rapid assessment of ecological pollution. Additionally, determining the ecological impact of both industrial and domestic waste on the reservoir in the region and determining whether the diatom community changes when exposed to various pollutants (including potential mortality), especially its role as an indicator of metal pollution; Samples taken from stations where domestic and industrial wastes were discharged with different chemical properties were evaluated and investigated. A total of 100 species were identified for Bacillariophyta. Although there was no significant change in the number of the species among the stations, significant changes were observed in the community structure. While *Achnanthidium minutissimum*, *Fragilaria capucina*, *Gomphonema parvulum*, *Nitzschia palea* and *Surirella angustatum* were the dominant diatoms in the impermeable artificial pool where the industrial wastewater of the factory was collected, *Nitzschia amphibia*, *N. palea*, *N. recta* and *Ulnaria ulna* were the dominant diatoms of the station where domestic wastewater was discharged. In the dam area where domestic wastewater is discharged, *Fragilaria capucina Ulnaria ulna* and *Diatoma vulgaris* are the dominant diatoms. *Achnanthidium minutissimum, Gomphonema parvulum Navicula cinta* and *Nitzschia amphibia*, *N. angustata* were the dominant diatoms of the station where both domestic and industrial wastewater was discharged. It was determined that benthic diatoms responded to different types of waste by changing their species composition, and that the change in the benthic community was not due to seasonal differences in stations under the influence of pollutants with different chemical properties. Diatom taxa which are known to tolerate metal concentrations, diatom diversities, and teratologies were determined.

**Keywords**: Epilithic diatoms; Water quality; Heavy metals; Diversity; Pollution; Dam lake.

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## Introduction

Rapid increase in human population, industrial and agricultural pollution, and human activities cause a gradually increasing stress on aquatic ecosystems. Mining and industrial activities are especially problematic as they generate environmentally hazardous waste and the effects of these waste persist for a very long time even after the activities are terminated. Anthropogenic effects also change the global climate and habitats, and more nutrients and chemicals enter in aquatic systems. When the intake of nutrients combines with human activities in various aquatic systems, metal contamination, acidification, and eutrophication occur and water pollution reduces environmental heterogeneity and, biodiversity (Wellnitz & Rader, 2006). The increasing effect of human activities in aquatic areas has directed researchers to develop biological monitoring schemes that can rapidly evaluate the status of aquatic (Kelly & Whitton, 1998). One of the most important reasons for using benthic algae, especially diatoms, as biological indicators in water quality studies is their wide variety of biomass and species composition (Soininen & Heino, 2005). In addition, such organisms are primarily used to evaluate the water quality as they are quite susceptible to physical and chemical changes, respond collectively to changes in environmental conditions in the habitat, and most of their species have a narrow tolerance range (Potapova et al., 2004).

The advantage of using benthic diatoms is that different species respond to different types of contamination. Different diatom species respond differently and characteristically to environmental (e.g., pH, salinity, ionic content, dissolved organic carbon) and anthropogenic (e.g., nutrients, heavy metals, pesticides, herbicides) stress factors. Due to these characteristics, diatoms are globally used to evaluate the ecological health of water bodies (Pandey et al., 2017). The effect of the pollutants in aquatic ecosystems can be evaluated in several scales. Most ecotoxicological tests are performed in a laboratory on small populations of certain species, and although they provide useful information about toxic effects, these tests are not entirely reliable in predicting their final effects within natural systems. Tests conducted on single species cannot help to understand the effects of toxic materials on community level and also, they are deprived of ecological reality. Also, an exact definition of the effects of a single metal on diatom communities is difficult. In contrast, the tests on natural communities suitably reflect the ecological reality of a natural system (Licursi & Gómez, 2013). When the ecological effect of pollution is investigated, a difficulty is the presence of multiple types of pollution and different sources (Clements et al., 2000). This naturally makes it difficult to control the cause of change in ecosystems and other factors, especially the environmental impact of each waste discharge.

The. As biological monitoring occurs under natural and unpredictable conditions where more than one factor interacts with one another, it can provide information for the improvement and development of biomonitoring tools to better understand the reaction of diatom communities to different types of pollution.

## Material and methods

### Study area

Keban Dam Lake was built on the Euphrates River in the eastern Turkey and is the second largest artificial lake in the country. It is 845 m above sea level and has a surface area of up to 675 $km^2$ . Its maximum depth is 160 m and its catchment area is 64,100 $km^2$. Keban Dam Lake holds an important place in Turkey as it is a major hub for electricity production, fishing, and fish farming.

