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Effects of flooding on the physical and chemical water composition of the alpine lake Kolové pleso (High Tatra, West Carpathians)

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Abstract. This study is a part of the physical and chemical limnology multiannual research of lake Kolové pleso to understand the response of the high mountain lake ecosystem to seasonal, climatic and anthropogenic impacts. Due to the extensive rainfall in July 2018, during the experiment, we had the opportunity to observe the effect of flooding on the lake. Flooding had a significant impact on the organic composition of the lake (COD) as well as on some chemical elements (S, K, Rb, Mo, Cd). The values of COD and measured elements sharply decreased after the flood disturbance. On the contrary, the pH level increased and the water in the lake became less acidic. We observed a negative correlation between pH and COD. We can concluded, that the flood disturbance had a major effect on the organic matter content in the water. The flood washed out deposits sediments. This plays a role in the saturation of water of organic and inorganic compounds and thus affects the overall chemical and physical state of the water in the lake and also will influence the ecosystem for the following months.

Key words: High Tatras, alpine lake, extensive rainfall, flood impact, organic composition, acidity (pH)

Introduction

Standing water is characterized by the absence of flow predetermining some of its physicochemical properties, which are significantly different from flowing water. Standing water includes lakes, and this study focuses on a glacial lake in the alpine level of High Tatra Mountains. Glacial lakes represent 90% of all lakes in Slovakia (Bitušík *et al.* 2006) and are mostly oligotrophic standing waters with specific characteristics (Psenner 1989; Drever and Zobrist 1992; Beracko *et al.* 2014). These ecosystems have been identified as key sites for studying global environmental change (Pienitz *et al.* 1997a). Despite their geographical isolation, without direct anthropogenic influences, due to their specific characteristics, alpine lakes are excellent indicators of seasonal changes, as well as increasingly frequent (IPCC 2001) climate change (Wathne *et al.* 1995). Current climate models show an increase in the frequency of irregular phenomena such as extreme rainfall, but also widespread drought, which disturbs water level fluctuations in lakes (IPCC 2001). These current trends have raised the question of how water level fluctuations and the floods impact on lakes (Wantzen *et al.* 2008). Because of fluctuating water levels, floods are notable biochemical events for lake ecosystems (McClain *et al.* 2003). Most lakes are heterotrophic and dependent on organic inputs from their basins and subsoil (Sobek *et al.* 2007). Floods have the effect of rapidly mobilizing and accumulating organic carbon and nutrients (Nogueira *et al.* 2002; Wantzen *et al.* 2008), which can lead to "wash out" and also cause leaching of heavy metals into the environment from lake bottom sediments; posing a potential risk to water quality (Chrastný *et al.* 2006). Alpine lakes are likely to experience dramatic future physical, chemical and biological changes (Antoniades *et al.* 2003). Therefore, understanding the impact of past, present, and likely future anthropogenic influences and climate change depends on understanding the basic state of lakes (Hamilton *et al.* 2001; Michelutti *et al.* 2002).

The aim of this study is, describe the impact of the flood on the monitored alpine lake. The data will serve as a reference for future programs for monitoring global environmental changes (Pienitz *et al.* 1997a) and the impact of flooding on the lakes.

Material and Methods

Field experiments

The Tatra Mountains are the highest mountain range of alpine character in Slovakia. Lake Kolové pleso (GPS position data: N 49° 13´ 13"; E 20° 11´ 28") is situated in Kolová dolina valley at an altitude of 1565 m a s.l. It has an area of 18 280 m^2, a perimeter of 735 m, a water volume of 10 846 m^3, a length of 225 m, a width of 123 m, a maximum depth of 1.2 m, and an average depth 0.59 m (Marček 1996).

