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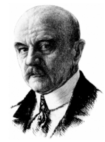

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THE NORTH ATLANTIC OSCILLATION (NAO) AND THE WATER TEMPERATURE OF THE SAVA RIVER IN SERBIA

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Abstract: The data on the water temperature of the Sava in Serbia (hydrological stations Šabac and Belgrade, period 1961–2015) were used for the research, as well as the data on the surface air temperature. The temperature trends were determined and the significance (at $p \leq 0.05$ and $p \leq 0.01$) was established on the basis of the t-test. The Pearson correlation coefficient (R) was used for the calculation of the correlation. Increasing trends of the water temperature of the Sava were recorded in all cases at both stations. However, in the case of the HS Šabac, the trends for 6 months (February–April and September–November) were not statistically significant. In the case of the HS Belgrade, all the calculations (except for April) showed statistically significant increasing trends, which can be explained by anthropogenic influence. High level of correlation between the surface air temperature and the water temperature was also determined. In this research, the lowest values of R were recorded for October (0.561 for Belgrade), and on the seasonal level, for autumn (0.625 for Šabac). The research on the correlation between the water temperature of the Sava River and the NAO index showed the highest values of R for January (0.512 for HS Šabac and 0.528 for HS Belgrade). On the seasonal level, the highest values were recorded for winter (0.422 for HS Šabac and 0.432 for HS Belgrade).

Key words: North Atlantic Oscillation, water temperature, river, Sava, Serbia

Introduction

The Sava is the right tributary of the Danube. It flows through Slovenia, Croatia (part of the border with Bosnia and Herzegovina), and Serbia. Milenković, Babić, Ducić, Krstić and Lazić (2016) researched the trends of the water temperature of the Sava River in Serbia in the periods 1983–2014 and 1998–2014. The data from the hydrological stations Šabac and Belgrade were used in the research. These data are more complete than the data from the other two

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hydrological stations on the Sava in Serbia: Jamena and Sremska Mitrovica. The increasing trends were mostly recorded at the HS Šabac, but they were not statistically significant. For the HS Belgrade, which is under strong anthropogenic influence, statistically significant (at $p \leq 0.05$) increasing trends were recorded for all seasons in the period 1983–2014, while in the period 1998–2014 there were no significant trends. The results are in compliance with the claims of the Intergovernmental Panel on Climate Change (IPCC, 2013) that there is a hiatus in the temperature growth after 1998[2]. These results were obtained with short sets of data, and the aim of the research is to determine the trends of the water temperature of the Sava River in longer period (1961–2015). Bonacci, Trninić and Roje-Bonacci (2008) researched the trends of the water temperature of the Sava River at the hydrological stations Zagreb and Slavonski Brod for longer period. An increasing trend in the maximum annual water temperature was recorded at both stations: Zagreb (0.06 °C per year) and Slavonski Brod (0.05 °C per year). It was also determined that since 1965 the river has not frozen, but in earlier period the freezing was frequent. Lovász (2012) determined increasing trends of the water temperature of the Danube and the Tisza in Hungary (1951–2010).

The North Atlantic Oscillation (NAO) is one of the factors connected with the temperature in this part of Europe. The NAO index is calculated on the basis of the difference in the sea surface air pressure between Iceland (low) and the Azores (high). It is characterized by both positive and negative phases. Strong positive phases of the NAO often tend to be associated with below-normal temperatures across southern Europe. They are also associated with above-normal precipitation over southern and central Europe. Opposite patterns are observed during strong negative phases of the NAO[3]. The NAO dominated the extreme temperature variability in Serbia during winter (Unkašević & Tošić, 2013). Pavlović-Berdon (2012) found the highest correlation between the NAO and temperature anomalies for January. Malinović-Milićević, Radovanović, Stanojević, and Milovanović (2016) established significant influence of the NAO on the duration of winter warm periods. The influence of the NAO on the precipitation in Serbia during winter was also determined (Jovanović, Reljin & Reljin, 2008). According to Tošić et al. (2013), the intensification of the positive phase of the NAO could represent one of the causes of the decrease in winter precipitation in Vojvodina.

The aims of the research were to determine:

[2] https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf
[3] https://www.ncdc.noaa.gov/teleconnections/nao/

– the trends of the river water temperature;
– the connection between the river water temperature and the surface air temperature;
– the correlation between the river water temperature and the NAO index.

