

INFLUENCE OF MULTIPLE ANTHROPOGENIC  
PRESSURES ON THE WATER QUALITY ASSESSMENT  
BASED ON BENTHIC DIATOMS OF THE IBAR RIVER  
BASIN (KOSOVO AND METOHIIJA, SERBIA)

Nikola N. Djukić✉, Tatjana R. Jakšić, Slavica Ćirić,  
Tamara Petronijević, Željko Bulatović

*Received on May 28, 2025*

*Presented by K. Stoykova, Corresponding Member of BAS, on October 28, 2025*

**Abstract**

Kosovo and Metohija province has a long tradition of mining activities that have caused an undesirable impact on the environment. We showed that the Ibar river is under multiple stressors by the industrial (mining-related) and urban discharges. The concentration level of heavy metals in water has elevated ( $\text{Cd} < \text{Cu} < \text{Zn}$ ) and ranged between  $< 15 \mu\text{g}\cdot\text{dm}^{-3}$  for Cd,  $< 151 \mu\text{g}\cdot\text{dm}^{-3}$  for Cu and  $< 1649 \mu\text{g}\cdot\text{dm}^{-3}$  for Zn. Diatom communities mainly responded to high levels of metal by the presence of specific metal tolerant species, while nutrient-rich environments were characterized by the presence of nutrient-tolerant taxa. A good fit was observed in this study between the frequency of teratologies and the presence of metals as contaminants. A significantly higher presence of teratological valves has been noticed at sites contaminated by metals.

**Key words:** biomonitoring, diatoms, deformities, water quality, Ibar river

**Introduction.** Kosovska Mitrovica district (Kosovo and Metohija, Serbia) is known for the industrial activity such as the Mining, Metallurgical and Chemical conglomerate (MMCC) “Trepča”, rich in lead and zinc ores. Today, most Trepča’s Combine factories are closed, there is a limited exploitation of minerals,

---

The study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-137/2025-03/200123).

<https://doi.org/10.7546/CRABS.2025.12.10>

and previous activities resulted in negative impact on the environment due to metal contaminations and the production of enormous quantities of waste (flotation and tailings dams). Among the seriously impacted aquatic ecosystems in the immediate vicinity to the mining Trepča activities is Ibar river. The Ibar river has been studied in the past to assess its ecological degradation in response to mining activities. However, to our knowledge most of these studies are all in respect of the water chemical quality and presence of heavy metals. In terms of biological monitoring, previous data from the Ibar river is scattered. Aquatic organisms such as diatoms rapidly respond to environmental changes, and their community structure accurately reflects changes of various anthropogenic and natural disturbances in their environments (e.g., by decrease in the abundance of sensitive diatoms, while tolerant ones increase) [1]. Diatoms are, therefore, considered to be significant bioindicators of water quality in aquatic ecosystems [2]. Diatoms have also been shown to react under metal stress by altering the composition, abundance, diversity and biomass of the community and changing the morphology and size of the cell wall and its deformation [2]. The goal of the study was to assess the ecological status of the Ibar river based on the diatom index, the Specific Pollution Sensitivity Index (IPS), according to Official Gazette of the Republic of Serbia (74/2011) [3] with focus on metal contamination. We also wanted to consider the effectiveness of using diatoms as indicators of the various pollutants: eutrophication and organic pollution vs. metal pollution.

**Materials and methods. Study area.** The Ibar river is the largest and the most important tributary of the Western Morava river and belongs to the Black Sea drainage basin. In the upper reach, illegal landfills and municipal waste water from small urban areas pose a threat to water quality as minor pollutants. Starting from the first large urban area of Kosovska Mitrovica, the Ibar river is a recipient of wastewater from mines, industry, flotation tailings (which are mostly located at the river bank), municipal water and diffuse pollutants (agriculture, illegal landfills) [4]. This leads to significant pollution of the Ibar river in terms of heavy metals [4]. Additional pollution of the Ibar river is caused by its largest tributary and the most polluted river in Kosovo and Metohija, the Sitnica river, which is the final recipient for effluents from the thermal power plants “Obilić” and untreated sewage waters.