Samples were taken monthly between August 2017 and December 2018. During sampling in the summer (18th of July 2018), the Tatra Mountains were hit by floods. To measure physical parameters of the water samples including water temperature, salinity, pH, U, conductivity, TDS (total dissolved solids) (mg/l), soluble oxygen / (oxygen level) and saturation of the water, we used a portable multimeter WTW 3430 (GEOTECH, Weilheim, Germany) in the field. Along with the Multi 3430 we used compatible probes: IDS pH electrode Sen TixR 940-3, conductivity electrode TetraCon 925-3 and an optic oxygen electrode FDO 925-3. For the subsequent analysis, other samples were placed into plastic containers containing 0.7 l. Water samples were taken at 0.5 meters from the left shore of the lake. Before the sampling, all containers were properly labeled and disinfected. We were careful about the proper transportation of the samples and their preservation, trying to keep intervals between sampling and analysis as short as possible.

Laboratory analyses and statistics

For the detection of the required components of the samples, we've used the following methods. Chemical oxygen demand (COD) - conventional potassium permanganate method, based on the oxidation of organic substances with 20 ml potassium permanganate (K_2MnO_4). It is defined as the amount of oxygen which, under specified conditions, is consumed for the oxidation of organic substances in water by a strong oxidizing agent (Mn - Manganese) (Diviš 2008). The x-ray method determines the values of some chemical elements (trace elements). We used a handle ED-XRF spectrometer DELTA (Innov-X Technologies, Canada) and analyzed the water sample in a plastic vial (minimum 15 mm of sample depth in a vial). We used multiple-beam measurement, in which every measurement consisted of 3 beams for 80 seconds, repeated three times, and then averaged. The results were given in ppm (parts per million) units. Standards used for basic calibration of device were in a clean homogenous SiO_2 matrix without interfering elements. We used also an additional calibration matrix for the correct measuring of surface water samples, which correspond to internationally accepted standards for measurement of elements in surface waters SPS-SW2 (Spectrapure Standards, Norway). Measurements were realized following the working manual DELTA handheld XRF Analyser, Canadian edition, 2015. Detections limits (X-ray) differ for different elements based on and fulfill the criteria described in the manual to Delta XRF.

For statistical analysis (Pearson´s correlation matrix, one way ANOVA and graphs) we used STATISTICA 8 software.

Results

In July of 2018, the High Tatra experienced an extensive flood and in the lake Kolové pleso the significant decrease in concentrations of sulfur (S), molybdenum (Mo), potassium (K) and rubidium (Rb) values were observed (Table 1).

The second impact of the flood was observed in the organic composition of the lake (COD). The level of COD after the summer of 2017 and during the winter months of 2017 and beginning of the 2018 was naturally slightly decreasing. The level of COD starts to increase in the spring months. This trend was interrupted by flood. The organic components were immediately washed out on the day of the flood, and the other element's values fell on the level of detection limits (Table 1).

After flooding acidity significantly decreased (Fig. 1). We can observe a negative correlation relationship between COD and pH level. The data confirm that flooding plays an important role in the life of healthy mountain lake ecosystems, it highly influences the concentrations of elements for a long period and improves the acidity of the water. In the present, flood effects also affect the accumulation of anthropogenic contaminants and as in the case of natural elements, they may cause their elution and further distribution in the watercourse to lowlands.

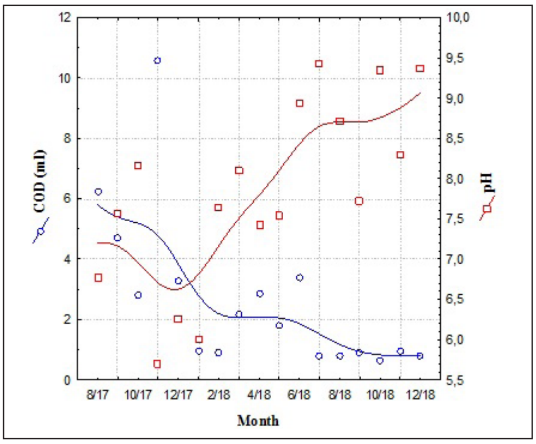

Fig. 1. Change in concentration of organic components (COD) and acidity (pH) values due to extensive summer flood in July 2018. The values were measured from August 2017 to December 2018.