The results of the research should contribute to better understanding of the connection between the NAO index and the water temperature of the Sava River in Serbia and also be the basis for the long-term forecast.

Data and methods

Mean monthly, seasonal and annual water temperature data from the hydrological stations Šabac and Belgrade[4] on the Sava were used in the research. The water temperature data refer to the period 1961–2015. The problem with missing data was solved by the method of interpolation. The data from the nearest climatological stations Šabac and Belgrade[5] were also used.

The linear trends were established for these datasets. In addition, statistical significance of the linear trend was determined for (n-2) and on the basis of the coefficient of determination (R^2). The t-test was used for testing the significance. The significance of the trends was determined by the equation:

$$t = R\sqrt{\frac{n-2}{1-R^2}} \quad (1)$$

(n — length of the series).

Monthly and seasonal values of the NAO index were used in the research. The NAO index data were downloaded from the Earth System Research Laboratory, National Oceanic & Atmospheric Administration, U.S. Department of Commerce[6].

The Pearson correlation coefficient (R) based on the linear trend was used for the calculation. Statistical significance was tested at $p \leq 0.05$ and $p \leq 0.01$.

4 http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php
5 http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php
6 https://www.esrl.noaa.gov/psd/data/correlation/nao.data

Results and discussion

The trends in the water temperature of the Sava are shown in the Table 1.

Table 1. The water temperature trends of the Sava (1961–2015): hydrological stations Šabac and Belgrade

Period	Trend (°C/ per year)	
	HS Šabac	HS Belgrade
January	0.0452**	0.057**
February	0.0163	0.0323*
March	0.0219	0.0368**
April	0.0114	0.0199
May	0.0324*	0.0419**
June	0.0343*	0.05**
July	0.0412**	0.0657**
August	0.0371**	0.0644**
September	0.024	0.0558**
October	0.0158	0.0442**
November	0.0175	0.0421**
December	0.037**	0.0585**
Winter	0.0345**	0.0499**
Spring	0.0219*	0.0329**
Summer	0.0375**	0.0601**
Autumn	0.0191*	0.0474**
Year	0.0278**	0.0474**

Source: Authors' calculation based on http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php

The calculations showed the increasing trends in the water temperature of the Sava River at both stations. However, in the case of the HS Šabac, the trends were not statistically significant for 6 months (February–April and September–November). In the case of the HS Belgrade, the statistically significant trends were found in all calculations, except for April. In addition, they were statistically significant at $p \leq 0.01$, with the exception of February (at $p \leq 0.05$). The growth of the water temperature of the Sava River in Belgrade could be explained by significant anthropogenic influence.

The trends in the surface air temperature are shown in the Table 2.

The analysis of the trends in the surface air temperature in Šabac and Belgrade showed less intensive growth in comparison with the water temperature of the Sava.

The correlation between the surface air temperature and the water temperature of the Sava is shown in the Table 3.

Table 2. The surface air temperature trends (1961–2015): meteorological stations Šabac and Belgrade

Period	Trend (°C/ per year)	
	CS Šabac	CS Belgrade
January	0.0561**	0.0645**
February	0.0059	0.023
March	0.0265	0.0378
April	0.0138	0.0292*
May	0.0328*	0.0355*
June	0.0352**	0.0413**
July	0.0513**	0.0662**
August	0.045**	0.0655**
September	0.0128	0.0202
October	0.0224	0.0172
November	−0.0014	0.0176
December	0.0218	0.0358*
Winter	0.0297*	0.0426**
Spring	0.0244**	0.0342**
Summer	0.0438**	0.0577**
Autumn	0.0113	0.0183
Year	0.0269**	0.0378**

* significant at p≤0.05;** significant at p≤0.01 Source: Authors' calculation based on http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

Table 3. Pearson correlation coefficient (R): The water temperature of the Sava and the surface air temperature (1961–2015)

Period	Pearson correlation coefficient (R)	
	Šabac	Belgrade
January	0.805**	0.851**
February	0.803**	0.840**
March	0.827**	0.855**
April	0.705**	0.704**
May	0.805**	0.824**
June	0.740**	0.770**
July	0.707**	0.806**
August	0.757**	0.856**
September	0.699**	0.714**
October	0.576**	0.561**
November	0.705**	0.668**
December	0.643**	0.710**
Winter	0.788**	0.856**
Spring	0.847**	0.887**
Summer	0.756**	0.876**
Autumn	0.625**	0.652**
Year	0.752**	0.878**

* significant at p≤0.05;** significant at p≤0.01 Source: Authors' calculation based on http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php and http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

October is the month with the lowest R. On the seasonal level, the lowest R value was recorded for autumn.

