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Short-term weather fluctuation and quality assessment of oxbows

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Abstract—Our aim was to study the effects of short-term weather fluctuations on the quality of oxbows, based on the physico-chemical parameters of the water. The present study explored the effect of precipitation, temperature, and the water level of the main river on the quality of oxbows. We assessed the quality of four oxbows in the Upper Tisza region (north Hungary) over a two-year period. Water samples were collected in the summer in 2011 and 2012, and 12 physico-chemical parameters were investigated.

We found positive correlations between the dissolved oxygen, water temperature, concentration of hydro carbonate, nitrate, pH, conductivity and the average temperature. Canonical discriminant analysis showed that the studied oxbows were similar in 2011 and 2012, based on physico-chemical parameters. Significant differences were found between the years, in terms of the water temperature, the content of suspended solids, and the concentrations of carbonate and chloride. Our results show that only short-term weather changes such as less precipitation and higher temperature cause the quality of oxbows to deteriorate.

Our results demonstrated that the water quality of oxbows is influenced by the River Tisza, because the decrease in the water level of the Tisza was also responsible for the differences between the years, based on the physical-chemical parameters of the water.

Key-words: physico-chemical parameters of water, weather change, drought index, degradation, emerse vegetation, submerse vegetation

1. Introduction

Conservation of oxbows is of central importance both in Europe and around the world. Although these oxbows are also endangered aquatic habitats, the management and conservation of freshwater resources mainly focuses on running water and larger water bodies (*Oertli et al.,* 2009). Due to their biodiversity, small oxbows are equally significant from a socio-economic and from a conservation biology point of view (*Oertli et al.,* 2009). Many oxbows were found in the Upper Tisza region, which is characterized by abandoned river channels, meanders, and periodical and permanent water marshy areas. Most of the oxbows were created during the regulation of the River Tisza (*Varga et al.,* 2013). There are about 70 oxbows along the Upper Tisza river. They are connected to the river during the floodplain events, when large quantities of suspended particles are transported into the floodplain (*Nguyen et al.,* 2009).

Weather fluctuation has effects on aquatic ecosystems: (i) the temperature increase causes an increase in water temperature which may result in an increase in conductivity that may in turn reduce the level of oxygen and severely stress aquatic fauna (*Bond et al.,* 2008); (ii) the seasonal changes in precipitation alter the hydrological relations existing in aquatic systems (*Georgi* and *Pal*, 2004). Regional patterns in precipitation and temperature predict changes which have the potential to alter natural flow regimes (*Palmer et al.,* 2009). However, the cumulative changes in temperature and precipitation may have both direct and indirect effects on oxbows, because these water bodies have substantial exchanges with atmospheric water in the form of precipitation and evapotranspiration (*Michener et al.,* 1997; *Winter,* 2000). The hydrologic conditions directly affect the chemical and physical processes, and the dynamic of nutrients and suspended solids (*Fink* and *Mitsch,* 2007).

Aquatic macrophytes influence the physical and chemical environment of lakes and oxbows (*Lukács et al.,* 2009, 2011). Macrophytes play a key role in biochemical cycles, organic carbon production, and phosphorus mobilization. They also have a direct influence on hydrology and sediment dynamics (*Bornette* and *Puijalon,* 2011). Numerous studies have demonstrated that they can dramatically alter the material and energy flows between lakes and oxbows (*Frodge et al.,* 1990). Earlier studies have also demonstrated that macrophytes have an influence on the physico-chemical parameters of water on a macro-scale; consequently, the vegetation and the physico-chemical parameters of water are closely related (*Barendregt* and *Bio,* 2003; *Heegaard et al.,* 2001).

The aim of our study was to assess the impact of short-term weather fluctuations, such as reduced precipitation and higher temperature. We also investigated the effect of the water level of the main river and vegetation types on the quality of oxbows, based on the physico-chemical parameters of the water. The physico-chemical parameters of the surface water of oxbows were studied during two years, 2011 and 2012. To compare the studied years a drought index was used, based on the mean temperature and rainfall of the years in question. At the same time, the effect of the water level of the Tisza on the quality of oxbows was also studied. The poor state of oxbows was evident in the field; thus, our hypothesis was that the weather parameters and water level of the Tisza may cause the deterioration of the physico-chemical parameters of the water, which leads to the degradation of the water quality. Thus, the aim of our study was to demonstrate that the precipitation, temperature, and water level of the River Tisza influenced the quality of these oxbows, and that the meteorological parameters and water level affected the oxbow fill up rate, even over a short time period. Our second hypothesis was that the macrophytes also had an effect on the physico-chemical parameters of the water, which may cause a change in the quality of oxbows. The present study explored the factors affecting the quality of oxbows, the precipitation and temperature, the water level, and/or the structure of vegetation.