**Sampling collection, physico-chemical data and diatom assemblage analyses.** Diatom sampling was performed in the Ibar river basin at 10 sites in September 2023 (Fig. 1). Measurements of physicochemical parameters were performed during the same period as the phytobenthos samples. Water temperature ( $t/^{\circ}\text{C}$ ), pH and conductivity ( $\text{EC}/\mu\text{S}$ ) were measured directly in the field with a multiparameter device (PCSTester 35K).

Nitrates ( $\text{NO}_3\text{-N}$ ), dissolved oxygen (DO), chlorides ( $\text{Cl}^-$ ) and orthophosphates ( $\text{PO}_4\text{-P}$ ) were measured using a Lovibond photometer PC Multidirect. Analyses of metals (Fe, Pb, Zn, Cu, Cd) have been determined by using the induc-

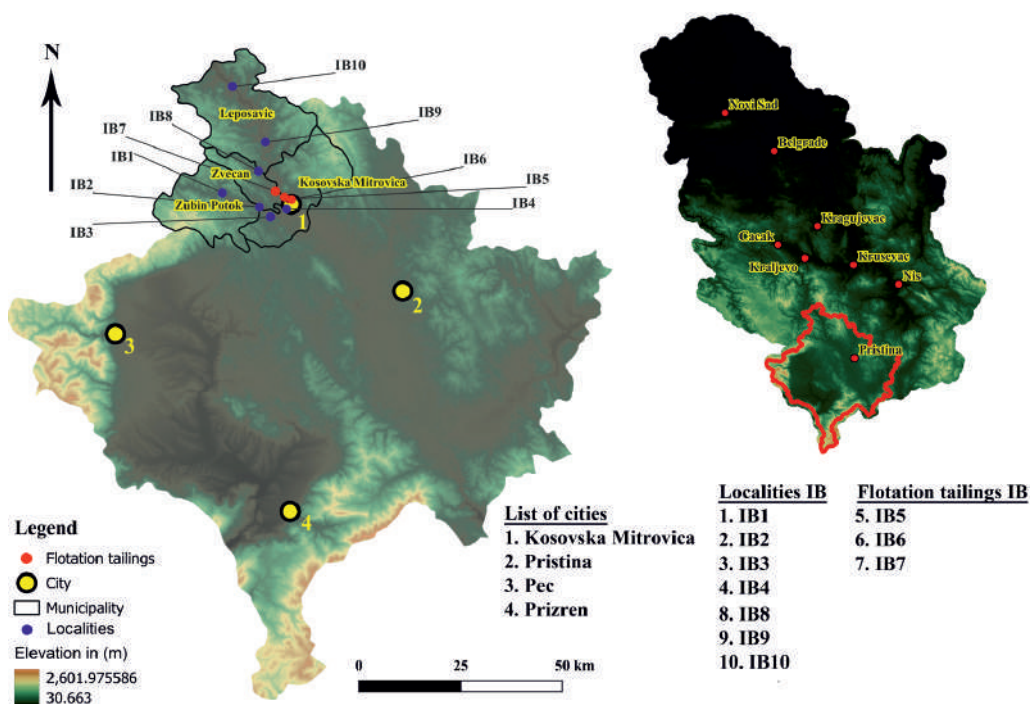


Fig. 1. Sampling sites in the Ibar river basin

tively coupled plasma mass spectrometry (ICP-MS). Heavy metals were measured in their ionic concentrations.

Diatoms were sampled and prepared according to TAYLOR et al. [5]. The results of the quantitative analysis of diatoms are presented as relative abundance (%) of each taxon in the sample by counting 400 valves on a slide, under the same microscope used for the qualitative analysis of diatoms at 1000 $\times$  magnification. Diatoms were classified according to LANGE-BERTALOT et al. [6]. The type of valve deformity was defined according to FALASCO et al. [7]. Deformities in diatom frustules were categorized into four types as (i) irregular valve outline/abnormal shape, (ii) aberrant striae/areolae pattern, (iii) atypical sternum/raphe and (iv) mixed deformities. Each aberration in valve morphology was noted.