The correlation between the NAO index and the water temperature is shown in the Table 4.

Table 4. Pearson correlation coefficient (R): NAO index and the water temperature of the Sava (1961–2015)

Period	Pearson correlation coefficient (R)	
	HS Šabac	HS Belgrade
January	0.512**	0.528**
February	0.205	0.295*
March	0.419**	0.424**
April	−0.005	0.012
May	0.045	0.004
June	−0.233	−0.292*
July	−0.092	−0.179
August	−0.054	−0.119
September	−0.008	−0.048
October	−0.210	−0.298*
November	−0.010	−0.034
December	0.337*	0.400**
Winter	0.422**	0.432**
Spring	0.287*	0.240
Summer	−0.234	−0.331*
Autumn	−0.076	−0.118
Year	0.247	0.166

* significant at $p \leq 0.05$;** significant at $p \leq 0.01$

Source: Authors' calculation based on https://www.esrl.noaa.gov/psd/data/correlation/nao.data and http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php

The highest values of R were recorded for January (Figure 1 and Figure 2), and winter on the seasonal level, which is expected. Thus, the increase of the water temperature of the Sava in January and winter is in the connection with the NAO index. Statistically significant values ($p \leq 0.01$) were also recorded for March and December (HS Belgrade). Negative values were recorded for summer and autumn months at both stations, and in case of the HS Belgrade, the values for June and October were statistically significant at $p \leq 0.05$.

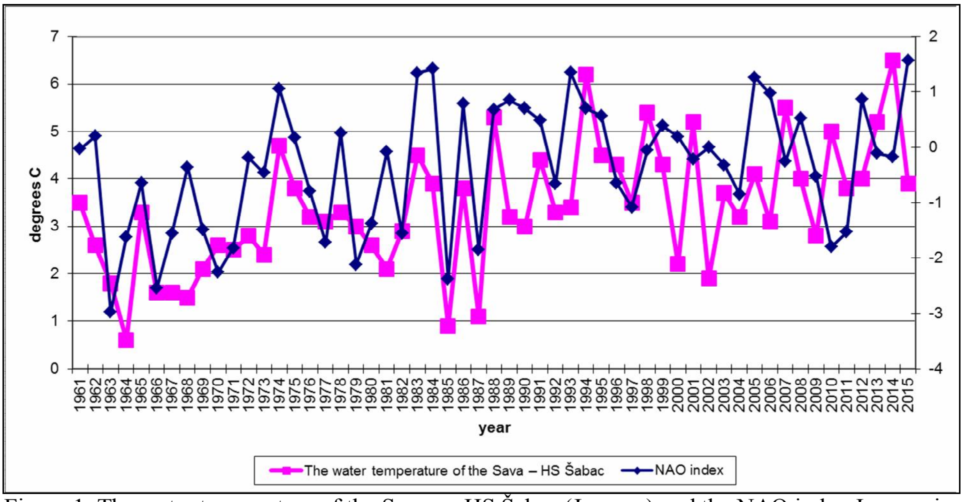

Figure 1. The water temperature of the Sava — HS Šabac (January) and the NAO index January in the period 1961–2015: R=0.512 (significant at p≤0.01)
Source: Authors' calculation based on https://www.esrl.noaa.gov/psd/data/correlation/nao.data and http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php

