EFFECTS OF CLIMATE CHANGE ON DAILY WATER TEMPERATURES IN THE HUNGARIAN LOWER DANUBE RIVER

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ABSTRACT. – Effects of climate change on daily water temperatures in the Hungarian Lower Danube river - The historical records prove that daily water temperature has been rise during the last decades. The rise is closely correlated with increasing air temperature in summer season. The climate scenarios in Hungary predict further warming of climate, so water temperatures are expected to increase in future. In the paper a simple method is shown for prediction of expected change in duration of daily water temperature above given temperature, especially above the temperature being critical from the exploitation of atomic power station in the Hungarian lower Danube River.

Key-words: Hungarian lower Danube, daily water temperature, duration curves of daily water temperature, mean summer air temperature, regional climate scenarios, climate-analogy

1. Introduction

Water temperature is an essential physical characteristic of water, and it has a direct and strong influence on the aquatic ecosystems. Its changes may lead to undesirable alteration of water ecological systems (Pöckl, 2003). Water temperature is closely correlated with the air temperature, and increase in the latter could lead to warming of stream water. Water temperature can be influenced also by human activities, especially the return of cooling water into the river, and the building of barrages and reservoirs may result in the warming of stream water. In the Hungarian lower course of Danube River it is possible to face both types of the effects. Here, at the Paks city is found the only atomic power station of Hungary. The power station takes out the water for cooling from the river, and returns a part of used water into the river with higher temperature. The return of used water is allowed only keeping some rules about the temperature conditions. The basic rule is that maximum water temperature in the river must not exceed the 30 °C after 500 m from the introduction of returned cooling water. Increase in the air temperature predicted by climate scenarios for the Hungary would make more difficult to keep

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this rule, might lead to increasing risk of the introduction of cooling water. The paper deals with the questions (i) what changes are observed in the water temperature in the past, (ii) what changes are expected in water temperatures of the Hungarian lower Danube River in the future due to climate change.

2. The changes in the water temperature in the past

Change in water temperature during the historical observation was analysed using data of hydrological station at Baja. Baja is a city lying beside Danube 60 km lower than Paks. This distance is large enough that returned cooling water was able to get mixed up with natural streamflow of the river. Daily data are available since 1974. Before 1989 the temperature was measured only once a day, at 7 a.m. in the summer, and 8 a.m. in the winter months. After 1989 the measurement was made more frequently, and since 2005 the automatic equipment provides practically continuous records of data. In the trend analyses only the data measured at morning time were used.

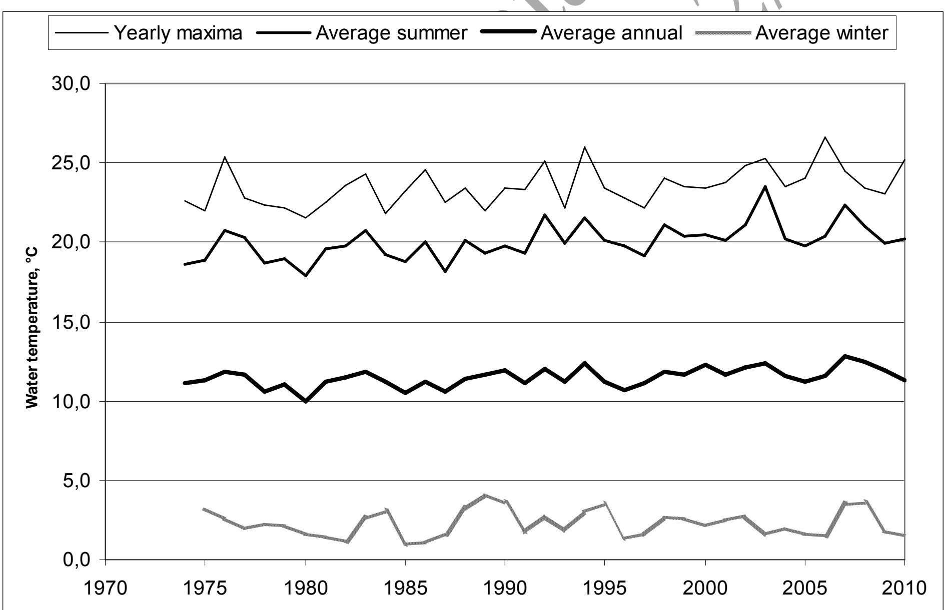

Figure 1. The time series of water temperature characteristics of Danube River at hydrological station Baja.

The trend was analysed for some typical water temperature characteristics, especially for the average annual water temperature, the average water temperature in summer (july-august) and in winter (december-february) seasons, and for yearly maximum during the 1974-2010 years. No any tendency is found in the winter water temperatures, while the average annual, summer and yearly maximum water temperatures show an upward trend during the 1974-2010 years (Figure 1). The rate of the increase in summer water temperature and yearly maximum is about 0,5 °c per decades.

