Seasonal behavior in the water quality of the River Tisza around the turn of the 21st Century

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As a result of climate change witnessed in the 19th-20th Century the meteorological seasonality is going through a change. The question is, how, and to what extent does this affect the seasonal behavior in water quality e.g. in the River Tisza. In the present study the seasonal behavior of the water quality parameters of the River Tisza, the second largest river in Central Europe is assessed using generally applicable and novel method, Combined Cluster and Discriminant Analysis. In the research 15 water quality parameters measured at 14 sampling sites in the Hungarian section of the River Tisza were assessed for the time period 1993 - 2005. As a result it was shown that in time there are basically four temporally similar sections (seasons) in the years in 1993-2005 with summer and winter four-four months long and fall and spring two-two months long.

Keywords: Combined Cluster and Discriminant Analysis (CCDA), homogeneous time intervals, river water quality, seasonality

Introduction

Analysis of long-term data set analysis could help in mitigating the negative impacts of climate change. The key meteorological elements influencing water balance and water quality of the rivers are (i) changes in temperature conditions, (ii) precipitation fallen on the watershed of the water body in question and as a consequence (iii) the sudden green floods. Bartholy et al. (2008) generated fine resolution (10-25 km) embedded regional climate models (CECILIA) for Hungary, where the initial boundary conditions were provided by the global circulation models with spatial resolution of 1-3°. On the basis of the regional model runs, the authors discussed the spatial and seasonal variation in temperature and precipitation events for the whole Carpathian Basin. For Hungary, the expected seasonal warming by 2021-2050 is around 2 to 4°C. The size of the variation in warming trend between different seasons is not consistent. The smallest increment of 1.9°C is in spring and the largest one is waited in winter (3.7°C). The prognosis about warming rates are significant at the level of $\alpha=0.05$. For the same projection period, the precipitation increase of 13% in winter and at about the same magnitude but opposite sign decrease in summer precipitation (-17%) are likely. The reference period was 1961–1990. The authors found realignment in rainfall distribution; the wettest month of the A2 scenario was the April with 70 mm rainfall sum. It means that the wettest month will occur a little earlier than it used to.

In the view of these phenomena the question was raised: do the changes in the regional climate – e.g. change in the length of the meteorological seasons (Trenberth, 1983) - emerge in the water quality parameters of the Hungarian section of the River Tisza; and if they do, how do they appear. To answer this question the application of a novel grouping method called Combined Cluster and Discriminant Analysis (CCDA, Kovács et al., 2014) is presented, which was developed to find not only similar but homogeneous groups of sampling sites or time intervals.

Materials and methods

The River Tisza collects the waters of the Carpathian Basin's eastern region, it is therefore a highly important ecological corridor (Zsuga et al., 2004). It stretches from its source in the Eastern Carpathians in Ukraine to its confluence with the Danube at Titel in Serbia. According to Lászlóffy (1982), the area of its watershed is 157,186 km^2 almost one third of which is located in Hungary (approx. 47,000 km^2). The average amount of water brought by the Tisza into the Danube is 25.4 billion m^3 y^{-1} (Pécsi, 1969). The main branch (966 km; Sakan et al., 2007) stretches through five countries (Ukraine, Romania, Hungary (594.5 km), Slovakia, and Serbia).