Ferrochrome factory has an area of 217.5 hectares. The main field of activity of the factory is the production of high-carbon ferrochrome and chrome ore as well as chrome enrichment, packaging, and ferrochrome recovery from waste. Wastewater originating from ferrochrome production facilities is collected in an impermeable pool. A part of the wastewater collected are used in slag cooling process by returning through the pump system. Remaining excess water is discharged to the dam lake. The wastewater of the ferrochrome factory and the lodging units of the factory are discharged to two separate areas in the Dam Lake.

In this study, benthic diatoms were examined in samples collected monthly at 4 stations determined for 12 months.

Station I: The sampling station is an impermeable artificial pool located on the factory site, where the process wastewater originating from the industrial units of the factory is collected

Industrial wastewater in the factory forms because of the contact of water with chromium during the cooling of chrome taken from the blast furnace. Pool is a stilling and balancing pool for industrial wastewater. The remaining water in the pool is discharged to the dam lake.

Station II: This is the station where domestic wastewater originating from administrative buildings in the factory is discharged through biological treatment.

Station III: This is the station where the domestic wastewater coming from the social facilities of the factory is discharged into the Dam Lake after biological treatment.

Station IV: This is the station where both domestic and industrial wastewater originating from the factory are discharged into the Dam Lake.

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, phosphate, and heavy metals) were analyzed in the laboratory by using standard methods (American Public Health Association [APHA], 2012). Epilithic diatoms were collected monthly by scraping 5 to 8 rocks with a sharped knife into plastic containers. In order to prepare permanent diatom slides, subsamples were taken and a strong acidic solution (50:50 nitric/sulphuric acid) was added to digest the 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, the samples were neutralized by rinsing with distilled water, left to dry on cover-slips and mounted on the slides using Canada balsam. Individual numbers were obtained by counting at least four hundred valves on each slide and the results were expressed as (%) relative abundance. Species were identified according to Krammer and Lange-Bertalot (2000-2002). The diatom community structural attributes of species richness (S) and

Shannon–Weiner index (H), that are commonly used in water quality bioassessment (Stevenson et al., 2010) were used to characterize each site to understand the species changes during study seasons.

## Results

Table 1 shows the physicochemical data obtained from each sampling station. During this study, a total of 100 diatom taxa were observed in the epilithic samples (Table 2). Members of Pennales were more dominant than the members of Centrales both in taxon richness and abundance (i.e. number of individuals). In this study, both the number of species and community structure differend between stations depending on physical and chemical conditions.

*Nitzschia* genus was the taxon represented by the most species, followed by *Fragilaria*, *Gomphonema*, *Cymbella*, *Diatoma*, *Achnanthes* and *Ulnaria* (Figure 1).The relative abundance of each dominant genus among the sites was quite different.

*Achnanthidium minutissimum* (Kützing) Czarnecki, *Fragilaria capucina* (Desmazières), *Gomphonema parvulum*, *Nitzschia palea*, and *Surirella angustatum* were the dominant diatoms of the benthic flora at Station 1.

*Nitzschia palea, N. amphibia, N. recta* and *Ulnaria ulna* species reached significant relative abundance at station 2. *Fragilaria capucina, Ulnaria ulna*, and *Diatom vulgaris* were the dominant diatoms of the benthic flora at station 3. *Achnanthidium minutissimum*, *Gomphonema parvulum, Nitzschia amphibia, N. angustata* and *N. palea* were the dominant diatoms of the benthic flora in station 4 (Table 2). Shannon diversity index varied between (1.78) and (3.53) in all the monthes (Figure 2). Wilhm and Dorris (1968) recommended diversity index range as ⩽1 for very polluted water, 1-3 for moderately polluted water and ⩾4 for unpolluted water. In addition, the range recommended by Staub *et al*., (1970) were 3-4.5 for mildly polluted water samples, 1-2 for moderately polluted ones and 0-1 for very polluted ones. Similar numbers of taxa were observed at all four stations, but species diversity and abundance were poor at stations 1 and 2. A long the contamination inputs, some species decreased whereas the relative abundances of other species increased (Table 2). 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 the frustule morfology of some certain specied. Hence, the results indicate that increasing leveles of pollution correspond diatom species with high tolerance levels to pollution.