The change in daily water temperature was also analysed through their duration curves calculated for every year. From the annual duration curves for every year the number of days with water temperature above given threshold values was taken for every year, thereafter the trends of duration values were analysed. The number of days usually shows an upward trend during the period of observation. The rise of trend is especially intensive for the duration of days above higher threshold temperature values. For example, the number of days with water temperature greater than or equal to 22 °C being critical for the exploitation of power station has been increased during this period at rate about 8 day per decade (Figure 2).

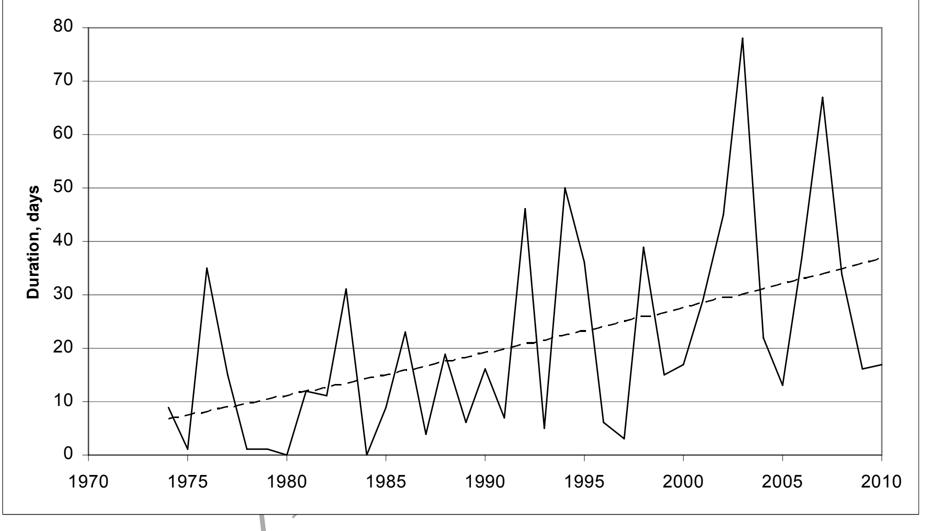

Figure 2. Trend in annual duration of daily water temperature above the 22 °C critical value

Although the rise in the water temperatures can be explained to some extent by the warming effect of introducing used cooling water from the atomic power station, the main reason can be believed in the increase of air temperature. The power station has been put completely in the operation in 1987 and its warming effect ought have been appeared after this year as a jumping trend. Nevertheless, such jumping trend is not found in the long-term records of water temperature. On the other hand the rate of increase in the air temperature equal to 0,50 °C per decades agree well with the rate of rise in summer water temperatures being 0,50 °C per decades (Figure 3).

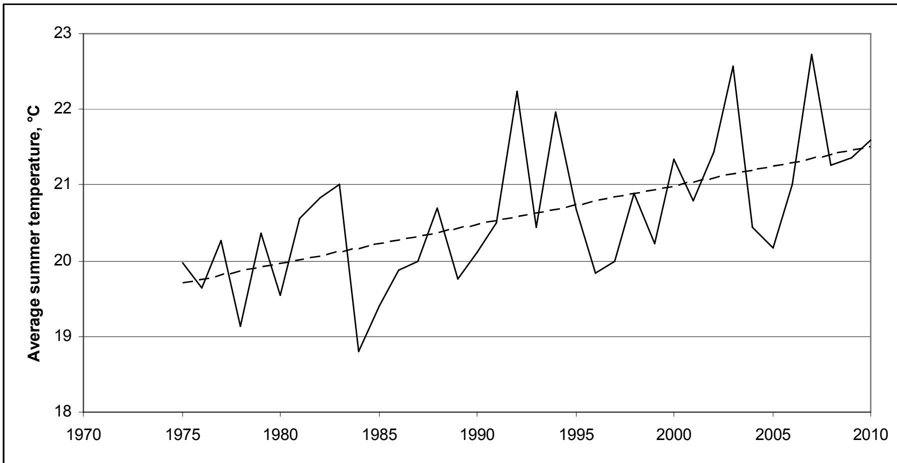

Figure 3. Average summer air temperature at meteorological station Baja.

Increase in the number of days with water temperatures above any given threshold value is in a good correlation with the rising average yearly and summer air temperature (Table 1). The correlation is especially high for the water temperatures in the interval 20-22°C, when can reach the 0,77-0,80.