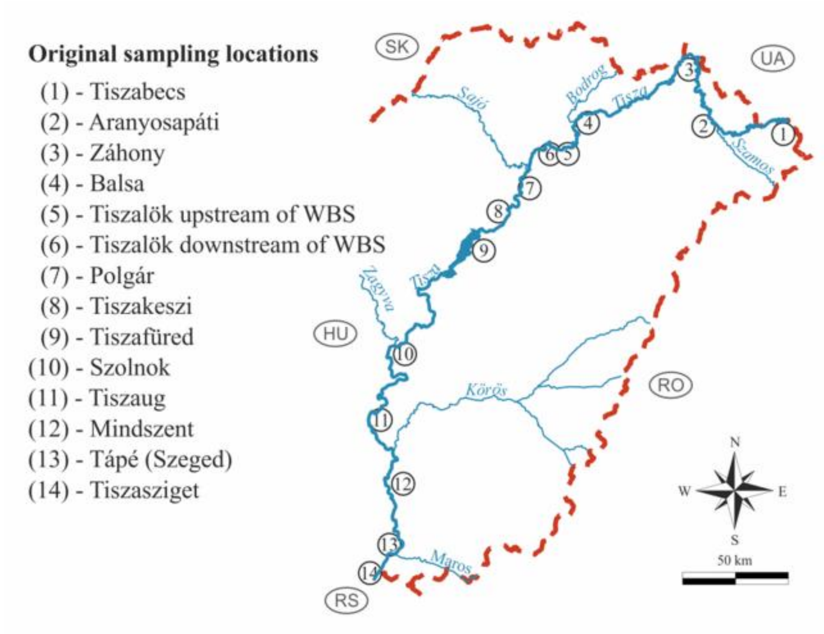

Fig. 1 Hungarian catchment of the River Tisza

During the analyses the time series of the following parameters were examined: runoff (m^3 s^{-1}), pH, dissolved O_2, BOD-5, Ca^{2+}, Mg^{2+}, Na^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^- (mg l^{-1}), NH_4-N, NO_2-N, NO_3-N, PO_4-P (µg l^{-1}) for the time period between 1993 and 2005 from 14 sampling sites (Fig. 1). The total number of data analyzed added up to 145,000.

In the study, hierarchical cluster analysis (HCA; Kovács et al., 2012) was used on monthly averages (all the monthly averages from January formed one average, all the Februaries formed one average etc.; 1993-2005) to find the similar within-year time intervals. As next step CCDA was applied to decide whether the found time intervals consist of homogeneous or just similar elements. Combined cluster and discriminant analysis (CCDA; Kovács et al., 2014) formed the backbone of the research. It consists of three main steps:

(I) a basic grouping procedure, e.g. using hierarchical cluster analysis, to determine possible groupings;

(II) a core cycle where the goodness of the groupings from step I and the goodness of random classifications are determined using linear discriminant analysis (LDA), these are then compared in the form of a "difference value";

(III) and a final evaluation step, where a decision about iterative further investigation of sub-groups is taken (Fig. 2).

The main idea hereby is that once the ratio of correctly classified cases for a grouping is higher than at least 95% of the ratios for the random classifications (i.e. the difference value is positive), then at the level of α=0.05 the given classification is considered as inhomogeneous. For a detailed description of the method see Kovács et al. (2014) and the corresponding R package ("ccda", http://cran.r-project.org/web/packages/ccda/) used for the computations.

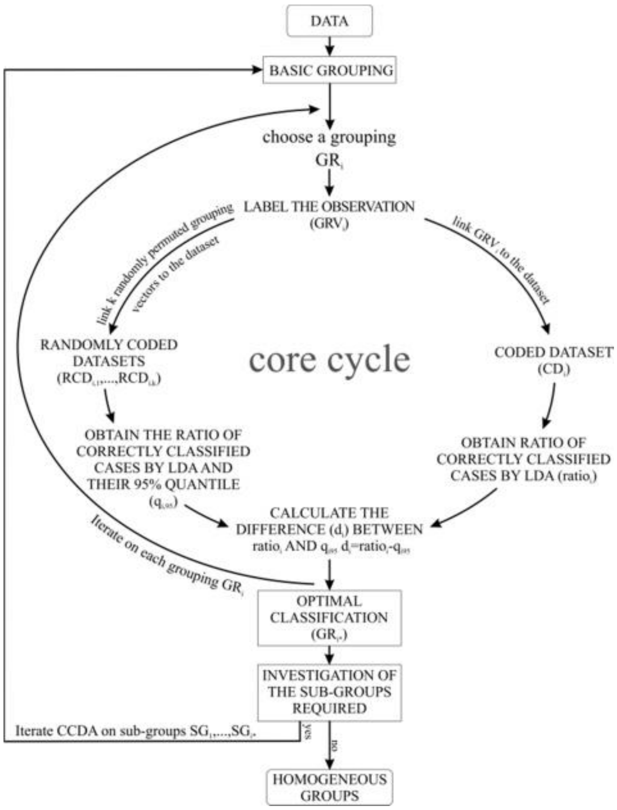

Fig. 2 Flowchart of CCDA (based on Kovács et al., 2014)

