

Research Article

Contribution to the Knowledge of the Blidinje Lake Sediment (Bosnia and Herzegovina)

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Abstract

Blidinje Lake is located in the northern part of the region Herzegovina (B&H). By the surface is the largest mountain lake in Bosnia and Herzegovina. In this study, the content of metals (Cu, Mn, Zn, Cd, Ca, Mg and Pb), chlorophylls *a* and *b*, pH and organic matter have been analyzed in five locations along the lake shore. The aim of the study was to obtain data which may be used as guidelines for future research and plan for sustainable management of the Nature Park "Blidinje". Mountain lakes are generally found as areas with little or no pollution sources which be used for simple assessment of atmospheric deposition from the region (transboundary pollution).

The catchment area is built of limestone with the domination of Ca and Mg. Content of CHL *a* and CHL *b* indicates increased production in the recent period. The concentration of organic matter is reduced to the surface layer. The concentrations of Zn and Cu are within the range of natural content in the sediments. Mn, Pb and Cd were higher than natural values in sediments. Ph is neutral or slightly alkaline.

Keywords: Sediment; Blidinje Lake; Metals; Chlorophyll

Introduction

Lake sediments are considered as an archive of physical, chemical and biological conditions in lakes and their drainage basin. Under relative steady sedimentation process and in the absence of bioturbation, depositional sequence of lake sediments provide a temporal composition pattern, therefore the onset, rate and variations in present and past environmental conditions could be assessed. In this sense, environmental impacts caused by human activities, mainly those related to the release of persistent pollutants, can be identified by appropriate analyses of sediment archives.

Lake Blidinje with area of some 2.5 km² (on average) is the biggest mountain lake in Bosnia and Herzegovina. It is located at an altitude of 1185 m (N 43°36'; EO 17°29'), between Čvrsnica and Vran mountains (Figure 1). The lake is very shallow with an average depth of about 0.5 m, and under the strong influence of meteorological conditions. The lake has variable volume and surface area. Lake Blidinje is an integral part of the Nature Park "Blidinje" founded in 1995. Nature Park "Blidinje" (364 km²) includes the Čvrsnica massif (2228 m), the Vran Mt. (2074 m), the valley Dugo polje and the western part of the mountain ridge Čabulja named Debelo brdo, (1500 m).

Geological base is very heterogeneous, made up of limestone from upper and middle Triassic, and has a young Jurassic limestone, werfenian layers of red sandstone, sandy shale, limestone plate marl, porous limestone and dolomite. On the surface most of the Nature Park "Blidinje" lithosphere breaks through the ground and form a single larger or smaller blocks to the tops form a rocky massif.

Blidinje Lake catchment area comprises an area of 48 km². Bedrock under the Quaternary lake sediments is built of limestones and dolomites of upper Jurassic and lower Cretaceous age with

distinguished karst permeability [1]. Quaternary cover is built of glacial and proluvial sediments with poor or good permeability, reaching average thickness 10-40 m. Quaternary bedrock up to the depth from 2 to 5 m is built of fine grained Aeolian sand and silts, brought by the north wind from the Vran Mt. This silty deposit seals the lake bottom preventing lake water drain, but at the same time fills the lake, so its depth decreases, and sinks in the south-eastern rim deepen. It is a real danger of desiccation of the lake without protective measures [1].

The amount of water in the lake depends on the amount of

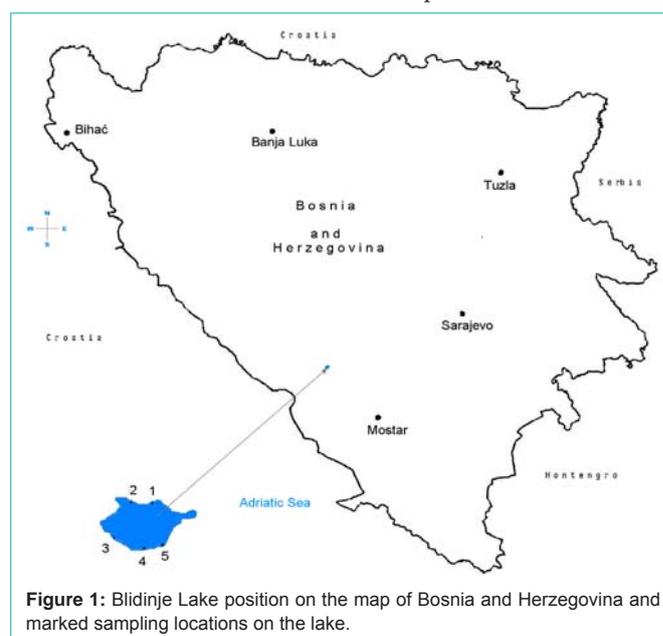


Figure 1: Blidinje Lake position on the map of Bosnia and Herzegovina and marked sampling locations on the lake.