2. Data and methods

2.1. Study sites

We studied the oxbows in the Upper Tisza region. The area studied covers 95 ha; it is an undisturbed area in the UpperTisza region, in the north part of Hungary. There are many oxbows in this region, and the following four oxbows were studied: the Kis-Zátony oxbow, the Nagy-Zátony oxbow, the Nagy-Pap oxbow, and the Sulymos oxbow (*Fig. 1*). In our study, two vegetation types (submersed and emersed) and open water were studied. The submersed vegetation type was characterized by *Ceratophyllum demersum Nymphaea alba* and *Schoenoplectus lacustris.* The emersed vegetation type was characterized by the following species: *Typha angustifolia, Typha latifolia,* and *Phragmites australis* (*Cook*, 1996). In the open water, there were no macrophytes. In the Kis-Zátony oxbow there were seven sampling points (two open water, four emersed, and one submersed vegetation). In the Nagy-Zátony oxbow, there were three sampling points (one open water, one submersed, and one emersed). In the Nagy-Pap oxbow, there were three sampling points (two emersed and one open water). In the Sulymos oxbow, there were six sampling points (one open water, one submersed, and four emersed vegetation type).

2.2. Water chemistry

We collected surface water samples in 1-liter plastic bottles; the bottles were rinsed out with deionized water three times. Until laboratory processing, samples were stored at 4 °C. We measured the physical and chemical parameters of the water. The following parameters were measured in the field: conductivity, temperature, content of dissolved oxygen (DO) with portable field instruments (WTW cond. 340i), and pH (WTW pH 315i).

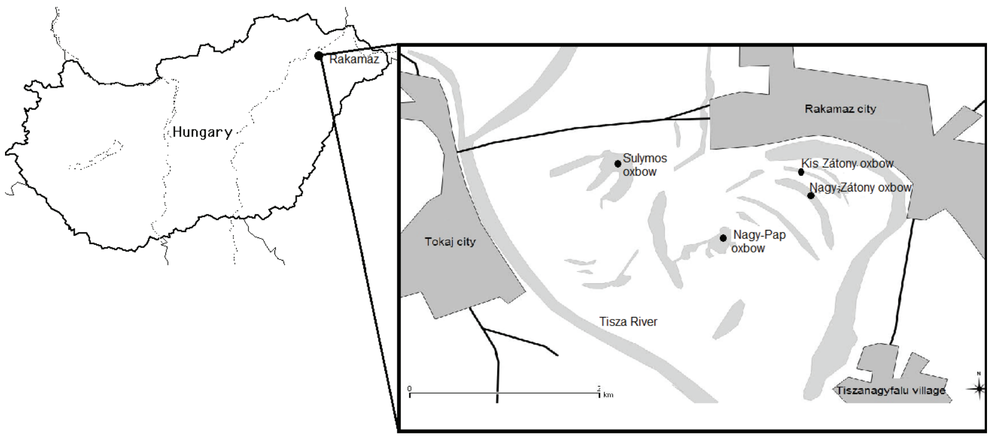

Fig. 1. Locations of oxbows.

We measured suspended solids from the original samples. For nitrite, nitrate, ortho-phosphate, carbonate, hydro-carbonate, carbon-dioxide and chloride concentration we used filtered samples. Water chemistry analysis was performed by the *USEPA* (1983) and *APHA* (2000) methods. For the assessment of quality, the *MSZ 12749* (1993) standard classification was used.

The local meteorological conditions of the study sites were based on the data from the websitwe of the MetNet Association (www.metnet.hu). The following parameters were used: rainfall, number of rainy days, and average temperature (*Table 1*). For our study, the results of four summer months were used. The water level of the Tisza was based on the data of the National Water Warning Service (www.hydroinfo.hu) (*Fig. 2*).