Results and discussion

As discussed, the intra-annual similarities were sought for on a monthly scale using simply HCA. It pointed out that there are basically four seasons (Fig. 3a) in alignment with the notion that, since Hungary is located in the continental climate zone, from a meteorological perspective four seasons exist. Huschke (1959) in his work entitled 'The Glossary of Meteorology' defines the seasons as follows: The warmest period in the year is summer everywhere in the world, except for a couple of tropic regions, while the coldest is winter. According to Trenberth (1983), between these two, spring and fall serve as transitional periods. The seasonal pattern obtained did not concur with the general meteorological aspect of the four seasons with equal length in the continental climate zone, however it is in harmony with the observation of Trenberth (1983). Summer and winter were both four months long, while spring and fall were each two months long (Fig. 3a).

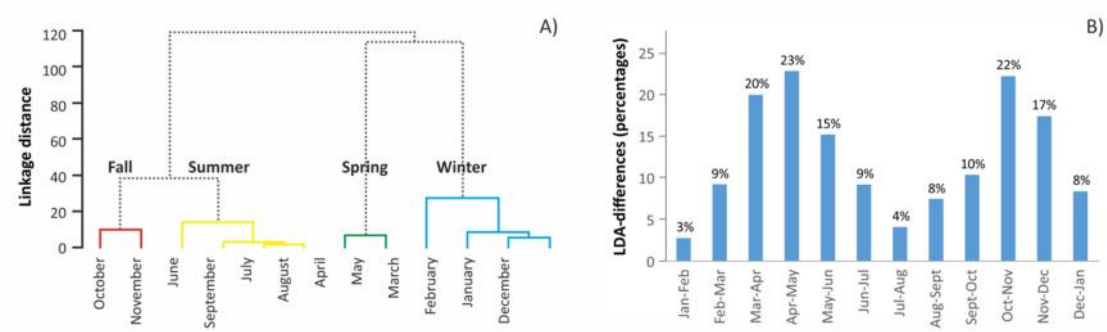

Fig. 3 Results of HCA conducted on monthly averages to find seasons A) and the Pairwise differences between the months pointed out by CCDA B)

In addition, CCDA provided the opportunity to explore homogeneity within the predetermined seasons. It showed that even though the previously determined seasons consist of similarly behaving months, these seasons cannot be considered as homogeneous. Moreover, the months would even form twelve separate homogeneous groups; each month forming a group separately. To point out the significant differences CCDA was applied for pairwise comparisons of consecutive months (Fig. 3b). Since the difference value between February and March (9%) was much smaller than the one for March-April (20%), it is reasonable that March rather joined the winter months. Similarly, September was closer to August than October (differences 8% and 10% respectively). The other bordering months between the seasons, December and June showed a similar behavior as well, justifying that they belong to the winter and the summer season respectively. This finding of unequal length seasons concurs with the research of Alpert et al. (2004) conducted on meteorological data. It is suspected that the reason behind this phenomenon lies in the fast transition of the characteristic processes of winter into summer - as projected significant warming in spring may affect the river's hydrological events - in spring and the other way around in fall.

Conclusions

With the aid of HCA and CCDA, it was shown that in time there are basically four temporally similar sections (seasons) in the years in 1993-2005. The months within seasons however can only be regarded as similar and not as homogeneous. The most explicit changes could be observed in April-May and October-November. On the contrary, in summer and winter the differences between the months were rather small. Unequal changes in seasonal trends of meteorological elements predict a shift in the seasons' length and their outset, directly impacting the river's hydrological processes. This statement is in harmony with the general conclusion about the possible changes for Hungary at the end of climate-projections, whereas the summers are likely to be warmer and drier, whereas the winters milder and wetter (Bartholy et al. 2014). Note that the methodology presented could easily be applied to longer time intervals and other datasets as well.

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