**Table 1.** Mean values of Physico-chemical parameters during study period of stations.

| Parameter | Unit | Station1 | Station2 | Station3 | Station4 |
|---|---|---|---|---|---|
| WT | C0 | 14.17±8.13 | 12.67±7.84 | 11.97±7.75 | 13.08±7.08 |
| EC | µS $cm^{-1}$ | 720±36.03 | 560,83±68,65 | 601,58±81,74 | 702.91±69.35 |
| pH | - | 8.17±0.23 | 7.98±0.25 | 7.83±0.27 | 7.85±0.26 |
| DO | mg $L^{-1}$ | 6.80±1.90 | 8.36±1.55 | 7.54±1.03 | 7.00±1.01 |
| COD | mg $L^{-1}$ | 43.59±10.61 | 35.58±13.22 | 49.71±10.63 | 39.51±9.30 |
| $PO_4$-P | mg $L^{-1}$ | 0.04±0.07 | 0.23±0.19 | 0.38±0.26 | 0.74±0.68 |
| $NO_3$-N | mg $L^{-1}$ | 0.00±0.00 | 1.23±0.52 | 1.20±0.42 | 1.72±0.52 |
| Cu | mg $L^{-1}$ | 1.11±0.11 | 0.016±0.01 | 0.044±0.06 | 0.55±0.08 |
| Fe | mg $L^{-1}$ | 3.52±0.19 | 0.020±0.17 | 1.52±0.01 | 1.67±0.20 |
| Cr | mg $L^{-1}$ | 1.61±0.09 | 0.011±0.01 | 0.61 ±0.04 | 0.82±0.06 |
| Zn | mg $L^{-1}$ | 1.47±0.18 | 0.015±0.03 | 0.43±0.03 | 0.76±0.06 |

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

| Taxa | Mean relative abundance (%) | | | |
|---|---|---|---|---|
| | Station 1 | Taxa | Station 1 | Taxa |
| *Melosira lineate* (Dillwyn) C.Agardh | - | - | - | 0.06 |
| *M. varians* C. Agardh | - | - | - | 0.12 |
| *Achnanthes conspicua* A.Mayer | - | - | - | 0.83 |
| *A. delicatula* (Küetzing) Grunow | - | 0.1 | 2.30 | 0.14 |
| *A. exigua* | - | - | 0.21 | - |
| *A. joursacense* Héribaud-Joseph | - | 0.05 | 0.85 | 0.57 |
| *A. lanceolata* (Brebisson) Grunow | - | - | - | 0.02 |
| *A. minutissima* Küetzing | 18.38 | - | | 12.46- |
| *Achnanthes montana Krasske* | - | - | - | 0.13 |
| *Amphora inariensis* Krammer | - | 0.05 | 0.02 | - |
| *A. libyca* Ehrenberg | 1.18 | 1.54 | - | - |