Table 1. Summary of meteorological data from May, June, July, and August (mean ± SE). The average temperature is the mean of the day, and the mean of rainfall is the average of the month

Year	**Temperature (°C)**	**Rainfall (mm)**	**Number of raining days**
2011	20 ± 2	68 ± 26	15 ± 7
2012	22 ± 3	47 ± 3	11 ± 4

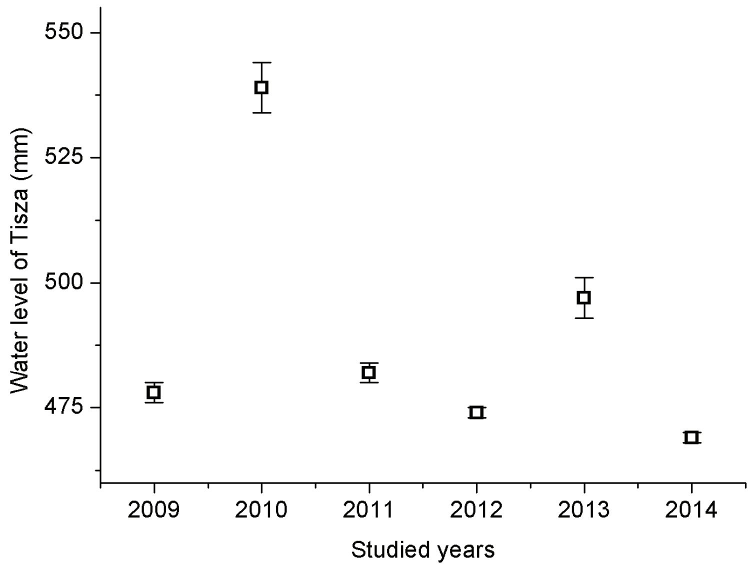

Fig. 2. The water level of the River Tisza (mean ± SE) over the past six years.

2.3. Drought index

To compare the years, a drought index (PaDI) was used. This index is a ratio of the mean temperature during the period from April to August and the rainfall from October to August (*Tsakiris* and *Vangelis,* 2004; *Tate* and *Gustard,* 2000). The following drought categories were used: PaDI < 4 represents a drought free year, 4 < PaDI < 6 a slight drought year, 6 < PaDI < 8 a moderate drought year, 8 < PaDI < 10 a medium moderate drought year, 10 < PaDI < 15 a severe drought year, 15 < PaDI < 30 a very severe drought year, and PaDI > 30 an extreme drought year.

2.4. Statistical analysis

SPSS/PC+ and Canoco for Windows statistical software packages were used during the calculations. Using redundancy analysis (RDA) we studied the correlation between the physico-chemical parameters of water and precipitation, and the temperature in the studied oxbows. canonical discriminant analysis (CDA) was used to study the physico-chemical parameters of oxbows. The physico-chemical parameters of the oxbows were compared by ANOVA, where the years and vegetation types were fixed factors. In the case of any significant differences, the Tukey's multiple comparison test was used to explore these significant differences.

3. Results

The correlation between the first component (RDA1) of redundancy analysis and the water physico-chemical parameters and weather parameters was 0.955, while for the second component (RDA2), the correlation was 0.562. The cumulative percentage variances were 31.3 (RDA1) and 7.5 (RDA2). In the case of water physico-chemical parameters and weather parameters, the relation was 79.5% (RDA1) and 19.1% (RDA2). For carbon dioxide, suspended solids, and carbonate, a positive correlation was found between concentration and rainfall and the number of rainy days (*Fig. 3*). A positive correlation was found between dissolved oxygen, water temperature, and the concentration of hydro carbonate, nitrate, pH, conductivity, and the average temperature (*Fig. 3*).