rainfall and the speed of outflow. Most of the water that flows into the lake is connected with the underground cracks in the surrounding wall of the calcareous alps. The devastation of forest cover and anthropogenically backfill abyss had an important role on the formation of the lake. According to the record of the Parish Office in Parish Poklečani, based on the testimony of older people, the lake was formed after numerous interventions of farmers who did not have water for their livestock, and they therefore decided to close the gap in the long field. For that reason they chopped branches with sawmills, tied them in bundles to cover the gap, and covered them by clay. During winter, rainwater and melting snow formed the lake. Although some authors believe that the lake Blidinje is of glacial origin [2], this aspect cannot be accepted due to the fact that today the lake has very variable surface. It means that the water is only of recent rainfall and snow. Most likely, in the past, during the Ice Age, was a glacial lake. However, the influence of slope processes (rinse, collapse and torrent) has buried it. Subsequent erosion processes transported part of the accumulated material in karst fracture systems. The lake is held until today because there was more removal than accumulated material from the hillside.

The average length of the lake is 3465 m, the width is 1585 m and the depth is 5.1 m at average area. Huge changes in area suggest also big fluctuation of water level, thus also depth. The average area of the lake is 2.5×10^6 m², and the maximum area is 6.05×10^6 m² [1]. The lake is highly variable in volume and surface area and in the literature different dimensions of Blidinje Lake can be found [3,4,5,1].

In September of 1990, the lake was nearly dry with average depth of just 15 cm, demanding fast closing of the swallowing area on the south-east part of the lake for the preservation of the lake with its flora and fauna. A test embankment of 600 m long, perpendicular to the direction of the biggest sinkhole, was built. It only partly slowed down the water flowing from the lake, because the embankment for the complete control of swallow-holes was not successfully built [1].

According to the long term observations (Stjepan Franciscan Petar Krsić, pers. comm.) the lake loses 4-5 mm of water daily in spring due to outflow, which corresponds to 24.000 m³ of water outflow per day. Lake serves as a trap for sediments. It is supposed that the lake lost its original capacity to retain water and to safeguard the lake for the future its water recover capacity should be reconstituted and increase [1].

This paper presents for the first time, chemical analysis of the sediment that can serve as a guideline for the future research and plan for the sustainable management of Nature Park "Blidinje".

The greater part of the Nature Park "Blidinje" area is dominantly built of sediments originating in the sedimentary system of the Mesozoic carbonate platform, which existed approximately 180 million years. It is Boran fold area built of 4.5 to 8.5 km thick complex carbonate sediments [6].

Sediments of Cretaceous age are distributed around Blidinje Lake, at the south-western slopes Čvrstica and at its peaks. At the end of the Cretaceous, due to the sea regression, Paleogene marine sediments created only in the south-western part of the external Dinarides. This regression is the consequence of large tectonic events and orogenic movements of the Laramian phase [7].

Remote mountain lakes are the most sensitive aquatic ecosystems. Because of their sensitivity remote mountain lakes are not only vulnerable to environmental change they are also excellent sensors of change, and the high quality of their sediment may be used for the conclusion of speed, direction and biological impact of changes in air quality and climate [8,9].

The resuspension of sediment may be the most important factor in the nutrients dynamics of shallow lake where the sediment is under the constant influence of waves. The waves affect the increase in turbidity which reduces the penetration of light into the water and thus disturb the primary production. That causes biological changes and increased recycling of nutrients due to sediment redistributed in water column [10].

According to Ivanković et al. (2011), Blidinje Lake is a shallow oligotrophic lake where phosphorous is limiting factor for trophic state. Low levels of dissolved reactive phosphorus can be sorbed to the sediment particles and subsequently released, and thereby define the trophic status of lakes [10].

