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Clustering oxbow lakes in the Upper-Tisza Region on the basis of stable isotope measurements

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SUMMARY

Several times a year the River Tisza floods areas between dikes, fills the oxbow lakes on the floodplain and changes their water. However the water addition in the oxbow lakes does not only take place through flooding; it is also likely that water can seep under the surface through the gravelled layers of the old river-beds, and furthermore, precipitation also plays a role. Our goal with this study is to acquire a full, comprehensive picture of the water addition of the oxbow lakes in the Upper-Tisza Region. Surface and groundwater samples were taken from the River Tisza, the oxbow lakes and the boreholes around four oxbow lakes, and stabile isotope ratios were measured. We can get information on the origin, the evaporation and the state of the waters, and the depth of the water table with the help of $\delta^{18}O_{VSMOW}$ (‰) and δD_{VSMOW} (‰). During the examination the question we addressed was how oxbow lakes can be classified according to their water addition on the basis of their stable isotope ratios. The results from the Tisza and the oxbow lakes, as well as the results from the oxbow lakes on the reclaimed side and the floodplain are also isolated.

1. Introduction

How can we live sustainably with our environment and with our life-giving water-courses over a long period of time? It is a question that we will always have to answer. Our initial answer is based on hypothesises alone; later we have to identify the damage and finally commit ourselves to re-establish the original state. This is, however, a much more difficult problem than preventing the damage itself. One of the main purposes of humanity is to find a transitional state in which we can exploit nature (de Graaff et al., 2008), and consequently the possibilities offered by rivers, while only influencing it to a limited extent. To do this it is of primary importance that we familiarise ourselves with our rivers and the environment feeding on them.

The dynamics of rivers and floods, the factors influencing them and their impacts on the environment have already been examined (e.g. Large and Petts, 1996; Négrel et al., 2003; Vinet, 2008). As a consequence of the growing population life-giving rivers pose larger and larger threats (Vinet, 2008). Owing to environmental changes, floods – which are becoming ever more disproportionate – destroy huge areas and destroy the existing life, while providing space for newer life forms.

The Tisza, as the second biggest river in Hungary, plays an important role in our life, and it is of primary importance that we should get a true picture of the state of its environment. Although these days we can frequently hear of the environmental problems of the River Tisza (floods, cyanide and heavy metal contaminations (Lakatos et al., 2003; Fleit and Lakatos, 2003)), we hardly know anything about many of the oxbow lakes along the river. The River Tisza has been examined in different ways in the last years by Hungarian and foreign scientists. They studied the flood management and dynamics, the chemical and biological character of the river, the flora and the fauna, etc. The distribution and accumulation of heavy metals, cyanide contamination were also measured, but the surrounding oxbow lakes have not been examined from isotope analytical respect in such a large scale. Of the important and extensive work concerning Hungarian oxbow lakes, we must mention those of Braun (1998), Pálfai (1995) and Wittner et al. (2004, 2005).

The Tisza basin has been exposed to many anthropogenic effects throughout history, but compared with the large rivers of Europe the River Tisza and its direct environment – even in its present form – are regarded as one of the river basins in the most natural state (Zsuga and Szabó, 2005). It has a fairly important role in water management and shaping the natural landscape of Eastern Hungary (Zsuga, 2003). These oxbow lakes are also economically essential for the inhabitants of their neighbouring settlements. Since the economic benefit of the oxbow lakes is huge it is of primary importance to know the origin of the water in the

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oxbow lakes, and to know from where water is added. Oxbow lakes have an important hydrological value as well. We can obtain a picture of the depth of the water table in the whole area around the oxbow lakes. Where the lakes contain less and less water or even run dry it means that they cannot obtain water from under the ground, so the water table decreases. If the weather is arid, the precipitation will be limited, and the River Tisza will not flood the floodplain; and so these oxbow lakes and also their surroundings will be in the danger of drying out. If the arid period is long-lasting, these lakes can disappear. These processes accompany a decrease in the groundwater. Since on the Great Hungarian Plain a certain amount of drinking water is taken from the groundwater, the decreasing water table can lead to problems with the drinking water supply.

Oxbow lakes maintain significant natural and nature conservation values, and improve the stability of the ecological corridors on the floodplain (Kerényi and Szabó, 2007). The river is surrounded by forests, regarded as ecological corridors, which can broaden near the oxbow lakes. The Upper-Tisza Region is one of the significant areas of the Ramsar Convention in Hungary.

The goal of this research is to give a general description of the state, quality and the water addition of the oxbow lakes in the Upper-Tisza Region. We analysed the isotope composition ($^2H/^1H$, $^{18}O/^{16}O$) of surface water samples taken from the river and the oxbow lakes between the border (Tiszabecs) and Tokaj, as well as groundwater samples in the vicinity of four oxbow lakes. The isotopes of water molecules are ideal tracers of water sources and movement because they are integral constituents of water molecules (e.g. Coplen, 1993; UNESCO/IAEA, 2000).

2. Study area

The River Tisza is the largest left-side tributary of the Danube, and it collects the waters of eastern Hungary. Its total length is 966 km, of which 596 km is found in our country. The River Tisza has a medium range water output; the average is 500 m^3/s.