Discussion

Oxygen concentration in Kolové pleso was around 10 mg/l and the average saturation was 98 %, which is characteristic for chemically pure waters (Diviš 2008) such as Tatra Mountain lakes (Bitušík 2013). Based on these parameters, particularly pH values, we can classify the Kolové pleso among oligotrophic lakes (Beracko *et al.* 2014). PH values during the analyzed annual cycle ranged from 5.7-9.4, which are also typical for this type of mountain lakes (Douglas and Smol 1994; Antoniades *et al.* 2000; Hamilton *et al.* 2001; Lim *et al.* 2001; Michelutti *et al.* 2002; Kopáček *et al.* 2006). The acidity of water in the lake seasonally fluctuated, the phenomenon may be caused by natural processes as well as industry located in the wider area of the Tatra Mountain region (Camarero *et al.* 2009; Van Drooge *et al.* 2011).

COD concentrations in the alpine environment range from 0.6 to 10 ml (Pienitz *et al.* 1997b). Low values and limited range are related to an almost complete absence of vegetation and poor drainage in the area (Antoniades *et al.* 2003). The effects of decreased acidity and increased washing of organic components from the lake water is known from several studies (Keddy and Fraser 2000; Nogueira *et al.* 2002; Coops *et al.* 2003). The behavior of the lake and its COD levels has shown that floods mobilize organic

Month	COD (ml)	S (ppm)	K (ppm)	Rb (ppm)	Mo (ppm)	Cd (ppm)
August 2017	6.25	76 ± 64	187 ± 12	1.6 ± 0.6	1.3 ± 0.5	ND (DL = 6)
September 2017	4.70	ND (DL = 62)	196 ± 12	1.6 ± 1.1	1.1 ± 1	ND (DL = 6)
October 2017	2.79	59 ± 48	210 ± 10	1.2 ± 0.8	1.1 ± 0.8	ND (DL = 4)
November 2017	10.59	96 ± 67	252 ± 15	1.5 ± 0.5	1.1 ± 1	ND (DL = 6)
December 2017	3.27	93 ± 34	193 ± 13	1.5 ± 0.6	ND (DL = 1)	ND (DL = 6)
January 2018	0.93	ND (DL = 56)	203 ± 11	1 ± 1	1.3 ± 0.9	ND (DL = 5)
February 2018	0.92	ND (DL = 57)	215 ± 12	1.2 ± 0.5	1.3 ± 0.4	ND (DL = 5)
March 2018	2.18	ND (DL = 63)	187 ± 13	ND (DL = 1.1)	ND (DL = 1)	ND (DL = 6)
April 2018	2.85	196 ± 145	134 ± 9	ND (DL = 0.4)	ND (DL = 0.1)	ND (DL = 6)
May 2018	1.80	ND (DL = 138)	152 ± 9	1.3 ± 0.2	ND (DL = 0.1)	ND (DL = 6)
June 2018	3.41	187 + 144	133 ± 8	1 ± 0.4	ND (DL = 0.1)	ND (DL = 6)
18th of July 2018	**0.82**	**ND (DL = 137)**	**137 ± 8**	**ND (DL = 0.4)**	**ND (DL = 0.1)**	**ND (DL = 6)**
August 2018	0.80	16 ± 12	1 ± 0.1	ND (DL = 0)	ND (DL = 0)	ND (DL = 0)
September 2018	0.91	ND (DL = 11)	1 ± 0.1	ND (DL = 0)	ND (DL = 0)	ND (DL = 0)
October 2018	0.66	ND (DL = 12)	1.1 ± 0.1	ND (DL = 0)	ND (DL = 0)	ND (DL = 0)
November 2018	0.98	ND (DL = 12)	1.1 ± 0.1	ND (DL = 0)	ND (DL = 0)	ND (DL = 0)
December 2018	0.77	13 ± 6	1 ± 0.1	ND (DL = 0)	ND (DL = 0)	ND (DL = 0)

Table 1. Average concentrations of chemical elements and organic components in the typical West Carpathian alpine lake. Extensive unusual flooding occurred in July 2018. COD – chemical oxygen demand values, ± standard error shown in 2-sigma - 95 % confidence, ND – not detected, DL – detection limit showed in ppm. Delta ED-XRF device in case of not detected values shows the actual detection limit for the measuring element in the sample.