Heavy metal in soil and sediment have different origins and sometimes is difficult to identify them due to daily deposition (dry and wet) remote transport through the atmosphere.

The natural content of heavy metals in soil and sediment, according to various authors, is the following: lead 10-35 mg kg⁻¹ soil, zinc 70-90 mg kg⁻¹ soil, and copper 20-30 mg kg⁻¹ soil [11,12]. It is usually taken as that for manganese less than 400 mg kg⁻¹, copper 5-20 mg kg⁻¹, zinc 10-50 mg kg⁻¹, leads to a 10 mg kg⁻¹ and cadmium to 0.5 mg kg⁻¹.

Materials and Methods

Sediment was sampled in May 2009 at five locations in the coastal area, three cores per location (Figure 1):

- Surface layer (0-3 cm)
- Bottom layer (3-10 cm)
- An integrated sample (0-10 cm) - as reference to previous sample.

Samples for the depth of 1-10 cm were taken to obtain the overall mean value and sample up to 3 cm, primarily to determine the content of chlorophylls.

Sediment sampling was performed at five locations along the

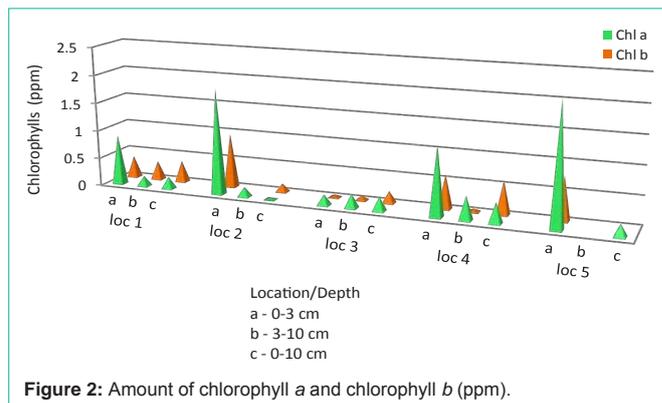


Figure 2: Amount of chlorophyll a and chlorophyll b (ppm).

Table 1: Amount of chlorophyll *a* and chlorophyll *b*.

| Location | Depth | Chl <i>a</i> | Chl <i>b</i> |
|----------|---------|--------------|--------------|
| | | ppm | ppm |
| 1 | 0-3 cm | 0.89 | 0.38 |
| | 3-10 cm | 0.18 | 0.33 |
| | 0-10 cm | 0.21 | 0.38 |
| 2 | 0-3 cm | 1.87 | 0.96 |
| | 3-10 cm | 0.17 | |
| | 0-10 cm | 0.03 | 0.15 |
| 3 | 0-3 cm | 0.19 | 0.05 |
| | 3-10 cm | 0.25 | 0.08 |
| | 0-10 cm | 0.25 | 0.21 |
| 4 | 0-3 cm | 1.23 | 0.6 |
| | 3-10 cm | 0.42 | 0.06 |
| | 0-10 cm | 0.36 | 0.6 |
| 5 | 0-3 cm | 2.15 | 0.77 |
| | 3-10 cm | | |
| | 0-10 cm | 0.22 | |

coast the same as earlier studies sampled water due to wind impact and possible horizontal stratification [13]. Water samples were taken at the surface at five locations along the edge of the lake. Vertical mixing is common in shallow lakes and stratification is rarely found [14]. Thus, surface samples are adequate to characterize water quality [15].

Sediment samples were collected with robust steel corer and stored in glass containers. All samples were delivered to the laboratory in a portable refrigerator. Fraction <2 mm was taken for analysis of the total sediment sample by sieving, as possible indication for contamination (processes of adsorption).