| | | | | |
|---|---|---|---|---|
| *A. veneta* Küetzing | - | 0.68 | 0.73 | 1.18 |
| *Aulacoseria alpigena* (Grunow) Krammer | - | - | - | 0.02 |
| *Bacillaria paradoxa* J. F. Gmelin | - | - | - | 0.73 |
| *Caloneis budensis* | - | - | 0.01 | - |
| *C. undulata* | - | - | 4.44 | - |
| *C. macedonica* Hustedt | - | - | - | 0.2 |
| *C. pulchra* Messikommer | | 0.07- | - | - |
| *Cocconeis pediculus* Ehrengberg | - | - | - | 1.79 |
| *C. placentula* Ehrenberg | - | 0.14 | - | 4.01 |
| *Cymbella affinis* Küetzing | | 2.99 | 0.66 | 3.78 |
| *C. amphicephala* Naegeli | | 1.42 | 0.29 | 0.23 |
| *C. caespitosa* (Küetzing) Brun. | | - | 1.38 | 1.03 |
| *C. cistula* (Ehrenberg) Kirchner | | 4.56 | 0.36 | 0.84 |
| *C. helvetica* Kützing | 4.11 | 0.45 | - | 0.2 |
| *C. silesiace* Bleisch | - | - | - | 0.25 |
| *C. tumidula* Grunow | 0.98 | 3.66 | 0.10 | 1.44 |
| *C. turgidula* Grunow | 0.74 | - | - | 0.11 |
| *Cymatopleura solea* (Brebisson) W.Smith | - | - | - | 0.06 |
| *Denticula kuetzingii* Grunow | - | - | - | 0.06 |
| *Diatoma moniliformis* Küetzing | - | 2.06 | - | - |
| *D. vulgaris* Bory De Saint Vincent | - | 3.16 | 17.57 | - |
| *Fragilaria biceps* (Küetzing) Lange-Bertalot | 0.74 | - | - | 0.29 |
| *F. brevistriata* Grunow | 0.55 | 0.35 | - | 0.02 |
| *F. capucina* (Kuetzing) Lange-Bertalot | 9.70 | 0.30 | 6.12 | 8.01 |
| *F. dilatata* (Brébisson) Lange-Bertalot | | 0.07 | - | - |
| *F. nana* (Meister) Lange-Bertalot | 0.97 | - | 0.10 | - |
| *Gomphonema acuminatum* Cleve | 0.05 | - | - | 0.04 |
| *G. affine* Küetzing | 0.88 | | 0.44 | 1.04 |
| *G. amoenum* Lange - Bertalot | - | - | - | 0.03 |
| *G. angustatum* (Kütz) Rabbenhorst | - | 0.04 | 1.29 | 0.02 |
| *G. clavatum* Ehrenberg | - | - | - | 0.02 |
| *G. insigne* Gregory | - | | 0.25 | 0.01 |
| *G. minutum* (J.G.Agardh) J.G.Agardh | 0.14 | - | - | - |
| *G. olivaceum* (Hornemann) Kützing | 0.07 | | - | 7.74 |
| *G. parvulum* (Küetzing) Küetzing | 12.47 | 1.12 | 2.95 | 8.65 |
| *G. tergestinum* Fricke | - | - | - | 0.15 |
| *G.truncatum* Ehrenberg | 1.86 | - | - | 2.5 |
| *Gyrosigma scalproides* (Rabenhorst) Cleve | - | - | - | 0.11 |
| *Hantzschia amphioxys* (Ehrenberg) Grunow | | 0.37 | 0.88 | 1.47 |
| *Navicula capitellata* Cleve-Euler | - | 0.21 | - | - |
| *N. capitatoradiata* Germain | | - | - | 0.04 |
| *N. cincta* (Ehrenberg) Ralfs | 0.27 | 0.39 | 0.77 | 3.62 |
| *N. cryptocephala* Kützing | | 0.037 | 6.74 | 0.55 |
| *N. cryptotenella* Lange-Bertalot | 3.99 | 0.29 | 0.13 | 1.84 |
| *N. eidrigiana* J.R.Carter | - | - | - | 0.01 |
| *N. gregaria* Donkin | 7.41 | - | 0.22 | 0.1 |
| *N. halophila* (Grunow) Cleve | 0.14 | - | - | 0.08 |
| *N. ignota* Krasske | 0.05 | 0.07 | - | 0.003 |
| *N. preateriata* Hustedt | - | 0.08 | - | - |
| *N. pseudolanceolata* Lange-Bertalot | - | - | - | 0.006 |
| *N. pseudanglica* Lange-Bertalot | - | - | - | 0.0025 |
| *N.* pupula Kützing var. | - | 0.05 | - | 0.73 |
| *N. radiosa* Kützing | 0.30 | 1.62 | 1.15 | 0.41 |
| *N. trivialis* Lange-Bertalot | 0.75 | - | 0.18 | 0.02 |
| *N. tuscula* (Ehrenberg) Grunow | - | 2.08 | 0.01 | 0.35 |
| *Nitzschia aequorea* Hustedt | - | - | - | 0.01 |
| *N. amphibia* Grunow | 0.95 | 5.58 | 0.71 | 5.46 |
| *N. amphibioides* Hustedt | 0.33 | - | - | - |
| *N. amphioxys* (Ehrenberg) W.Smith | - | 0.29 | - | - |
| *N. angustatula* Lange-Bertalot | - | 0.91 | - | - |
| *N. angustata* (W. Smith) Grunow | 0.01 | 2.17 | 2.95 | 5.54 |
| *N. brevissim* Grunow | - | - | - | 0.1 |
| *N. calida* Grunow | 0.02 | - | - | - |
| *N. capitellata* Hustedt | 0.02 | 3.93 | 0.09 | - |
| *N. constricta* (Kützing) Ralfs | 0.35 | - | 0.90 | 0.25 |
| *N. communis* | - | - | 0.03 | - |
| *N. dissipata* (Kuetzing) Grunow | 1.31 | 0.05 | - | 0.79 |