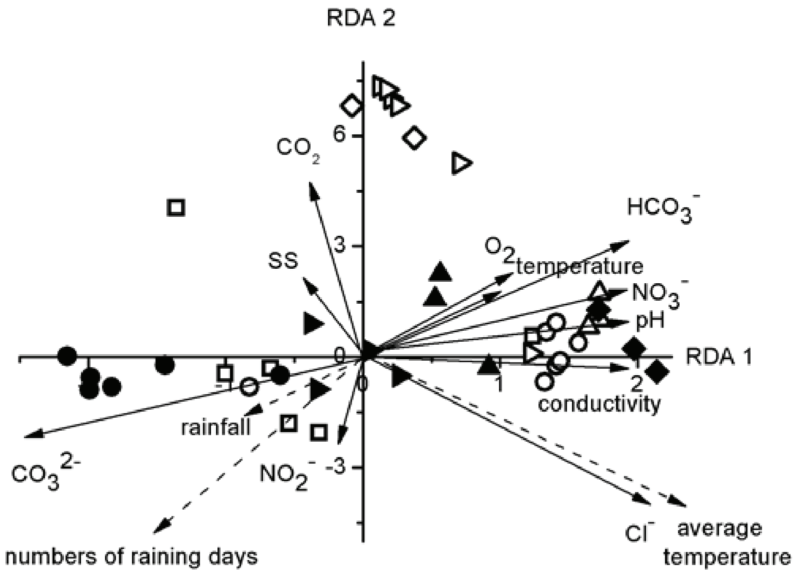

Fig. 3. Redundancy analysis biplot to show the interaction between the physico-chemical parameters of water and the meteorological conditions. Notations: solid arrow – physico-chemical parameters of water, dash arrow – precipitation and temperature.

Based on the physical and chemical parameters of water, the separation of the studied oxbows was similar in 2011 and 2012, based on the canonical discriminant analysis (*Fig. 4A-B*). There were differences between 2011 and 2012 only in the Nagy-Zátony oxbow. The canonical variance percentage was 99.6 in the first and 0.3 in the second axis, based on the 2011 data. The canonical variance percentage was 83.9 in the first and 10.0 in the second axis, based on the 2012 data.

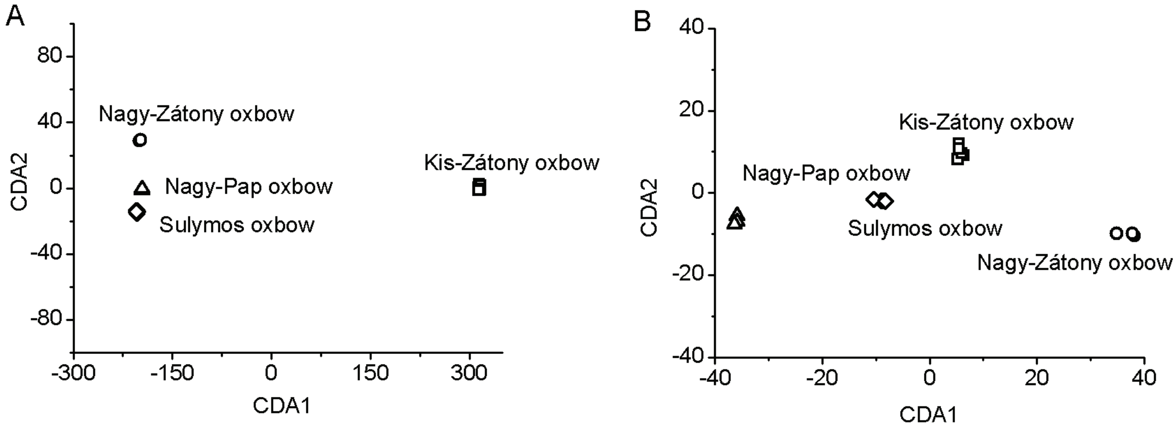

Fig. 4. Canonical discriminant biplot based on the physical and chemical parameters in the studied oxbows in 2011 (A) and 2012 (B).

Based on the vegetation types, the separation was also similar in both years (2011 and 2012). A slight change was found in the case of submersed vegetation types in 2011 and 2012 (*Fig. 5A-B*). The variance percentage was 93.3 in the first and 6.7 in the second axis in 2011. However, in 2012, the variance percentage was 70.8 in the first and 29.2 in the second axis.