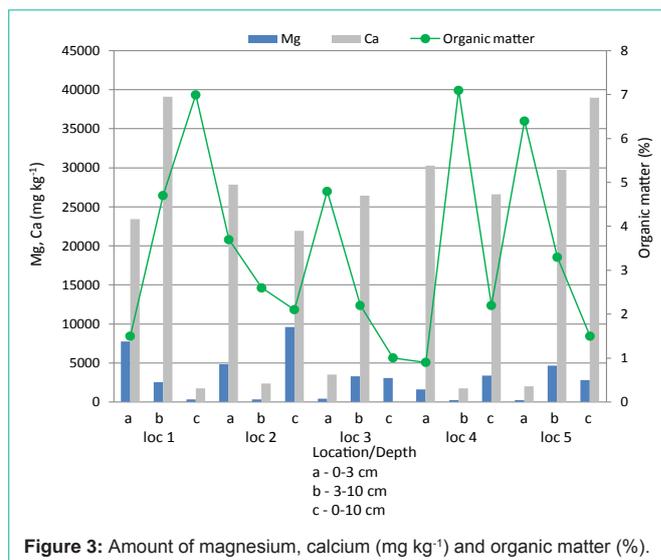
For determination of chlorophyll (*a* and *b*) concentration sample weight of about 10 g of fresh sediment scam for 3 minutes with 10-15 mL of acetone protected from light with aluminium foil. Filtered on a vacuum pump (Millipore), filter paper blue bars (0.45 µm). After adding acetone and agitation filtrate was transferred into a volumetric flask of 25 mL and amendments to the mark [16]. The absorbance of the solution is read at two wavelengths: 663 and 645 nm by Varian, Carry 1E UV-VIS spectrophotometer. Chlorophyll content in sediment calculated according to the following equations:

$$\text{Chl.}a = (12.7 \times A_{663} - 2.69 \times A_{645}) \times V / \text{mass} \times 1000 \quad (1)$$

$$\text{Chl.}b = (22.9 \times A_{645} - 4.68 A_{663}) \times V / \text{mass} \times 1000 \quad (2)$$

Analysis of metal content in sediments (Cu, Mn, Zn, Cd, Ca, Mg and Pb) was carried out after homogenization of all fractions, drying at 105°C and decomposition with a mixture of concentrated acids (65% strength HNO₃, 37% strength HCl and 40% strength HF) and H₂O₂ in a microwave oven (Anton Paar Multiwave 3000) by atomic absorption spectrophotometry (Varian Spectra AA-30) on a graphite cuvette (US EPA method, 1994).

Determination of organic matter was done by colorimeter, with method based on the wet digestion of sediment with potassium

**Figure 3:** Amount of magnesium, calcium (mg kg⁻¹) and organic matter (%).

dichromate in a strongly acidic media (96% strength H₂SO₄) [17].

Chemical indicators of sediment were analyzed using statistical test Pearson index of correlation for determining the significance of relations between chemical parameters of the sediment and to compare the elemental composition bedrock.

Results and Discussion

The chemical composition of lake's sediments is under influence of numerous processes that simultaneously, with different rates, contribute to dynamic exchange of chemical composition in time. It was demonstrated that the erosion of surrounding terrain is the most significant process in formation of lake's sediments and that 70–80% of inorganic sediment has formed in such a way [18]. The erosion, by itself, is a very complex process, which depends, first of all, on topography. That means more of the resulting particles of soil into the lake, but also of chemical species (molecules, ions, radicals) that could speed up chemical processes. This is a very selective process: wind erosion results in distribution of particles by mass, while precipitation makes selection based on solubility of soil minerals. As result, newly formed sediment has different composition from the surrounding soils.

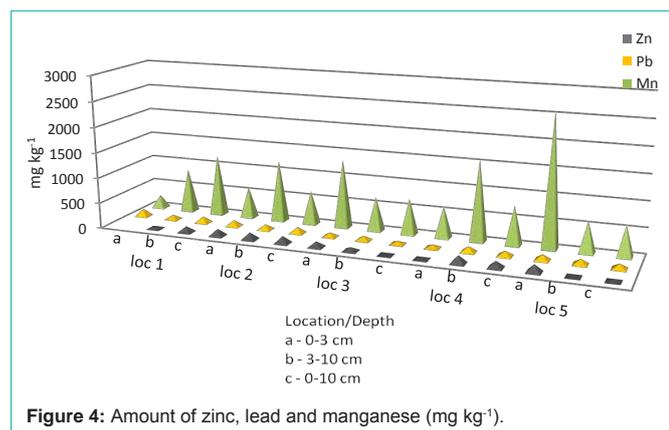
Chlorophylls

Chlorophylls *a* and *b* were determined in the sediment as indication of organic production in different sediment layers. Chlorophyll *a* is a nonspecific pigment because it is produced by all types of plants, while chlorophyll *b* may be produced only by Chlorophyceae, Euglenophyceae and Tracheophyceae [19]. The positive correlation between concentration of chl. *a* and *b*, is significant ($P = 0.01$) and in average, their quantitative relation 2:1.