| | | | | |
|---|---|---|---|---|
| *N. filiformis* (W. Smith) Hustedt | - | 0.33 | - | 0.07 |
| *N. flexoides* Geitler | 0.17 | - | - | - |
| *N. hungarica* Grunow | - | 3.78 | - | 0.71 |
| *N. inconspicua* Grunow | 0.06 | 0.24 | 5.25 | 0.99 |
| *Nitzschia intermedia* Hantzsch | 1.25 | 0.41 | 3.00 | 2.14 |
| *N. levidensis* (W. Smith) Grunow | - | - | - | 0.02 |
| *N. nana* Grunow | 2.78 | - | - | 0.07 |
| *N. palea* (Kützing) W. Smith | 8.77 | 23.38 | 2.00 | 12.51 |
| *N. paleacea* Grunow | | 0.29- | 0.60- | - |
| *N. recta* Hanitzsch | 1.86 | 11.09 | 0.40 | 3.84 |
| *N. reversa* W. Smith | | 0.01 | - | - |
| *N. solita* Hustedt | | -0.34 | - | - |
| *N. sinuata* (W. Smith) Grunow | - | - | - | 0.1 |
| *N. vitrea* G.Norman | | - | - | 0.07- |
| *Pinnularia microstauron* (Ehernberg) Cleve | 0.15 | 0.19 | 0.20 | 0.04 |
| *P. obscura* Krasske | - | - | 0.10 | 0.01 |
| *Surirella angusta* Kützing | 12.49 | 0.66 | - | 0.19 |
| *S. minut* Brebisson | - | 0.04 | - | 0.31 |
| *S. ovalis* Brebisson | - | 0.18 | 0.09 | 0.75 |
| *Stauroneis spicula* Hickie | 0.04 | - | - | 0.87 |
| *Ulnaria ulna* P. Compere | 2.24 | 9.79 | 7.17 | 1.16 |