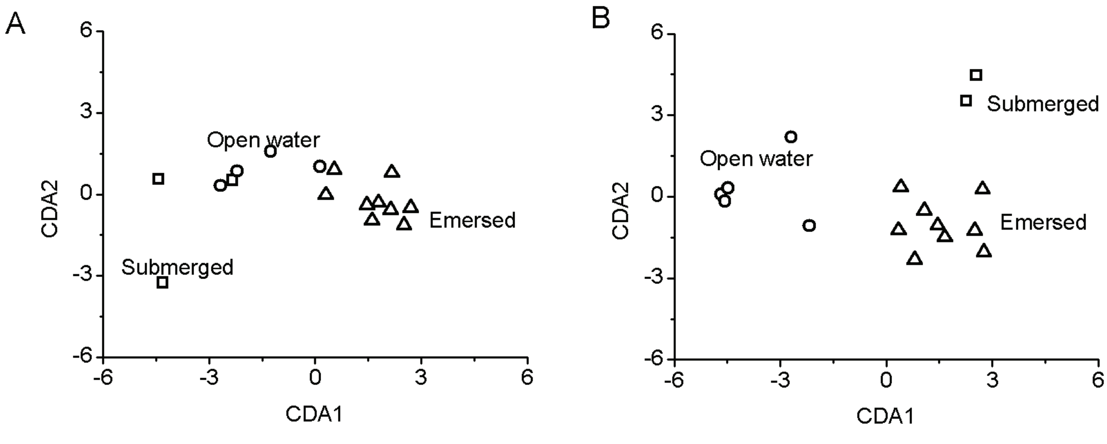

Fig. 5. Canonical discriminant biplot based on the physical and chemical parameters in the vegetation types in 2011 (A) and 2012 (B).

The result for the drought index was similar in the studied years. In 2011 the drought index value was 4.2, while in 2012 the value was 5.9. The index values suggest that each year was a slight drought year. In spite of this, when comparing the water physico-chemical parameters, a difference was found between the years, but differences were not found among vegetation types using two-way ANOVA. There was a significant difference between the years in the water temperature, the suspended solid content, and the concentration of carbonate and chloride (*Table 2*). A significantly higher temperature, suspended solid content, and carbonate and chloride concentration were found in 2012 than in 2011. Significantly higher water temperatures were found in 2011 than in 2012 in the Kis-Zátony oxbow (t_5=–5.413, p=0.003), the Nagy-Pap oxbow (t_3=–52.200, p<0.001), and the Sulymos oxbow (t_8=–26.960, p<0.001). However, the water temperature did not differ between the two years (t_8=–26.960, p<0.001) in the Nagy-Zátony oxbow. The concentration of carbonate was significantly higher in 2012 than in 2011 in the Kis-Zátony oxbow (t_5=–5.541, p=0.003) and the Sulymos oxbow (t_8=–26.960, p<0.001). The concentration of hydro-carbonate was significantly higher in 2011 than in 2012 in the Kis-Zátony oxbows (t_5=7.194, p=0.001). In the Nagy-Zátony oxbow, the concentration of hydro-carbonate was significantly higher in 2012 than in 2011 (t_2=–111.449, p<0.001). Significantly higher concentrations of chloride-ion were observed in 2012 than in 2011 in the Nagy-Pap (t_3=–24.498, p<0.001) and Sulymos oxbows (t_8=–32.680, p<0.001). In the Nagy-Zátony oxbow, the concentration of chloride-ion did not differ between the years (t_2=–2.452, p=0.134) (*Table 3*). There was no significant difference among habitat types in their physical-chemical parameters.

Table 2. Results of ANOVA based on the physical and chemical parameters of years and vegetation types.

	year		**vegetation type**	
	F	***p***	**F**	***p***
temperature (°C)	10.294	0.003	0.232	0.795
pH	2.914	0.099	1.581	0.224
conductivity(µS/cm)	0.239	0.629	0.281	0.757
dissolved oxygen (mg/l)	0.855	0.363	0.526	0.597
suspended solid (mg/l)	11.286	0.002	0.426	0.657
carbonate (mg/l)	11.097	0.002	0.019	0.981
hydro carbonate (mg/l)	2.970	0.096	0.596	0.558
carbon dioxide (mg/l)	0.701	0.409	0.537	0.590
chloride (mg/l)	5.627	0.025	0.202	0.819
orthophosphate (mg/l)	0.109	0.744	0.421	0.661
nitrite (N mg/l)	2.296	0.141	0.630	0.540
nitrate (N mg/l)	1.712	0.201	0.396	0.677

Table 3. Physical and chemical parameters in the surface water of the studied oxbows (mean ± SD). Notations: n.m. means not measured, n.d. means not detected.