At all locations, except the location 3, concentration of chlorophyll *a* was significantly higher in the surface sediment layer (0-3 cm) (Table 1). The concentration of chlorophyll *b* at the location 1 is rather uniform, at location 2 appears only at the first depth (0-3 cm) and integrated sample (0-10 cm), at the location 3 chlorophyll *b* increases with depth, at the location 4 there is much higher concentration of chlorophyll *b* at a depth of 0-3 cm and in integrated sample (0-10

Table 2: Amounts of metals, organic matter and pH.

| Loc./Depth | Ca ($\mu\text{g/g}$) | Mg ($\mu\text{g/g}$) | Mn ($\mu\text{g/g}$) | Pb ($\mu\text{g/g}$) | Zn ($\mu\text{g/g}$) | Cu ($\mu\text{g/g}$) | Cd ($\mu\text{g/g}$) | Org. mat. % | pH |
|---------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-------------|------|
| 1. 0-3 cm 3-10 cm 0-10 cm | 23447.2 | 7738.74 | 256.21 | 147.13 | / | 2.99 | 0.139 | 1.5 | 8.21 |
| | 39110.52 | 2527.275 | 856.925 | 90.4 | 54.105 | 11.42 | 0.38 | 4.7 | 7.91 |
| | 1713.73 | 324.95 | 1201.16 | 124.95 | 116.05 | 11.19 | 0.3735 | 7 | 7.36 |
| 2. 0-3 cm 3-10 cm 0-10 cm | 27853.26 | 4815.6 | 609.47 | 118.01 | 136.25 | 11.84 | 0.437 | 3.7 | 7.9 |
| | 2326.47 | 298.065 | 1203.63 | 105.42 | 139.22 | 21.345 | 0.6655 | 2.6 | 7.73 |
| | 21905.36 | 9599.87 | 657.305 | 119.38 | 140.21 | 4.545 | 0.3265 | 2.1 | 7.81 |
| 3. 0-3 cm 3-10 cm 0-10 cm | 3480.83 | 385.22 | 1345.32 | 80.98 | 113.19 | 22.09 | 0.655 | 4.8 | 7.76 |
| | 26425.48 | 3287.45 | 664.57 | 93 | 75.3 | 13.67 | 0.305 | 2.2 | 7.89 |
| | 26629.17 | 3066.33 | 700.15 | 65.36 | 13.18 | 6.68 | 0.229 | 1 | 8.1 |
| 4. 0-3 cm 3-10 cm 0-10 cm | 30266.72 | 1586.5 | 620.41 | 71.7 | 31.5 | 5.8 | 0.181 | 0.9 | 7.89 |
| | 1735.02 | 234.62 | 1598.97 | 114.16 | 156.15 | 24.74 | 0.82 | 7.1 | 7.32 |
| | 26603.69 | 3368.75 | 765.44 | 104.09 | 132.23 | 10.04 | 0.277 | 2.2 | 7.9 |
| 5. 0-3 cm 3-10 cm 0-10 cm | 1993.43 | 237.82 | 2598.61 | 116.97 | 148.49 | 24.21 | 0.962 | 6.4 | 7.58 |
| | 29758.19 | 4654.84 | 612.32 | 108.23 | 29.84 | 8.33 | 0.4 | 3.3 | 7.87 |
| | 38997.65 | 2787.78 | 610.81 | 101.98 | 40.33 | 7.21 | 0.223 | 1.5 | 8.1 |

**Figure 4:** Amount of zinc, lead and manganese (mg kg^{-1}).

cm), while at the location 5 it appears only in the first depth sediment (0-3 cm). According to Choudhary et al. [20] increased concentration of chlorophylls *a* and *b* in surface layers of sediments indicate higher production in the recent period.

Metals

Concentration of calcium, has ranged from 1.71 g kg^{-1} to maximum 3.91 g kg^{-1} (Figure 3), the values indicated by other authors for similar lake conditions [21] (Table 2). The concentration reflects slightly alkaline and alkaline waters (as well as limestone and dolomite bedrock). In general, its concentration negatively correlates with concentration of Mn, Zn, Cu, Cd and organic matter, and positive with pH ($P = 0.01$).