Only the IPS index, without the Index of European Economic Community (CEE) was used to assess the ecological status of the sampling sites according to Official Gazette of the Republic of Serbia (74/2011) [3]. This is based on the results of DJUKIĆ et al. [8], which show that the use of the CEE index is not reliable in assessing the ecological status of rivers in Serbia. SHANNON's diversity index [9] was used to assess the biodiversity of the diatom community along the Ibar river. The IPS diatom index and the Shannon's diversity index were calculated using the OMNIDIA 5.3 software package [10]. Canonical correspondence analysis (CCA) [11] was performed to relate changes in the composition of the diatom community to the particular environmental data.

**Results and discussion.** A total of 108 taxa were identified in the Ibar river. The benthic diatom taxa of the Ibar river belong to 40 genera, with the highest diversity observed in *Nitzschia* Hassall sp. (19), *Navicula* Bory sp. (16) and *Gomphonema* Ehrenberg sp. (9). The most frequent taxa, represented in over 75% of the samples were *Achnantheidium minutissimum* (Kützing) Czarnecki, *Amphora pediculus* (Kützing) Grunow, *Gomphonema olivaceum* (Hornemann) Brébisson, *G. pumilum* (Grunow) E. Reichardt & Lange-Bertalot, *Nitzschia palea* (Kützing) W. Smith, *N. capitellata* Hustedt, *N. fonticola* (Grunow) Grunow, *Navicula cryptotenella* Lange-Bertalot, *Cocconeis placentula* Ehrenberg, and *C. pediculus* Ehrenberg. Both Shannon's diversity index and the community structure varied among the sampling sites along the Ibar river. Sampling sites (IB1, IB2, IB3) in the upper course of the river, from relatively unpolluted areas, showed higher relative abundances of *Cymbella excise* Kützing, *Encyonopsis minuta* Krammer & E. Reichardt, *Denticula tenuis* Kützing, *Cymbella affinis* Kützing, and *Encyonopsis subminuta* Krammer & E. Reichardt. The highest Shannon's diversity values (3.84–4.29) were observed in these samples (Table 1). IB4, IB8, IB9 and IB10 sites, downstream of the town of Kosovska Mitrovica and small municipalities (Leposavić and Lešak), are characterized by lower Shannon's diversity values (2.11–2.81) than upstream (Table 1) and a dominance of *Gomphonema parvulum* (Kützing) Kützing, *Eolimna minima* (Grunow) Lange-Bertalot, *Mayamaea atomus* (Kützing) Lange-Bertalot, *Navicula gregaria* Donkin, *Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot, and *Melosira varians* C. Agardh. The other three sites (IB5, IB6, IB7), in the immediate vicinity of the flotation waste landfill were dominated by *A. minutissimum*, *Fragilaria capucina* Desmazières var. *capucina*, *N. palea*, *Navicula cryptotenella* Lange-Bertalot, *Meridion circulare* (Greville) C. Agardh, and *Diatoma moniliformis* (Kützing) D. M. Williams. These sampling sites were characterized by the lowest Shannon's diversity values (1.63–1.96) (Table 1).

Heavy metals concentrations were evaluated (with values reaching up to 1649  $\mu\text{g}\cdot\text{dm}^{-3}$  Zn, 151  $\mu\text{g}\cdot\text{dm}^{-3}$  for Cu, and 15  $\mu\text{g}\cdot\text{dm}^{-3}$  Cd) at sites (IB5, IB6, IB7) in the immediate surroundings of flotation tailings (Table 1). Concentrations of nitrates ( $\text{NO}_3\text{-N}$ ) and orthophosphates ( $\text{PO}_4\text{-P}$ ) reflected nutrient enrichment at several sites (IB4, IB8, IB9, IB10) influenced by urban wastewater and agriculture (Table 1).