Table 1. Correlation coefficients between number of days exceeding the threshold value and average summer temperature

	Threshold value of water temperature (°C)						
	19	20	21	22	23	24	25
Year	0,567	0,636	0,609	0,532	0,337	0,237	0,179
Summer (June-August)	0,670	0,800	0,779	0,757	0,604	0,484	0,366

Increase in average yearly water temperature during the long-term periods of observation was shown for the most of sections of Danube River even for those where the air temperature didn't show any increasing tendency (Stancikova et al., 1993). Particularly, the average annual water temperature of the River has been increasing at Linz during 1901-1998 by 0,8 °C (Webb and Nobilis, 2007), at Wien during 1951-2003 by 1,3 °C (Zweimüller, 2007), at Bratislava during 1926-2005 by 0,6 °C (Pekarova et al., 2008). More rapid rise is observed after 1970s, particularly the average annual water temperature at Bratislava did not show increasing trend until 1970s (Pekarova et al., 2008). Yearly maximum of water temperature has been increased by approximately the same magnitude as mean stream temperature (Haag, 2009). The rise of average water temperatures is closely correlated with the rise of average air temperature (Webb and Nobilis, 1995; Webb and Nobilis, 2007), so the significant rise in water temperatures during the 20th century is broadly driven by rising air temperature. Therefore the authors conclude that the observed upward trend of stream water temperature is to a great extent owing to climate change. Nevertheless, increase of the water temperatures can be explained to some parts by human activity (Stancikova et al., 1993, Haag, 2009), especially by the construction of barrages during the period of investigation (Webb and Nobilis, 1995; Webb and Nobilis, 2007).

3. The effect of climate change on the water temperature

The water temperature of Danube River including its Hungarian lower course has been rising during the last decades meanly because of rising air temperature. There is an agreement among the climatologists about the further warming of global climate in the 21.century (IPCC, 2007), and in Hungary (Bozó, 2010). As a consequence of climate warming the water temperature of rivers is expected to rise in the future. In terms of exploitation of atomic power station it is most important how the daily water temperature, especially the day number with temperature above critical temperature will be changed. However, nowadays there is not any tool on hand which would be able to predict with sufficient reliability the change in meteorological and/or hydrological events on daily level, including daily water temperature. We can say at the same time how they and/or their duration curves were shaped in the past in years with different climatic conditions. Using the historical data of air temperature we can select such years, the mean statistics of which are equal or similar to those of the predicted future climate. The climate of the years selected on a manner like this can be accepted with a more and less uncertainty as a climate-analogy of predicted future climate. The hypothesis about climate analogy can be extended to hydrological data. Using the method of climate-analogy requires three main steps. Firstly, to choose climate scenarios in the future, secondly, to select their climate-analogy in the past, thirdly to compute the duration curves of daily water temperature for the climate-analogies using the historical data-records.

CLIMATE SCENARIOS

Climate of Hungary is predicted warmer and drier in the 21.century as a consequence of global warming. Air temperature would rise in year and in all seasons and the climate would become more similar to Mediterranean one

(National Climate Change Strategy, 2008). The regional climate scenarios in 2010-2040 are projected setting out from the greenhouse gases emission scenario of medium size (A1B), three different global climate models (ECHAM, NCAR, ARPEGE), and using three regional climate models (REMO, RegCM, ALADIN) differently for selected GCMs (Bartholy et al., 2009). Regional climate scenarios predict the change compared to the basic period of 1961-1990. Air temperature is predicted to increase in year and all seasons, particularly in summer by up to 2,4 °C (Table 2). The predictions of precipitation are less uncertain, the predicted changes are not significant, mostly may be considered as a consequence of natural variability.

Table 2. Change in average annual and seasonal temperature and precipitation in 2011-2040 as compared with 1961-1991 averaged on three regional scenario

	Year	Spring	Summer	Autumn	Winter
Temperature, (°C)	0,8 – 1,8	1,0 – 1,6	0,5 – 2,4	0,8 – 1,9	0,8 – 1,2
Precipitation, (mm)	(-40,8; +2,4)	(-15,9; +6,0)	(-15,0; +3,0)	(-4,8; +5,1)	(-22,8; +10,8)

According to the regional climate scenarios in the region of Hungarian lower Danube River the average summer air temperature might be higher by 1-1,5 °C in 2021-2040, and by 2,5 °C at the end of the 21.century than in the basic period 1961-1990. The expected rate of increase in summer is 0,27 ± 0,09 °C per decades that is in good agreement with the rate of changes calculated for last decades of historical period being equal to 0,20-0,22 °C per decades. The good agreement allows us to make a conclusion that warming has been started already in the present decades.

CLIMATE ANALOGY

Climate scenarios predict the change in temperature (and other climate elements) compared to the basic period of 1961-1990 year. The mean monthly and annual temperatures calculated from the observed data of the meteorological station Baja are shown in Table 3.