At the location 1 levels of calcium are significantly higher in depths of 0-3 cm and 3-10 cm than in the integral sample, which corresponds to the content of organic matter which is highest in the integrated sample (0-10 cm).

At the location 2, the lowest concentration of calcium was at a depth of 3 to 10 cm, also on the location 4, while on the third and locations 5; the lowest calcium concentration was in the surface sediment layer (0-3 cm). These values of calcium and organic matter

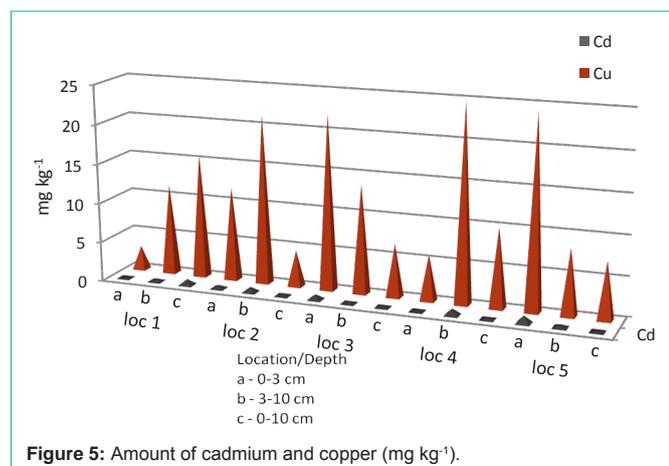
indicate a high exposure of lake to winds in the past. According to Scheffer [22] if the sediments of a shallow lake were heavily exposed to the wind in the same periods (at the same depths), at different locations lakes qualitatively different profiles of sediment appear.

Magnesium values, some 10 times less than calcium, ranged from $234.62 \text{ mg kg}^{-1}$ to $9599.87 \text{ mg kg}^{-1}$. The pattern of Mg distribution corresponds to the distribution of calcium having similar trend for their concentration profiles, which could indicate erosion as the most dominant process in sediment formation. It was established the same level of negative correlation to concentration of Mn, Cu, Cd and organic matter and positive to pH. Common distribution of these two elements could be explained by same source: carbonate origin and wind erosion (Figure 3).

Manganese values varied from $256.21 \text{ mg kg}^{-1}$ to the maximum of $2598.61 \text{ mg kg}^{-1}$ (Figure 4). All values of manganese, except the smallest one at (location 1, upper layer), were significantly higher than the usual content of natural manganese in soils and sediments ($<400 \text{ mg/kg}$). According to many authors, the natural content of manganese in the sediment is $<400 \text{ mg kg}^{-1}$ [11,12], indicating intense redox processes on the sediment-water interface at the time of deposition. High positive correlation with organic matter (0.74 , $P = 0.01$) (Figure 3) is argument that support this assumption.

Lead concentrations ranged from 65.36 mg kg^{-1} to $147.13 \text{ mg kg}^{-1}$. The natural content of lead in soils and sediments, according various authors, is very different as the result of different water solubility of its compounds. The transformation of lead species is suspected to be caused by reactions involving essentially insoluble organic material, with inorganic precipitation by carbonate and sorption by hydrous oxides [23].

The concentration of zinc ranged from 13.18 mg kg^{-1} to $156.15 \text{ mg kg}^{-1}$. Natural zinc content in soils and sediments in various authors is also very different; according to Kabata-Pendias and Pendias (1992) it can be $10\text{-}300 \text{ mg kg}^{-1}$. Thus the concentration of zinc was mainly within the limits of its natural content in soil.



The concentration of copper in the sediment ranged from minimum 2.99 to 24.74 mg kg^{-1} (Figure 5). These values according to many authors belong to the natural copper content in soils [24,12,25]. Concentrations of cadmium in the sediment were from 0.14 to 0.96 mg kg^{-1} . Several obtained values of cadmium on all locations except the first one are greater than its natural content 0.53 mg kg^{-1} according to [25].