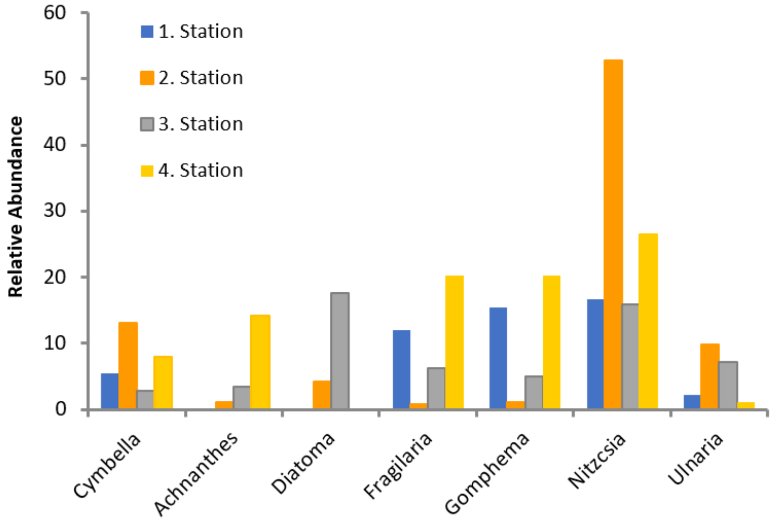


**Figure 1.** Composition of some important diatom genera (relative abundance of each genus at sampling stations).

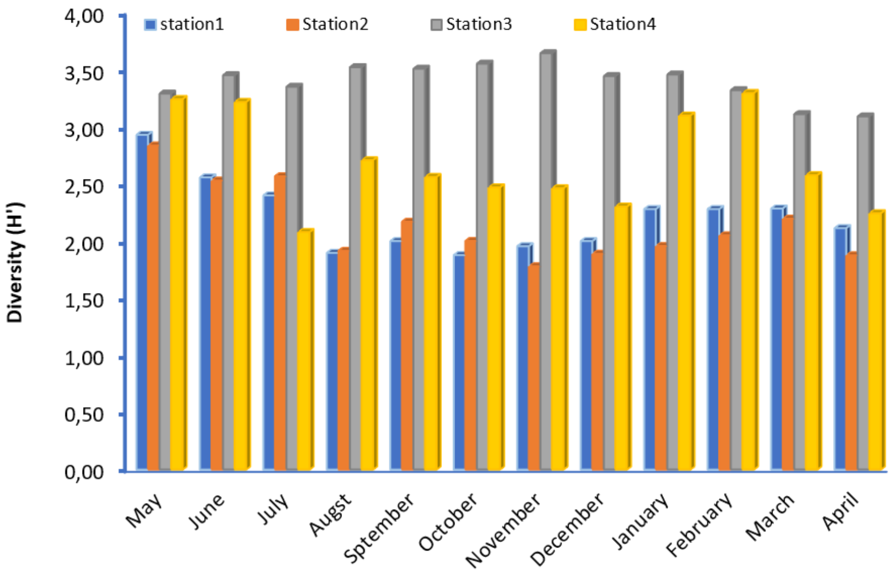


**Figure 2.** Diversities (H') of epilithic diatom communites.

## Discussion

At the station , which has an impermeable artificial located in the factory site and where process wastewater originating from the industrial units of the factory comes, *Achnanthidium minutissimum, Fragilaria capucina, Gomphonema parvulum, Nitzschia palea,* and *Surirella angustatum* were the species reaching a significant relative abundance at station 1. In various publications, *Achnanthidium minutissimum* (Morin et al., 2012), which is reported as a metal-tolerant species, mostly dominated in the communities at station 1 (up to 99%). *Gomphonema parvulum* and *Nitzschia palea* have been iden tified as metal-tolerant species in a number of studies. In addition, *Achnanthidium minutissimum* species, which is frequently dominant in lotic environments exposed to toxic events, is accepted as the indicator of metal contamination and it is a good indicator of general water quality. In fact this species present in conditions with intense metal contamination (Morin et al., (2012).

Among the algae, *Achnanthidium minutissimum* is a diatom that is well-adapted to of aquatic environments. In this study, it was considered that it has a specific tolerance against heavy metals (Cu, Zn, Fe, and Cr). The correlation between the concentrations of heavy metals in the water and the relative abundances of diatom taxon in the study area was examined in detail and it was determined that the higher the concentration of heavy metals in the environment, the higher the relative abundances of *Achnanthes minutissima*. Diatom species have specific characteristics and each species has different ecological tolerance and optimum value for different environmental variables. Among these species, cosmopolitan species are more advantageous than non-cosmopolitan because they have high optimum and tolerance levels. The relative abundance of the species in the community identifies both the tolerance of the species and the preference for dominant conditions and the competitive power of the species is maximum under the most suitable conditions (Tilman, 1977, McCormick, 1996).

According to the concept of pollution-induced tolerance of Blanck et al. (1988) a pollutant applied a selection pressure on the community, causing the sensitive species to be replaced with the tolerant ones, and thus leading to an overall increase in the community's tolerance. In this station, which has been exposed to metal contamination in the long term, metal contamination may have given these species more tolerance. Nakanishi et al. (2004) stated that there was a correlation between *A. minutissimum*, *S. angustatum* and heavy metal concentration and they can be used as a bioindicator of heavy metal contamination. *Achnanthidium minutissimum* and *S. angustatum* are reported as metal-tolerant species in various publications (Lavoie et al., 2012). In their study, Nakanishi et al. (2004), stated that the diatom in the Kakehashi river and Godani river polluted by the wastewater from the Ogoya copper mine had a certain tolerance to heavy metals (Cu, Zn, Pb and Cd, etc.) in the river water samples, and the diatom community consisted almost exclusively of *Achnanthes minutissima*. As a result, the higher the concentration of heavy metals in the river environment, the higher the relative abundances of *Achnanthes minutissima*. Thus, they stated that this taxon can be used as a bioindicator of heavy metal contamination. In their experimental studies, Poulsan et al. (2000) stated that Zn was effective on benthic algae, and Ivorra et al., (2002) found that Zn, Cd, and P had a combined effect on algae. Deniseger et al. (1986), and Medley and Clements (1998) stated that *A. minutissimum* was resistant against toxic compounds. In their study, Nakanishi et al. (2004) indicated that *A. minutissimum* and *S. angustatum* were tolerant species against Cu pollution in rivers and as a result, *these species* can be used as the indicators for heavy metal contamination. In the present study, *A. minutissimum* and *S. angustatum* were detected at a very high abundance at the Station 1, where metal contamination is intense when compared to the other stations. As *A. minutissimum* was also observed in numerous streams that do not show metal contamination, it can be combined with other metrics in order to evaluate information provided by metal-tolerant taxa appropriately. Pham (2020) stated that *A. minutissimum* was an indicator of low-nutrient concentration and (Panoder & Patova, 2017) specified that *A. minutissimum* was an indicator of low-nutrient concentration even though it is reported as a metal-tolerant species. Chen et al. (2014) stated that *Nitzschia palea* and *A. minutissimum* were metal-tolerant species, and on the other hand, *A. minutissimum* was generally adapted to oligotrophic water. In the present study, high relative abundance of this species at the station 1 may reflect low-nutrient concentration as well as metal contamination. In their study, Licursi and Gómez (2013) found a positive correlation between the relative abundance of *Nitzschia palea* and the chrome concentration, highlighted that metal contamination was one of the main reasons of teratological forms in diatoms. In the study by GuoYing Du et al. (2016) on heavy metal contamination at high concentrations, they stated that metal contamination caused the deformation of diatoms and also, deformity frequency of