nutrients in the lake (Mooij *et al.* 2005; Wantzen *et al.* 2008). The process is influenced by a release of organic sediment deposition which usually participates in water saturation by dissolving organic substances. Due to the flood, these organic substances were washed out and stored in the aquatic-terrestrial transition zone (Grossart and Simon 1998). We expect that this effect also caused the observed decrease in monitored elements values. This trend has been observed mainly in the level of potassium, but we also found the decreasing trend in sulfur, rubidium, molybdenum, and cadmium. Decrease of heavy metals concentrations in surface waters after flooding has been confirmed by Chrastný *et al.* (2006) whose study of the impact of floods on heavy metals revealed that floods may in particular cause the release of cadmium into the environment. Potassium concentrations in alpine waters are strongly governed by the chemical weathering of silicates (rock-forming minerals) such as biotite, K-feldspar, and clay minerals. It reflects qualitatively the relative abundance of silicates in the catchment and works as a nutrient for aquatic plants (Zobrist 2010). In work Wu *et al.* (2013) authors show the specific ecosystem relations between decreasing or increasing of this element and vegetation richness and aboveground biomass and also wider relations of this element with concentrations of main macronutrients - phosphorus and nitrogen in soil and water. Although our study only shows measurements of selected elements (K, S, Rb, Mo, Cd), we can expect that also other unmeasured macronutrient elements (P, N) are washed on during the flood, and limitate biomass development in following months.

One of the most important observations in our monitoring is founding the increase of pH level after the flood. The elements which caused the acidity of water were washed out. In surface waters, the pH is most influenced by sedimentation (McNeely *et al.* 1979; Michelluti *et al.* 2002) and precipitation (Judová *et al.* 2015). Lowes pH values were measured in winter months. This corresponds to the potential pollution effect from fossil fuel burning in winter months, which could influence the mountain ecosystem with acid precipitation. Sulfur compounds from precipitation also play a role in the process of transformation and subsequent deposition of inorganic sulfur in sediments (Evans and Monteith 2001; Liu *et al.* 2017). This deposition of sulfur was washed out by the flood with massive sediment removal. With this process also Acid Neutralising Capacity (ANC) increased proportionally to reductions in SO_x, as mentioned by Monteith *et al.* (2014) in the long-term study of surface waters.

Finally, we confirm a negative correlation between concentrations of organic components and levels of pH. This negative correlation was measured in many alpine lakes (Donahue *et al.* 1998; Evans and Monteith 2001; Kopáček *et al.* 2003; Kopáček *et al.* 2006). Harriman and Taylor (1999) point out in their work that, regardless of the cause, the rising values of organic composition will have a significant impact on the lake's acidity. In our case, flood and precipitation reduced the amount of organic matter and therefore affected the acidity of lake Kolové pleso.

Conclusions

Our research noted a less frequent phenomenon of natural floods and their impact on the aquatic ecosystem of alpine lake waters in high mountains.

The phenomenon of flooding is specific because it does not condition an annual but several-year cycle of water biota. In this long-term cycle, the ecosystem has to adapt after major disturbance and in the long run, many organisms are forced to overcome physiological, morphological and genetic changes to survive. Due to this, we consider this study as exceptional.

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References

Antoniades, D., Douglas, M.S.V. and Smol, J.P. 2000: Limnology and autecology of freshwater diatoms from Alert, northern Ellesmere Island, Nunavut. *Proceedings of the 6th National Student Conference on Northern Studies*, 1-11.

Antoniades, D., Douglas, S.V.M. and Smol, J.P. 2003: The physical and chemical limnology of 24 ponds and one lake from Isachsen, Ellef Ringnes Island. *Canadian High Arctic Internat. Rev. Hydrobiol.*, **88**: 519-538.

Beracko, P., Bulánková, E. and Stloukalová, V. 2014: Freshwater ecosystems. Comenius University publisher, Bratislava.

Bitušík, P. 2013: A recent limnological survey of the Tatra Mountain lakes. *Environment*, **47**: 134-139.

Bitušík, P., Svitok, M., Kološta, P. and Hubkova, M. 2006: Classification of the Tatra Mountain lakes (Slovakia) using chironomids (*Diptera, Chironomidae*). *Biologia (Bratislava)*, **61**: 191-201.