After plotting the studied locations using CCA analysis (Fig. 2), three groups of the diatom taxa could be distinguished (Fig. 2). The first two CCA axes accounted for 45.3% of the variance in diatom communities due to the environmental variables. The first cluster (the left part of the CCA diagram) includes polluted locations, which are characterized by high concentrations of Zn, Cu and Cd (Table 1) due to close proximity of flotation tailings of the former plants. Diatom taxa showing maximum abundance in this group were *A. minutissimum*, *F. capucina* var. *capucina*, *N. palea*, and *N. cryptotenella*. *A. minutissimum* frequently co-occurs in the assemblages with taxa *F. capucina*, *N. cryptotenella*, and *N. palea*

T a b l e 1

Physico-chemical water variables and biological characteristics of the Ibar river by localities

| Parameter                           | Unit                | IB1    | IB2     | IB3    | IB4      | IB5    | IB6     | IB7     | IB8      | IB9     | IB10   |
|-------------------------------------|---------------------|--------|---------|--------|----------|--------|---------|---------|----------|---------|--------|
| pH                                  | /                   | 8.03   | 7.75    | 7.89   | 7.68     | 7.01   | 6.82    | 7.06    | 7.61     | 7.55    | 7.67   |
| Water temperature ( <i>t</i> )      | °C                  | 14.8   | 15.1    | 15.5   | 16       | 16.2   | 15.8    | 17      | 16.9     | 16.5    | 17.1   |
| Electrical conductivity (EC)        | µS/cm               | 355    | 313     | 389    | 425      | 416    | 483     | 431     | 450      | 496     | 405    |
| Dissolved oxygen (DO)               | mg l <sup>-1</sup>  | 8.7    | 8.5     | 9.2    | 6.9      | 4.19   | 3.95    | 4.75    | 6        | 6.27    | 5.5    |
| Chlorides (Cl <sup>-</sup> )        | mg l <sup>-1</sup>  | 11.4   | 9.6     | 8.5    | 19.9     | 17.3   | 13.5    | 21.7    | 25.9     | 29.4    | 38.2   |
| Nitrate (NO <sub>3</sub> -N)        | mg l <sup>-1</sup>  | 0.89   | 0.96    | 0.72   | 10.5     | 1.52   | 1.48    | 1.55    | 7.7      | 6.4     | 8.6    |
| Orthophosphate (PO <sub>4</sub> -P) | mg l <sup>-1</sup>  | 0.013  | 0.017   | 0.01   | 1.88     | 0.091  | 0.082   | 0.098   | 1.62     | 1.45    | 1.79   |
| Iron (Fe)                           | µg·dm <sup>-3</sup> | 110    | 145     | 138    | 271      | 563    | 456     | 715     | 440      | 363     | 605    |
| Lead (Pb)                           | µg·dm <sup>-3</sup> | 2      | 16      | 15     | 27       | 45     | 49      | 38      | 33       | 21      | 19     |
| Zinc (Zn)                           | µg·dm <sup>-3</sup> | 38     | 65      | 72     | 371      | 1244   | 1649    | 1230    | 405      | 258     | 342    |
| Copper (Cu)                         | µg·dm <sup>-3</sup> | 22     | 17      | 12     | 93       | 134    | 126     | 151     | 87       | 79      | 68     |
| Cadmium (Cd)                        | µg·dm <sup>-3</sup> | 1      | 0.5     | 0.3    | 5        | 12     | 15      | 10      | 4        | 6       | 3      |
| % teratologies                      | /                   | 0      | 0       | 0.1    | 1.4      | 19.6   | 12.5    | 11.2    | 1.45     | 1.2     | 0.9    |
| IPS index/Class                     | /                   | 18.1/I | 15.9/II | 16.6/I | 12.9/III | 16.4/I | 14.1/II | 15.4/II | 12.1/III | 11.5/IV | 9.8/IV |
| Shannon's diversity index (H')      | /                   | 4.29   | 3.84    | 3.92   | 2.43     | 1.84   | 1.63    | 1.96    | 2.48     | 2.81    | 2.11   |