*Fragilaria capucina* was significantly lower in uncontaminated regions than the contaminated regions. Interestingly it was stated that although station 1 was the most contaminated one, slight deformity was observed in the diatom community in which *A. minutissimum* was dominant. Morin et al. (2008) stated that small species could be less susceptible to deformation. At this station, deformity was mostly observed in *Fragilaria capucina*, another dominant species. This showed that this species was more resistant to deformation. Several studies have also reported that *F. capucina* was metal-tolerant (Lavoie et al., 2012). Almost all the community at the station 1 consisted of metal-tolerant species in the whole sampling period. These findings suggested that the rate of species known to be metal-tolerant may represent a valuable indicator of metal contamination. Metal contamination suggested that the changes in relative abundances in species composition in the benthic community were caused by the selection of species that were tolerant to this pollution. Composition of diatom species is directed by various environmental factors. Among the chemical parameters, exposure to toxic materials such as metals can be an important determinant; however, it is generally hard to differentiate the effects caused by metals from other environmental effects. In the current study, the effect of metals was more dominant than other effects due to the reason that especially Station 1, under the influence of metals, was an isolated and artificial pool. Numerous studies have revealed that small-sized species tended to be dominant in metal-contaminated environments(Pandey et al., 2018). In the current study, the station that was mostly affected from metals (the station 1) was characterized by the domination of small adnate diatom species. In the stations 3 and 4 which seemed not to reflect metallic contamination, small-sized diatoms reached a significant relative abundance. It is also possible that the factors other than contamination, including grazing and colonization phase after a physical disorder, support small-sized diatoms. However, the dominance of moderate- and large-sized diatom species drew attention at the stations that are accepted to be less contaminated.

At the station 2, where domestic wastewater was discharged, *Ulnaria ulna*, *Nitzschia palea*, *N. recta,* and *N. amphbia* reached significant relative abundances. Such diatoms are the generalized pollution algae that are determined in wastewater at different regions of the world (Palmer, 1980). Pham (2020) stated that *Nitzschia palea* and *N. recta* were heavy pollution indicators and these species were dominant in these areas. Some researchers reported that *N. palea* grows widely in waters with high nitrate concentrations (Patric and Remier, 1975), and in eutrophic environments (Round, 1981), and it is tolerant to very heavy organic pollution in many areas and the dominant species in urban downstream areas (Besse-Lototskaya et al., 2011). Van Dam et al. (1994) stated that *N. amfibia* was tolerant against organic pollution. This species was also found to have a high relative abundance at the station 2 where domestic wastewater was discharged in the study area. High relative abundance of these species at isolated stations may indicate that these species can be used as the indicators of such types of pollutions.

*Fragilaria capucina, Ulnaria ulna, Diatoma vulgaris,* and *Navicula cryptocephala* were the important diatoms of the station 3, which was the region where the domestic wastewater coming from the social facilities of the factory was discharged into the Dam Lake via biological treatment. Out of these species, *Nitzschia palea*, *Navicula cryptocephala*, and *Ulnaria ulna* take place among the species with high tolerance, which can live in very polluted water, according to the biological classification of water quality. Especially, *N. palea* and *Ulnaria ulna* are accepted as the indicator of organic pollution (Palmer, 1980).