	Kis- Zátony oxbow		Nagy- Zátony oxbow		Nagy-Pap oxbow		Sulymos oxbow	
	2011	2012	2011	2012	2011	2012	2011	2012
temperature (°C)	25.1 ± 0.3	27.5 ± 0.2	22.6 ± 0.2	20.7 ± 0.1	18.8 ±0.04	29.7 ± 0.2	18.4 ± 0.2	29.4 ± 0.3
pH	7.2 ± 0.01	7.4 ± 0.1	7.1 ± 0.2	7.1 ± 0.2	7.0 ± 0.1	9.0 ± 0.2	7.0 ± 0.1	7.9 ± 0.2
conductivity(µS/cm)	615 ± 8	699 ± 25	825 ± 7	875 ± 27	694 ± 4	558 ± 7	805 ± 57	621 ±9
dissolved oxygen (mg/l)	8.2 ± 0.1	4.2 ± 0.4	n.d.	n.d.	2.4 ± 1.6	6.3 ± 0.7	8.2 ± 0.4	5.0 ± 0.5
suspended solid (mg/l)	7.4 ± 1.1	18.9 ± 2.3	10.1 ± 2.8	14.9 ± 4.5	15.4 ± 5.5	54.4 ± 12.9	16.8 ± 5.1	40.7 ± 12.9
carbonate (mg/l)	6.3 ± 3.0	27.1 ± 3.9	n.d.	4.5 ± 0.1	n.d.	n.d.	n.d.	3.8 ± 0.4
hydro carbonate (mg/l)	81 ± 1	5.0 ± 1.7	n.d.	102 ± 3	n.d.	n.d.	n.d.	79.4 ± 0.9
carbon dioxide (mg/l)	28.1 ± 2.4	35.8 ± 4.2	22.5 ± 1.6	42.9 ± 7.4	22.7 ± 2.3	n.d.	13.1 ± 3.1	5.7 ± 1.1
chlorine (mg/l)	25.5 ± 2.2	15.7 ± 1.4	13.6 ± 1.9	18.5 ± 1.0	n.d.	24.3 ± 2.5	n.d.	24.8 ± 2.5
orthophosphate (mg/l)	0.2 ± 0.01	0.1 ± 0.04	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.2 ± 0.04	0.1 ± 0.03	0.2 ± 0.01
nitrite (N mg/l)	0.05 ± 0.03	0.02 ± 0.01	0.01 ± 0.001	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.02	0.2 ± 0.1	0.002 ± 0.001
nitrate (N mg/l)	0.2 ± 0.03	0.02 ± 0.01	0.1 ± 0.01	0.05±0.00	0.05±0.01	0.11±0.07	0.02±0.01	0.1 ± 0.01

4. Discussion

The chemical composition of lakes and oxbows is determined by natural and anthropogenic factors; these include geological, climatic, and biological factors (*Moiseenko et al.,* 2013). Many papers have reported the effects of climatic and weather factors on oxbows (*Cullum et al.,* 2006; *Hunyady,* 2010, *Zhao et al.,* 2013). Earlier studies demonstrated that dry seasons and dry years cause worse water quality, similarly to our findings (*Pesce* and *Wunderlin,* 2000, *Vega et al.,* 1998).

The quality of the Kis-Zátony oxbow and the Nagy-Pap oxbow were good, while the Nagy-Zátony oxbow and the Sulymos oxbow were contaminated in 2011, based on the conductivity findings (*MSZ*,1193). A similar conductivity was found in the second year – 2012 – in each oxbow, except for the Sulymos oxbow, where the quality was good in 2012. *Michalska-Hejduk et al.* (2009) found similar conductivity values and the use of their classification shows that the oxbows we studied are ion-rich.

Of the chemical parameters, dissolved oxygen is an important component of the surface water (*Michalska-Hejduk et al.,* 2009). In our study, based on the concentration of dissolved oxygen, the quality of the Kis-Zátony and Sulymos oxbows was excellent in 2011. The quality of the Nagy-Pap oxbow was contaminated in 2011, but in 2012 it was good. Concentrations of dissolved oxygen in the Kis-Zátony and Sulymos oxbows were contaminated in 2012. Anthropogenic activities were not detected in the area of this oxbow; thus, the lower oxygen concentration is probably the result of a decreasing water level. The water level decrease may result in higher organic matter, which has a direct effect on the dissolved oxygen concentration in the water ecosystem (*Michalska-Hejduk et al.,* 2009).

Kröger et al. (2013) found a positive correlation between the concentration of suspended solids and wind speeds. They demonstrated that turbidity has an indirect effect on suspended solid concentrations (*Kröger et al.,* 2013). Similarly to their findings, our results also indicated that weather parameters have an effect on the concentration of suspended solids. We found higher results in 2012 than in 2011 in every oxbow.