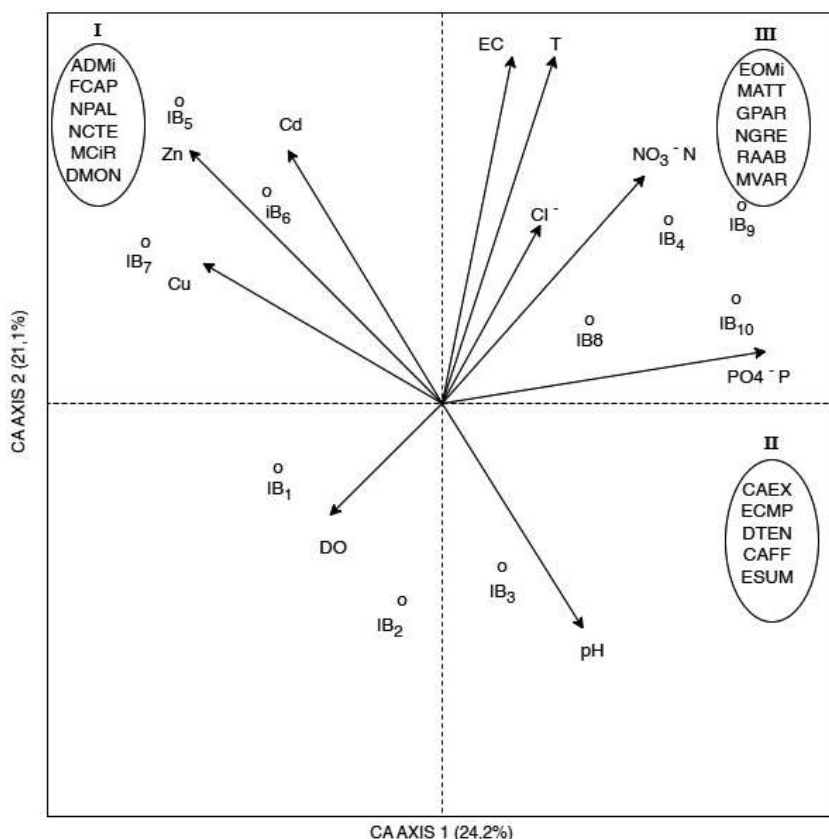


Fig. 2. CCA biplot based on the relationships between diatom species and environmental parameters along the Ibar river. Species are coded as follows: ADMi – *Achnanthes minutissimum*, FCAP – *Fragilaria capucina*, NPAL – *Nitzschia palea*, NCTE – *Navicula cryptotenella*, MCiR – *Meridion circulare*, DMON – *Diatoma moniliformis*, CAEX – *Cymbella excisa*, ECMP – *Encyonopsis minuta*, DTEN – *Denticula tenuis*, CAFF – *Cymbella affinis*, ESUM – *Encyonopsis subminuta*, EOMi – *Eolimna minima*, MATT – *Mayamaea atomus*, GPAR – *Gomphonema parvulum*, NGRE – *Navicula gregaria*, RAAB – *Rhoicosphenia abbreviata*, MVAR – *Melosira varians*

in metal-contaminated sites [12,13]. The IPS index values indicate generally good water quality (classes I and II) (Table 1), while diatom assemblages composing first cluster are characteristic of the degraded conditions. In fact, nutrients at those sites are low (Table 1), which partly explains the good water quality. When interpreting the index values in this situation, it should be taken into consideration that the IPS values most likely reflect the dominance of *A. minutissimum* recorded in abundances (above 60%) at IB5, IB6 and IB7 sites. The second cluster (the lower part of the CCA diagram) comprised locations in the upper course of the river which are reference or least-disturbed from a relatively unpolluted area. Diatom taxa most abundant in these samples were *C. excisa*, *E. minuta*, and *D. tenuis*. According to KELLY et al. [14], these species are considered an