It was the river control in the 19th century that had one of the most remarkable impacts on the River Tisza. To assure shipping and flood-control 114 meanders were cut, and owing to this the river gradient increased, its length decreased and the flood runoff accelerated. During the controls 3168 km of defensive dikes were built (Martonné Erdős, 2004). Consequently many artificial oxbow lakes were formed. Before the controls, however, oxbow lakes took shape in a natural way as well; these are called cut off meanders. Oxbow lakes can be divided into two categories according to their location: active floodplain oxbow lakes are situated between the dike and the river, and reclaimed side oxbow lakes can be found outside the dike. Many cut off meanders have already filled up and run dry. There is water in their shallow beds only after heavy rainfalls and floods. The meanders cut off in the course of river control are younger, but many of them are in the same state as the earlier cut off oxbow lakes (Wittner et al., 2004). There are more than 90 of them in the section of the river we examined between the frontier and Tokaj. The Upper-Tisza Region can be interpreted differently. During our work we examined the Hungarian section of the Upper-Tisza River; i.e. between the frontier (Tiszabecs) and Tokaj.

It is well-known that the Tisza floods (Kovács, 2003) areas between the dikes owing to melting and heavy rainfalls. In this way it fills the active floodplain oxbow lakes and renews their water. However their water refill does not only result from floods; subsurface infiltration may also occur through the gravelled, quite permeable layers of the old river-bed and precipitation plays a role in this process as well. In this work we apply isotope analysis to examine which refill type is dominant in the oxbow lakes.

3. Materials and methods

During our research eight samples were taken from the River Tisza and 45 samples from 45 different oxbow lakes, on three occasions: in October 2005, May 2006 and August 2006 (Fig. 1). With these results we wanted to acquire a general picture of the separation and aggregation of the river and the oxbow lakes, and the possible sources of the water which supplies it. In November of 2008 the surface water investigations were supplemented with groundwater measurements in the vicinity of four floodplain oxbow lakes (Fig. 1) (near the settlements of Gávavencsellő, Tiszahát, Mezőladány and Gulács). We drilled monitoring boreholes (Fig. 2) outside the oxbow lakes (1), between the Tisza and the oxbow lakes (4) and in the abandoned part of the river-bed (3). Fig. 2 – as an example – shows the position of these holes on an oxbow lake. Water samples were taken from the boreholes, the oxbow lakes (2) and the river itself (5).

The water samples after chemical analysis were submitted for stabile isotope ratio measurements to get information about the extent of the evaporation and their origin as well. In most low-temperature environments, stable hydrogen and oxygen isotopes behave conservatively. The main processes that dictate the oxygen and hydrogen isotopic compositions of waters in a catchment area are: (1) phase changes that affect the water above or near the ground surface (evaporation, condensation, melting) and (2) simple mixing at or below the ground surface (e.g. Fontes and Edmunds, 1989; Coplen, 1993; Mazor, 1997; Clark and Fritz, 1997; Gat, 1996; UNESCO/IAEA, 2000; Cook and Herczeg, 2000; Négrel et al., 2003; Kortelainena and Karhu, 2004). These changes are small but can be reliably detected with specialised mass spectrometric techniques. They are normally reported as δ values in parts per thousand (‰) enrichments or depletions relative to a standard of known composition. In the case of H and O the internationally accepted standard is the Vienna Standard Mean Ocean Water (VSMOW). The δ value can be calculated:

$$\delta\ (‰) = \frac{R_{\mathrm{sample}} - R_{\mathrm{standard}}}{R_{\mathrm{standard}}} \cdot 1000$$

where R_{sample} is the isotope ratio measured in the sample and R_{standard} is the internationally accepted value for the standard (VSMOW). The changes in ^{18}O and D concentrations in meteoric waters were shown to be fairly well correlated (Craig, 1961) so that in the ($\delta^{18}O$, δD) graph the isotopic compositions of precipitation are aligned along what is referred to as a Meteoric Water Line (MWL) for which a global average is $\delta D = 8\ \delta^{18}O + 10‰$ (hereinafter GMWL). On the average global scale the ($\delta^{18}O$, δD) relation turns out to be satisfactorily described by the GMWL. Regionally, and for certain periods (such as seasons), Local Meteoric Water Lines (LMWL) may be found, depending on the conditions forming the local water source of each region. The isotopic composition of evaporating lake water (Vandenschrick et al., 2002; Yi et al., 2008; Turner et al., 2010) will evolve along the ($\delta^{18}O$, δD) line which has a slope significantly smaller than the LMWL. Yi et al. (2008) concluded that the three main sources of water input to lakes are snowmelt, river water and rainfall, and these sources can be evaluated by the position of the δ value along the LMWL.

The stabile isotope ratios (δ) were measured with a Thermo Finnigan DELTA$^{\mathrm{plus}}$XP mass spectrometer in the HELES (qualified according to ISO 9001/2009 and MS 0624-043 standards) in the ATOMKI. The uncertainty of the stabile isotope results is $\delta^{18}O$: ±0.2‰, δD: ±3‰.

Statistical analysis was carried out on the results; for this we used SPSS 15.0 software. Cluster analysis was executed with the Ward method. Clusters were formed from oxbow lakes with the use of δD and $\delta^{18}O$ values of every three samplings using standardised values. The propriety of the clustering was checked by discriminance analysis. After this we examined what relationships were