Kelly (2002) stated that *Ulnaria ulna* is a common species with high ecological tolerance in fresh waters with a pH greater than 7. This species reached high relative abundance in the dam region. This showed that the dam region was under the effect of organic pollution. At the station 4 where both domestic and industrial wastewater from the factory were discharged into the Dam Lake, *Achnanthidium minutissimum, Gomphonema parvulum, Nitzschia amphibia, N. angustata* and *N. palea* were the species reaching significant relative abundance. *Nitzschia palea* tolerates heavy metals and is defined as the characteristic species of rivers and lakes with heavy metal contamination (Chen et al., 2014). In their experimental study, Duong et al. (2010) stated that the increase in Cd concentration significantly increased the growth of *N. palea*. At the stations 1 and 4 exposed to metal contamination, *N. palea* had high abundance and also was the dominant species at the station 2 where domestic wastewater was discharged. Throughout the world, *Nitzschia palea* has been recorded as the most-tolerant species against organic pollution (Szczepocka & Szulc, 2009). The structure of diatom community is affected by both nutrients and metals. In the current study, *Nitzschia palea* reached significant relative abundance at the station 4. Chen et al. (2014) stated that in some algae, multiple tolerance and co-tolerance phenomenon and actually high nutrient would ensure protection for them against metal toxicity.

In their study, Ivorra et al. (2002), reported that the toxicities of Zn and Cd were modified by phosphate and metal effect possibly reduced by P complexity, and there were correlations between the growth of algae as a result of increasing dissolved P concentrations and the decrease in the toxic effects of metals. This is supported by dominance of the tolerant species at the station 4 against diatom community, nutrients, and metals (e.g., *A. minutissimum, G. parvulum* and *N. palea*). Pollution may have contributed to the increase in tolerance levels of the species in the areas subject to long-term metal contamination.

Benthic diatom diversity (S, H', J', D) and similarity indices are routinely used to evaluate the ecological health and the effects of various human activities of freshwater ecosystems. The richness and abundance of diatom species may vary according to the degree and type of pollution (Pham, 2020). In the current study, Shannon- Wiener diversity index was used as the water pollution indicator. Wilhm and Dorris (1968) recommended diversity index range as <1 for very polluted water, 1–3 for moderately polluted water and >4 for unpolluted water. In addition, the range recommended by Staub et al., (1970) were 3 - 4.5 for mildly polluted water samples, 1-2 for moderately polluted ones and 0-1 for very polluted ones.

In the current study, Shannon diversity index varied between (1.780) and (3.53) in all the months (Figure 2). Thus, all the areas monitored under classified ecological regions are accepted as moderately polluted areas according to Staub et al. (1970) and the diversity index of Wilhm and Dorris (1968). Biodiversity determinants such as Shannon's diversity index and richness of the species are regularly used as the tools for investigating the biological integrity status of an ecosystem. For example, Verb and Vis (2000) reported significantly lower species richness and Shannon diversity index in acid mine drainage areas than the recovered areas, while Barral Fraga et al. (2016) reported lower values for these metrics in diatom-based biofilms that are contaminated with arsenic. Likewise, the diatom communities collected in this study had lower richness of species at the polluted stations. Diversity index and species richness were lower especially at the station 1, which was heavily contaminated with metal, when to the other stations; however, Blanco et al. (2012) reported that diversity and richness are not always good representatives of water quality and perhaps should not be used as a bioindicator on its own, and diversity indices generally exhibited weak linear correlations with environmental factors indicating ecological status. In addition, adequate sampling or sample size can strongly affect the richness and diversity values, thus the comparisons of water quality situations. However, as the same protocol was used for all the samples, this did not cause any problem in the current study (~400 frustule per sample).

The results of the present study revealed that diatoms in polluted waters reacted to the environmental degradation at both community and individual levels by altering the dominant taxon and species diversity and frustule morphology of some species, respectively. Thus, the results showed that the increase in the pollution levels correspond to the diatom species with high tolerance levels against pollution. Diatom species detected in the present study represented the species in the pool subjected to only industrial pollution (the diatom communities at the Station 1 were not exposed to multiple stress factors that could exacerbate the effects of metal contamination), the isolated pool containing only domestic wastes, and in the dam areas affected by different stress sources such as both organic pollution and industrial pollution. At the stations selected during the study, there were significant differences in both organic pollution and industrial pollution pressure and accordingly, the diatom diversity and community structure. In addition, cosmopolite species and their wide distribution advantage are also observed.

Consequently, the diatoms detected had significant differences at the selected sampling stations with special pollution. These differences were observed in diversity, mean relative abundance, and species composition, While some species decreased depending on contamination, some reached significant relative abundance. The community structure well reflected the changes in the chemical structure of the water. The presence and dominance of a large number of taxa known to tolerate high metal concentrations was also a good indicator of metallic contamination.

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