indicator of good water quality (classes I and II), tolerating lower nutrient concentrations, which is in agreement with our data (Table 1). The third cluster (the right side of the CCA diagram) includes sites located downstream of the first large urban area of Kosovska Mitrovica and small municipalities (Leposavić and Lešak) characterized by high nutrient concentrations potentially reflecting eutrophication. The diatom assemblages were characterized by the dominance of *G. parvulum*, *E. minima* and *M. atomus*. These species are common to streams with elevated pollution (i.e. high nutrient levels) or moderate/poor water quality (classes III and IV) species [14] that VAN DAM et al. [15] describe to be nitrogen autotrophic taxa tolerating elevated concentrations of organically bound nitrogen/facultatively nitrogen-heterotrophic and eutraphentic. *M. atomus* is often regarded as one of the most pollution resistant diatom taxa, but is often found to occur in moderate/poor water quality [16].

In our study, a significant increase of deformed valves was observed in the samples of the IB5, IB6 and IB7, at locations under metals exposure, with values reaching up to 19.6% at IB5, with other localities exhibiting lower valve frequencies (< 1.5%) (Table 1). These results may be considered a response to the high concentrations of metals at these locations, inasmuch as frequencies around 10% or higher have been proposed as being caused by this type of contamination in rivers [17]. Overall, abnormal valve outline was the most frequently observed aberration, occurring in species such as *A. minutissimum*, *G. parvulum*, *E. minima*, *M. varians*, *M. circulare*, *D. moniliformis*, *N. cryptotenella* and *N. gregaria*. Mixed deformities were observed only at sites IB5, IB6 and IB7, and exclusively in *F. capucina*. The deformities in the striation pattern were found only at sites IB4 and IB8, and only in *R. abbreviata*. Deformed raphes were rarely observed and found only at the IB6 site (and only in *N. palea*). Several studies have highlighted that elevated metal concentration can induce the appearance of species deformation proneness and different types of deformity [7, 18, 19], which is in agreement with our data.

**Conclusions.** The diatom assemblages studied were found to reflect that Ibar river is under multiple stressors, caused by mining activities in the region, but also from untreated urban wastewater. The composition and distribution of benthic diatom communities were directly dependent on the quality properties of water and were sensitive to changes caused by pollution (eutrophication and metal pollution). As expected, at locations under metals exposure (IB5, IB6, IB7), the abundance of metal-tolerant taxa increased, and at locations with high level of nutrients (IB4, IB8, IB9, IB10), the abundance of nutrient-tolerant taxa increased. The number of deformed valves in the samples from the Ibar river sites (IB5, IB6, IB7) reflects a response to metals as contaminants. In conclusion, diatoms are successfully used as ecological indicators of freshwater environmental conditions and can be employed for short- and long-term monitoring of aquatic ecosystems' function and health.