Organic matter

The organic material that reaches the bottom of the lake can be embedded in the sediment, where it is exposed to diagenetic or microbiological processes, mineralized and has a direct impact on the concentration of nutrients in the water [26]. Many processes in the sediment are regulated by microbial oxidation of organic matter using O_2 , NO_3^- , MnO_2 , Fe_2O_3 , SO_4^{2-} and CO_2 [27]. Many compounds that are formed in the pores of the sediment and after the release in water (HCO_3^- , N_2 , Mn^{2+} , NH_4^+ , Fe_2^+ , H_2 and CH_4) are important nutrients. As a result of mineralization of organic matter may occur anaerobic conditions in the hypolimnion and sediment as the majority of oxygen consumed by microorganisms in the oxidation of CH_4 , NH_4^+ and H_2S [28]. Decomposition of organic matter during the early stages of diagenesis is an important process that affects the quality of surface water and sediment geochemistry.

Concentration of organic matter in the sediments is shown in the Figure 3. The concentration of organic matter at the first depth of 0

Table 3: Descriptive statistics of chemical indicators of sediment.

| | No. meas. | Min | Max | Average value | Median | Standard deviation | Coefficient of variation (%) |
|----------------------------|-----------|---------|----------|---------------|----------|--------------------|------------------------------|
| Ca (mg kg^{-1}) | 15 | 1713.73 | 39110.52 | 20149.78 | 26425.48 | 13912.77 | 69.05 |
| Mg (mg kg^{-1}) | 15 | 234.62 | 9599.87 | 2994.25 | 2787.78 | 2817.14 | 94.08 |
| Mn (mg kg^{-1}) | 15 | 256.21 | 2598.61 | 953.42 | 700.15 | 575.07 | 60.32 |
| Pb (mg kg^{-1}) | 15 | 65.36 | 147.13 | 104.12 | 105.42 | 21.38 | 20.53 |
| Zn (mg kg^{-1}) | 14 | 13.18 | 156.15 | 94.72 | 114.62 | 51.50 | 54.37 |
| Cu (mg kg^{-1}) | 15 | 2.99 | 24.74 | 12.41 | 11.19 | 7.30 | 58.82 |
| Cd (mg kg^{-1}) | 15 | 0.14 | 0.96 | 0.42 | 0.37 | 0.24 | 57.14 |
| Organic matter (%) | 15 | 0.90 | 7.10 | 3.40 | 2.6 | 2.14 | 62.94 |
| pH | 15 | 7.32 | 8.21 | 7.82 | 7.89 | 0.25 | 3.20 |
| Chl a (ppm) | 14 | 0.03 | 2.15 | 0.60 | 0.25 | 0.68 | 113.33 |
| Chl b (ppm) | 12 | 0.05 | 0.96 | 0.38 | 0.35 | 0.30 | 78.95 |

to 3 cm was 0.9 to 6.4%. At the bottom layer of 3 to 10 cm organic matter concentration was slightly higher, from 2.2 to 7.1%. Only at the location 1 concentrations of organic matter were the highest in the integral sample.

Organic matter is subject to a variety of biogeochemical processes (mineralization) which can significantly change its molecular structure and distribution of these compounds [29]. Of course in addition to these, there are compounds which are relatively persistent and not under the influence of biogeochemical processes. These compounds can be considered indicators of events that occurred in the past [30].

pH

pH values were neutral to slightly alkaline and ranged from 7.32 to 8.31, generally somewhat lower values than those measured in the lake water. It should be noted that when the pH values were more than 5.5 most of the metals were in the form of carbonate and prevented to pollute the water [31].

Statistical analysis of the sediment quality

Descriptive statistics (minimum, maximum, mean, median and standard deviation) of all measured parameters of the sediment is shown in Table 3.

Chemical indicators of the sediment were analyzed using statistical test Pearson index of correlation (Table 4).

Values of calcium have strong and statistically highly significant negative correlation with all the heavy metals, except for lead.

Concentrations of calcium have a strong negative correlation with organic matter ($r = -0.655$, $P < 0.01$). Natural values of heavy metals are higher in organic than in the mineral fraction of the sediment [32]. Correlation between organic matter and heavy metals was medium to high (Table 4). Lack of correlation between calcium and lead, increased concentrations of lead in relation to the natural content, which points to pollution of sediments with lead in earlier periods, it probably came through aero-pollutants (cross-border pollution).