The concentrations of anions, including carbonate, hydro carbonate, chloride, nitrite, and nitrate are dependent on atmospheric deposition and conditions, as it is shown in the redundancy analysis. Based on the nitrite concentrations, the quality of the Nagy-Zátony, Nagy-Pap, and Sulymos oxbows was good, while the quality of the Kis-Zátony oxbow was tolerable in 2011. Nevertheless, in 2012, the water quality of the Kis-Zátony oxbow improved to the same level as that of the other oxbows. This could be explained by higher microbial activity, which may have caused the higher temperature and lower water level in this year (*Davidson et al.,* 1998). Similarly to the earlier finding, the conductivity is related to alkalinity which may regulate the aquatic production (*Zablotowicz et al.,* 2010). The concentration of orthophosphate was similar among the oxbows and also between years. Water quality was contaminated in the Kis-Zátony oxbow, based on orthophosphate concentrations in 2011. The other oxbows were tolerable in 2011. In the next year, the quality of water was contaminated in the Nagy-Pap and Sulymos oxbows, while in the Nagy-Zátony and Kis-Zátony oxbows it was tolerable. In spite of earlier findings (*Moiseenko et al.,* 2013), we did not find an increase in the orthophosphate concentration, despite the increase in the daily temperature.

Unlike earlier studies (*Lukács et al.,* 2009, 2011) we did not find any differences between the vegetation types based on the physico-chemical parameters of water. *Lukács et al.* (2009) demonstrated that nitrogen and carbonate were the most important variables for vegetation development. *Lukács et al.* (2011) also observed that among water chemical parameters, calcium, chemical oxygen demand, nitrite, magnesium, and chloride-ion were important in differentiating the vegetation. Our study showed that the physico-chemical parameters of water did not differ among vegetation types, which was probably caused by the low level of the water.

In spite of the poor state of the oxbows which was visible in the field, differences were not found between the weather parameters in the years under investigation. Based on the drought index, each year experienced a slight drought, although with some parameters, such as water temperature, suspended solids content, and the concentration of carbonate and chloride, significant differences between the years were found. Using the water level data for the River Tisza, the results show that in the past years the water level of the river has changed remarkably.

5. Conclusions

We demonstrated that precipitation and temperature influenced the open-water surface area, the water level, and the physico-chemical parameters of oxbows. These oxbows were connected to the main river only during floods; thus, the water level of the main river also had a remarkable effect on the quality of oxbows. The physico-chemical parameters indicated that the anthropogenic activities did not cause the degradation in the state of the oxbows. Our findings suggest that the degradation of the water quality of the oxbows is only slightly influenced by precipitation and temperature. The degradation depends on the water level of the main river, and the frequency and duration of the flooding.

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References

APHA, 2000: American Public Health Association, Washington (DC).

Barendregt, A., and *Bio, A.F.M.,* 2003: Relevant variables to predict macrophyte communities in running waters. *Ecol. Modell. 160,* 205–217.

Bond, N.R., Lake, P.S., and *Arthington, A.H.,* 2008: The impacts of drought on freshwater ecosystems: an Australian perspective. *Hydrobiologia 600*, 3–16.

Bornette, G., and *Puijalon, S.,* 2011: Response of aquatic plants to abiotic factors: a review. *Aquat. Sci. 73*, 1-14.

Cook, C.D.K., 1996: Aquatic Plant. Academic Publishing, Amsterdan/New York.

Cullum, R.F., Knight, S.S., Cooper, C.M., and *Smith, S.,* 2006: Combined effects of best management practices on water quality in oxbow lakes from agricultural watersheds. *Soil. Till. Res. 90,* 212–221.

Davidson, E.A., Belk, E., and *Boone, R.D.,* 1998: Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. *Glob. Change. Biol. 4,* 217–227.

Fink, D.F., and *Mitsch, W.J.,* 2007: Hydrology and nutrient biogeochemistry in a created river diversion oxbow wetland. *Ecol. Eng. 30*, 93–102.

Frodge, J.D., Thomas, G.L., and *Pauley, G.B.,* 1990: Effects of canopy formation by floating and submergent aquatic macrophytes on the water quality of two shallow Pacific Northwest lakes. *Aquat. Bot. 38*, 231–248.

Georgi, F.X., and *Pal, J.,* 2004: Mean, interannual variability and trends in a regional climate change experiment over Europe. II: climate change scenarios (2071–2100). *Clim. Dynam. 23*, 839–858.

Heegaard, E., Birks, H.H., Gibson, C.E., Smith, S.J., and *Wolfe-Murphy, S.,* 2001: Species–environmental relationships of aquatic macrophytes in Northern Ireland. *Aquat. Bot. 70,* 175–223.