## REFERENCES

- [1] LAVOIE I., S. CAMPEAU, N. ZUGIĆ-DRAKULIC et al. (2014) Using diatoms to monitor stream biological integrity in Eastern Canada: an overview of 10 years of index development and ongoing challenges, *Sci. Total Environ.*, **475**, 187–200, <https://doi.org/10.1016/j.scitotenv.2013.04.092>.
- [2] SIENKIEWICZ E., M. GAŚSIOROWSKI, I. SEKUDEWICZ et al. (2023) Responses of diatom composition and teratological forms to environmental pollution in a post-mining lake (SW Poland), *Environ. Sci. Pollut. Res.*, **30**, 110623–110638.
- [3] Official Gazette of the Republic of Serbia (74/2011) Ordinance on the parameters of the ecological and chemical status of surface waters and the parameters of the chemical and quantitative status of groundwater, Belgrade, Government of Republic of Serbia (in Serbian).
- [4] OBRADOVIĆ S. (2015) Water quality of the middle and lower course of the Ibar river in two testing season, *Srb. J. Geosci.*, **7**, 15–23.
- [5] TAYLOR J. C., W. R. HARDING, C. G. M. ARCHIBALD (2005) A Methods Manual for the Collection, Preparation and Analysis of Diatom Samples, WRC Project No. K5/1588, Pretoria, Water Research Commission.
- [6] LANGE-BERTALOT H., G. M. HOFMANN, M. WERUM et al. (2017) Freshwater Benthic Diatoms of Central Europe: Over 800 Common Species Used in Ecological Assessment (eds M. Cantonati et al.), Schmitten-Oberreifenberg, Koeltz Botanical Books, 942 pp.
- [7] FALASCO E., L. ECTOR, C. E. WETZEL et al. (2021) Looking back, looking forward: a review of the new literature on diatom teratological forms (2010–2020), *Hydrobiologia*, **848**, 1675–1753, <https://doi.org/10.1007/s10750-021-04540-x>.
- [8] DJUKIC N. N., B. VASILJEVIC, D. MILOSEVIC et al. (2020) A water quality assessment based on benthic diatoms of the Timok river basin (eastern Serbia) under multiple anthropogenic pressures, *C. R. Acad. Bulg. Sci.*, **73**(12), 1696–1702, <https://doi.org/10.7546/CRABS.2020.12.09>.
- [9] SHANNON C. E. (1948) A mathematical theory of communication, *Bell Syst. Tech. J.*, **27**(3), 379–423.
- [10] LECOINTE C., M. COSTE, J. PRYGIEL (1993) Omnidia: Software for taxonomy, calculation of diatom indices and inventories management, *Hydrobiologia*, **269/270**(1), 509–513.
- [11] BRAAK C. J. F. T. (1987) The analysis of vegetation-environment relationships by canonical correspondence analysis, *Vegetatio*, **691/3**, 69–77.
- [12] VERB R. G., M. L. VIS (2005) Periphyton assemblages as bioindicators of mine-drainage in unglaciated Western Allegheny Plateau lotic systems, *Water Air Soil Pollut.*, **161**, 227–265.
- [13] DENICOLA D. M., A. J. LELLOCK (2015) Nutrient limitation of algal periphyton in streams along an acid mine drainage gradient, *J. Phycol.*, **51**(4), 739–749.
- [14] KELLY M., G. URBANIC, E. ACS et al. (2014) Comparing aspirations: Intercalibration of ecological status concepts across European lakes for littoral diatoms, *Hydrobiologia*, **734**(1), 125–141.
- [15] VAN DAM H., A. MERTENS, J. SINKELDAM (1994) A coded checklist and ecological indicator values of freshwater diatoms from The Netherlands, *Neth. J. Aquat. Ecol.*, **28**, 117–133.

- [16] LANGE-BERTALOT H. (2001) *Navicula sensu stricto*, 10 Genera Separated from *Navicula sensu lato*, *Frustulia* (2nd ed., *Diatoms of Europe*), Ruggell, A.R.G. Gantner Verlag KG, 526 pp.
- [17] MORIN S., T. T. DUONG, A. DABRIN et al. (2008) Long-term survey of heavy-metal pollution, biofilm contamination and diatom community structure in the Riou Mort watershed, South-West France, *Environ. Pollut.*, **151**(3), 532–542.
- [18] LAVOIE I., P. B. HAMILTON, S. MORIN et al. (2017) Diatom teratologies as biomarkers of contamination: Are all deformities ecologically meaningful?, *Ecol. Indic.*, **82**, 539–550.
- [19] PANDEY L. K., I. LAVOIE, S. MORIN et al. (2018) River water quality assessment based on a multi-descriptor approach including chemistry, diatom assemblage structure, and non-taxonomical diatom metrics, *Ecol. Indic.*, **84**, 140–151.

*Department of Biology, Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, 29 Lola Ribar St, 38220 Kosovska Mitrovica, Serbia*  
*e-mails: nikola.djukic@pr.ac.rs, tatjana.jaksic@pr.ac.rs,*  
*slavica.ciric@pr.ac.rs, tamara.petronijevic@pmf.edu.rs,*  
*zeljko.bulatovic@pr.ac.rs*