Values of magnesium showed a strong and statistically highly significant correlation with manganese and copper, and medium negative correlation with organic matter (Table 4). The sample of Mg

Table 4: Pearson correlation of all parameters.

| | | | | | | | | | | | | |
|------------|------------|------------|------------|-----------|-----------|------------|------------|------------|--------|-----------|-------|--|
| | Ca | | | | | | | | | | | |
| Ca | 1 | Mg | | | | | | | | | | |
| Mg | 0.504 | 1 | Mn | | | | | | | | | |
| Mn | -0.736(**) | -0.649(**) | 1 | Pb | | | | | | | | |
| Pb | -0.258 | 0.381 | 0.054 | 1 | Zn | | | | | | | |
| Zn | -0.691(**) | -0.088 | 0.555(*) | 0.688(**) | 1 | Cu | | | | | | |
| Cu | -0.743(**) | -0.720(**) | 0.837(**) | -0.030 | 0.617(*) | 1 | Cd | | | | | |
| Cd | -0.751(**) | -0.564(*) | 0.907(**) | 0.123 | 0.661(**) | 0.936(**) | 1 | Org. matt. | | | | |
| Org. matt. | -0.655(**) | -0.528(*) | 0.741(**) | 0.302 | 0.555(*) | 0.695(**) | 0.746(**) | 1 | pH | | | |
| pH | 0.770(**) | 0.564(*) | -0.709(**) | -0.190 | -0.660(*) | -0.681(**) | -0.708(**) | -0.856(**) | 1 | Chl a | | |
| Chl a | -0.065 | -0.055 | 0.346 | 0.225 | 0.213 | 0.153 | 0.297 | 0.157 | -0.027 | 1 | Chl b | |
| Chl b | 0.187 | -0.010 | 0.095 | 0.222 | 0.160 | -0.097 | 0.026 | -0.015 | 0.109 | 0.830(**) | 1 | |

**Correlation is significant at 0.01 level;

*Correlation is significant at 0.05 level

distribution corresponds to the distribution of calcium having similar trend for their concentration profiles, which could indicate erosion as the most dominant process in sediment formation.

Lead shows no correlation with any of the measured indicators of sediment except for zinc concentration ($r = 0.688$, $P < 0.01$), which again proves that there is some sediment contamination by lead and possibly manganese. High levels of air pollution are the main reason why the content of metals, particularly lead, increases in lake sediments [33,34].

Concentrations of chlorophyll *a* and chlorophyll *b* are not correlated with any measured indicators, but their mutual correlation is very strong and highly statistically significant ($r = 0.830$, $P < 0.01$).

Conclusions

- In general, concentrations of chlorophyll *a* and chlorophyll *b* point to an increased production in the recent period (increased values in upper layer).
- The lake is shallow and is constantly exposed to the wind which affects many chemical parameters.
- Limestone base is dominantly composed of calcium and magnesium. Concentration of organic matter is limited to the surface layer and rapidly reduces to the bedrock (in correlation with amount of chlorophylls).
- Maximal concentrations of heavy metals, zinc ($156,15 \text{ mg kg}^{-1}$) and copper ($27,74 \text{ mg kg}^{-1}$) are in the range of natural content in the sediments.
- Maximal concentrations of heavy metals, manganese ($2598,61 \text{ mg kg}^{-1}$), lead ($147,13 \text{ mg kg}^{-1}$) and cadmium ($0,96 \text{ mg kg}^{-1}$) are higher than the natural values of the non-polluted sediments.
- pH was neutral to slightly alkaline (max. 8,21).
- For the future research a systematic study of the sediment is recommended, as well as the assessment of the sediment amount, analysis of total suspended material (TSS) - which represents the total amount of all biotic and abiotic agents suspended in the water column. Sampling of sediment varies depending on the type and level of monitoring. If increasing rate of sediment is small (0.1 mm

per year up to 1 cm per year) sampling should be done periodically, usually once in five years [35].

- Also the processes of sedimentation and resuspension of sediment should be examined to determine their impact on the dynamics of nutrients.

- It is necessary to identify all potential pollutants. Any discharge of wastewater into the lake may cause irreversible consequences for the ecosystem that is very sensitive to organic pollutants. Short vegetation season, hot and dry summers and shallow depth of the lake contribute to the size and severity of the problem.

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