Camarero, L., Botev, I., Muri, G., Psenner, R. and Rose, N. 2009: Trace elements in alpine and arctic lake sediments as a record of diffuse atmospheric contamination across Europe. *Freshwater Biol.*, **54**: 2518-2532.

Coops, H., Beklioglu, M. and Crisman, T.L. 2003: The role of water-level fluctuations in shallow lake ecosystems - workshop conclusions. *Hydrobiologia*, **506**: 23-27.

Diviš, M. 2008: Water monitoring. SPŠ, Karviná.

Donahue, W.F., Schindler, D.W., Page, S.J. and Stainton, M.P. 1998: Acid-induced changes in DOC quality in an experimental whole-lake manipulation. *Environ. Sci. Technol.*, **32**: 2954-2960.

Douglas, M.S.V. and Smol, J.P. 1994: Limnology of high arctic ponds (Cape Herschel, Ellesmere Island, N. W. T.). *Arch. Hydrobiol.*, **131**: 401-434.

Drever, J.I. and Zobrist, J. 1992: Chemical weathering of silicate rocks as a function of elevation in the southern Swiss Alps. *Geochim. Cosmochim. Ac.*, **56**: 3209-3216.

Evans, C.D. and Monteith, D.T. 2001: Chemical trends at lakes and streams in the UK Acid Waters Monitoring Network, 1988–2000: Evidence for recent recovery at a national scale. *Hydrol. Earth Syst. Sci.*, **5**: 351-366.

Grossart, H.P. and Simon, M. 1998: Bacterial colonization and microbial decomposition of limnetic organic aggregates (lake snow). *Aquat. Microb. Ecol.*, **15**: 127-140.

Hamilton, P.B., Gajewski, K., Atkinson, D.E. and Lean, D.R.S. 2001: Physical and chemical limnology of 204 lakes from the Canadian Arctic Archipelago. *Hydrobiologia*, **457**: 133-148.

Harriman, R. and Taylor, E.M. 1999: Acid Neutralising Capacity (ACN) and Alkalinity (ALK): Concepts and Measurement. Report SR (99) 06F, Pitlochry: Freshwater Fisheries Laboratory.

Chrastný, V., Komarek, M., Tlustoš, P., and Švehla, J. 2006: Effects of flooding on lead and cadmium speciation in sediments from a drinking water reservoir. *Environmental monitoring and assessment*, **118**: 113-123.

IPCC 2001: Climate Change 2001: Synthesis Report. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

Judová, J., Šalgovičová, D., Pavlovičová, D., Kosová, I. 2015: Environmental monitoring. Institute of High Mountain Biology, University of Žilina, Tatranská Javorina, Slovakia.

Keddy, P. and Fraser, L.H. 2000: Four general principles for the management and conservation of wetlands in large lakes: the role of water levels, nutrients, competitive hierarchies and centrifugal organization. *Lakes and Reservoirs: Research and Management*, **5**: 177-185.

Kopáček, J., Hejzlar, J., Kaňa, J., Porcal, P. and Klementová, Š. 2003: Photochemical, chemical, and biological transformations of dissolved organic carbon and its impact on alkalinity production in acidified lakes. *Limnol. Oceanogr.*, **48**: 106-117.

Kopáček. J., Stuchlík, E. and Hardekopf, D. 2006: Chemical composition of the Tatra Mountain lakes: Recovery from acidification. *Biologia*, **61**: 21-33.

Lim, D.S.S., Douglas, M.S.V., Smol, J.P. and Lean, D.R.S. 2001: Physical and chemical limnological characteristics of 38 lakes and ponds on Bathurst Island, Nunavut, Canadian High Arctic. *Internat. Rev. Hydrobiol.*, **86**: 1-22.

Liu, J., Jiang, T., Huang, R., Wang, D., Zhang, J., Qian, S. and Chen, H. 2017: A simulation study of inorganic sulfur cycling in the water level fluctuation zone of the Three Gorges Reservoir, China and the implications for mercury methylation. *Chemosphere*, **166**: 31-40.

Marček, A. 1996: Tarns of Tatras. *Vysoké Tatry*, **6**: 18.