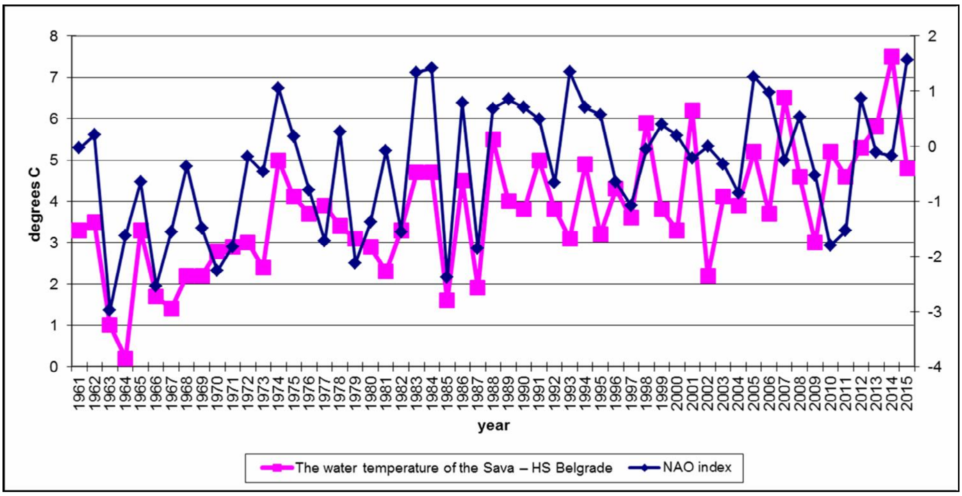

Figure 2. The water temperature of the Sava – HS Belgrade (January) and the NAO index January in the period 1961–2015: R=0.528 (significant at p≤0.01)
Source: Authors' calculation based on https://www.esrl.noaa.gov/psd/data/correlation/nao.data and http://www.hidmet.gov.rs/ciril/hidrologija/povrsinske_godisnjaci.php

The correlation between the NAO index and the surface air temperature is shown in the Table 5.

Table 5. Pearson correlation coefficient (R): NAO index and the surface air temperature (1961–2015)

Period	Pearson correlation coefficient (R)	
	CS Šabac	CS Belgrade
January	0.543**	0.565**
February	0.155	0.202
March	0.251	0.311*
April	−0.105	−0.061
May	−0.079	−0.046
June	−0.312*	−0.319*
July	−0.234	−0.253
August	−0.094	−0.155
September	0.091	0.078
October	−0.208	−0.212
November	−0.312*	−0.315*
December	0.319*	0.374**
Winter	0.321*	0.397**
Spring	0.081	0.150
Summer	−0.415**	−0.442**
Autumn	−0.123	−0.140
Year	0.069	0.095

* significant at $p \leq 0.05$;** significant at $p \leq 0.01$
Source: Authors' calculation based on https://www.esrl.noaa.gov/psd/data/correlation/nao.data and http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

The calculations of the surface air temperature showed the highest R values for January. However, on the seasonal level, the highest correlation is found for summer, and there is also the shift in the sign of the connection.

The results of the NAO index and the water temperature are mainly in compliance with the results of Ducić et al. (2015). They researched the connection between the NAO index and the water temperature of the Danube at Bogojevo gauge in the period 1961–2013. The authors recorded the highest value of R on the monthly level for January (0.60), while 0.51 for winter. The values statistically significant at $p \leq 0.01$ were also recorded for February, March and December. Thus, the main difference is in the case of February – the value of R for the HS Šabac is not statistically significant, while for the HS Belgrade it is statistically significant at $p \leq 0.05$. Basarin, Lukić, Pavić and Wilby (2016) also found statistically significant correlation between the water temperature and the NAO index for winter period at Bogojevo station. At the same station they observed the growth of the seasonal maximum water temperature (0.05 °C per year on average).

Conclusion

The increasing trends in the Sava River water temperature were recorded at the HS Šabac and the HS Belgrade (period 1961–2015). The trends were not statistically significant for 6 months (February–April and September–November) in the case of the HS Šabac, while in the case of the HS Belgrade, all calculations (except April) showed statistically significant increasing trends. The growth of the surface air temperature in Šabac and Belgrade was less intensive in comparison with the growth of the water temperature. In the case of Belgrade, the growth was not statistically significant for 5 months (February, March, September–November).

The research on the correlation with the NAO index showed the highest values of R for January (0.512 for HS Šabac and 0.528 for HS Belgrade), and winter (0.422 for HS Šabac and 0.432 for HS Belgrade) on the seasonal level. The statistically significant values ($p \leq 0.01$) were also recorded for March and December (HS Belgrade). Negative values were recorded for summer and autumn months at both stations, and in the case of the HS Belgrade, the obtained values for June and October were statistically significant at $p \leq 0.05$. The calculations of the surface air temperature also showed the highest values of R for January. However, on the seasonal level, the highest correlation is found for summer, and there is a shift in the sign of the connection.

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