Hunyady, A., 2010: Projected climate change effects on water level of an oxbow. *Phys. Chem. Earth. 35*, 70–75.

Kröger, R., Dibble, E.D., Brandt, J.R., Fleming, J., Huenemann, T.W., Stubbs, R.B., Prevost, J.D., Tietjen, T.E., Littlejohn, K.A., and *Pierce, S.C.,* 2013: Spatial and temporal changes in total suspended sediment concentrations in an Oxbow Lake from implementing agricultural landscape management practices. *River Res. Appl. 29*, 56–64.

Lukács, B.A., Dévai, G., and *Tóthmérész, B.,* 2011: Small scale macrophyte-environment relationship in an oxbow-lake of the Upper-Tisza valley (Hungary). *Community Ecol. 12*, 259–263.

Lukács, B.A., Dévai, Gy., and *Tóthmérész, B.,* 2009: Aquatic macrophytes as bioindicators of water chemistry in nutrient rich backwaters along the Upper-Tisza river (in Hungary). *Phytocoenologia 39*, 287–293.

Michalska-Hejduk, D., Kopeć, D., Drobniewska, A., and *Sumorok, B.,* 2009: Comparison of physical and chemical properties of water and floristic diversity of oxbow lakes under different levels of human pressure: A case study of the lower San River (Poland). *Int. J. Ecohydrol. Hydrobiol. 9*, 183–191.

Michener, W.K., Blood, E.R., Bildstein, K.L., Brinson, M.M., and *Gardner, L.R.,* 1997: Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. *Ecol. Appl. 7*, 770–801.

Moiseenko, T.I., Skjelkvale, B.L., Gashkina, N.A., Shalabodov, A.D., and *Khoroshavin, V.Y.,* 2013: Water chemistry in small lakes along a transect from boreal to arid ecoregions in European Russia: Effects of air pollution and climate change. *Appl. Geochem*. *28*, 69–79.

MSZ, 1993: MSZ 12749. Hungarian Standard Association.

Nguyen, H.L., Braun, M., Szalóki, I., Baeyens, W., Van Grieken, R., and *Leemarkers, M.* 2009 Tracing the metal pollution history of the Tisza River through the analysis of a sediment depth profile. *Water Air Soil Pollut. 200*, 119–132.

Oertli, B., Céréghino, R., Hull, A., and *Miracle, R.,* 2009 Pond conservation: from science to practice. *Hydrobiologia 634*, 1–9.

Palmer, M.A., Lettenmaier, D.D., Poff, N.L., Postel, S.L., Richter, B., and *Warner, R.,* 2009: Climate Change and River Ecosystems: Protection and Adaptation Options. *Environ. Manage. 44*, 1053–1068.

Pesce, S.F., and *Wunderlin, D.A.,* 2000: Use of water quality indices to verify the impact of Córdoba City (Argentina) on Suquía River. *Water Res. 34*, 2915–2926.
Tate, E.L., and *Gustard, A.,* 2000: Drought definition: A hydrological perspective. In (eds.: *Voght, J.V., Somma, F.*) Drought and drought mitigation in Europe. Kluwer Academic Publishers, Dordrecht.
Tsakiris, G., and *Vangelis, H.,* 2004: Towards drought watch system based on spatial SPI. *Water Resour. Manag. 18*, 1–12.
USEPA, 1983: United States Environmental Protection Agency, Washington (DC).
Varga, K., Dévai, G., and *Tóthmérész, B.,* 2013: Land use history of a floodplain area during the last 200 years in the Upper-Tisza region (Hungary). *Reg. Environ. Change*. *13*, 1109–1118.
Vega, M., Pardo, R., Barrado, E., and *Deban, L.,* 1998: Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Res*. *32*, 3581–3592.
Winter, T.C., 2000: The vulnerability of wetlands to climate change: a hydrologic landscape perspective. *J. Am. Water Resour. As. 36*, 305–311.
Zablotowicz, R.M., Zimba, P.V., Locke, M.A., Knight, S.S., Lizotte, R.E., and *Gordo, R.E.,* 2010: Effects of land management practices on water quality in Mississippi Delta oxbow lakes: Biochemical and microbiological aspects. *Agr. Ecosyst. Environ. 139*, 214–223.
Zhao, Y., Xia, X., and *Yang, Z.,* 2013: Growth and nutrient accumulation of *Phragmites australis* in relation to water level variation and nutrient loadings in a shallow lake. *J. Environ. Sci*. *25,* 16–25.