McClain, M.E., Boyer, E.W., Dent, C.L., Gergel, S.E., Grimm, N.B., Groffman, P., Hart, S.C., Harvey, J., Johnston, C., Mayorga, E., McDowell, W.H. and Pinay, G. 2003: Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. *Ecosystems*, **6**: 301-312.

McNeely, R.N., Neimanis, V.P. and Dwyer, L. 1979: Water quality sourcebook: a guide to water quality parameters. Environment Canada, Inland Waters Directorate, Water Quality Branch, Ottawa, Ontario, Canada.

Michelutti, N., Douglas, M.S.V., Lean, D.R.S. and Smol, J.P. 2002: Physical and chemical limnology of 34 ultra-oligotrophic lakes and ponds near Wynniatt Bay, Victoria Island, Arctic Canada. *Hydrobiologia*, **48**: 1-13.

Monteith, D.T., Evans, C.D., Henrys, P.A., Simpson, G.L. and Malcolm, I.A. 2014: Trends in the hydrochemistry of acid-sensitive surface waters in the UK 1988–2008. *Ecol Indic*, **37**: 287-303.

Mooij, W.M., De Senerpont Domis, L.N., Nolet B.A., Bodelier, P.L.E., Boers, P.C.M., Pires, L.M.D., Gons, H.J., Ibelings, B.W., Noordhuis, R., Portielje, R., Wolfstein, K. and Lammens, E.H.R.R. 2005: The impact of climate change on lakes in the Netherlands a review. *Aquat. Ecol.*, **39**: 381.

Nogueira, F., Couto, E.G. and Bernardi, C.J. 2002: Geostatistics as a tool to improve sampling and statistical analysis in wetlands: A case study on dynamics of the organic matter distribution in the Pantanal of Mato Grosso, Brazil. *Braz. J. Biol.*, **62**: 861–870.

Pienitz, R., Smol, J.P. and Lean, D.R.S. 1997a:. Physical and chemical limnology of 59 lakes located between the southern Yukon and the Tuktoyaktuk Peninsula, Northwest Territories (Canada). *Can J Fish Aquat Sci*, **54**: 330-346.

Pienitz, R., Smol, J.P. and Lean, D.R.S. 1997b: Physical and chemical limnology of 24 lakes located between Yellowknife and Contwoyto Lake, Northwest Territories (Canada). *Can. J. Fish Aquat. Sci.*, **54**: 347-358.

Psenner, R. 1989: Chemistry of high mountain lakes in siliceous catchments of the Central Eastern Alps. *Aquat. Sci.*, **51**: 108-128.

Sobek, S., Tranvik, L.J., Prairie, Y.T., Kortelainen, P. and Cole, J.J. 2007: Patterns and regulation of dissolved organic carbon: an analysis of 7,500 widely distributed

lakes. *Limnol. Oceanogr.*, **52**: 1208-1219.
Van Drooge, B.L., López, J., Fernández, P., Grimalt, J.O. and Stuchlík, E. 2011: Polycyclic aromatic hydrocarbons in lake sediments from the High Tatras. *Environ. Pollut.*, **159**: 1234-1240.
Wantzen, K.M., Wolfgang, J.J. and Rothhaupt, K.O. 2008: An extension of the floodpulse concept (FPC) for lakes. *Hydrobiologia*, **613**: 151-170.
Wathne, B.M., Patrick, S.T., Monteith, D.T. and Barth, H. 1995: AL: PE, acidification of mountain lakes; paleolimnology and ecology. Ecosystems Research Report 9, European Commission, D-G XII, Luxembourg.
Wu, G.L., Ren, G.H., Wang, D., Shi, Z.H. and Warrington, D. 2013: Above and below ground response to soil water change in an alpine wetland ecosystem on the Qinghai-Tibetan Plateau, China. *J. Hydrol.*, **476**: 120-127.
Zobrist, J. 2010: Water chemistry of Swiss alpine rivers. In: *Alpine waters. The handbook of environmental chemistry, Vol 6* (ed. U. Bundi), pp: 96-117. Heidelberg: Springer, Berlin.

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