Mean air temperature and precipitation during the summer seasons are 20,2 °C and 192 mm respectively.

As the water temperature data in the past are available only in 1974-2010 and they are missing in 1961-1973 the present climate also was described using only the meteorological data in 1974-1990 year.

Table 3. The mean monthly and annual values of temperature (°C) and precipitation (mm) in 1961-1990.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Temperature	-1,4	1,2	5,7	11.1	16,3	19,4	21,0	20,3	16,6	11,0	5,2	0,7	10,6
Precipitation	36	33	34	49	61	84	52	56	39	35	56	48	583

The reliability of the replacement of the basic period by a shorter period was checked comparing the mean monthly temperature and precipitation calculated for basic period 1961-1990) and period 1974-1990 (Figure 4). Comparison show an excellent agreement between two periods, when the monthly differences usually doesn't exceed some 0,1 °C-s, in average for summer seasons the 0,2 °C. For monthly precipitations the agreement is less good. However, mean summer precipitation calculated for 1974-1990 years is 188 mm, 2 % less than that calculated for basic period 1961-1990 being equal to 92 mm.

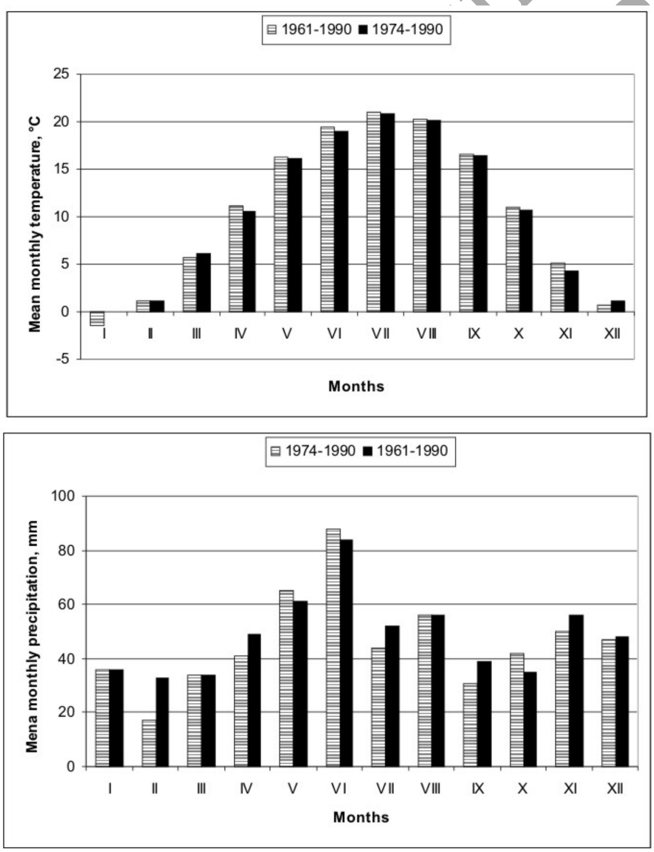

Figure 4.Comparison of mean monthly temperature and precipitation between two periods of 1961-1990 and 1974-1990.

The present climate is characterised by the climate in 1974-1990. Mean summer air temperature calculated for this period is equal to 20,0 °C. According to regional climate scenarios four different rates of increase in mean summer temperature within the interval 0,5-2,0 °C by step of 0,5 °C were taken into consideration in climate impact assessment (Table 4). For every predicted rate of increasing summer temperature the years were selected from the historical records so that mean summer air temperature for these years was higher than for this value in the present climate by the predicted rate. For example, assuming a temperature rise equal to 1,5 °C we has been selected the years 1982-1983, 1994, 2000-2003 and 2006-2010, during which the mean summer temperature is 21,5 °C being 1,5 °C higher than its value at present climate. Climate representing by 12 years selected from the historical records can be accepted as a climate analogy of the future climate in the past. The years selected for the climate analogy at different rate of warming are listed in Table 4. Naturally, as higher the rate of warming as less number of years may be selected from the past for climate analogy, and this limitation may highly limit also the reliability of climate description.

Table 4. Selected years from the past being representative as climate-analogy of predicted climate in future.

Climate-analogy	Selected years for describing climate analogy
Present climate (basic climate)	1974-1990
+0,5 °C warming	1974-2010
+1,0 °C warming	1977, 1979, 1981-1983, 1988, 1991-1995, 1998-2010
+1,5 °C varming	1982-1983, 1994, 1998, 2000, 2002-2003, 2006-2010
+2,0 °C warming	1994, 2002-2003, 2007, 2009-2010

Duration curves of daily temperature for climate-analogy

Having climate-analogies of predicted future climate at different rate of warming the duration curves of daily water temperatures can be calculated using the historical records. The duration curves calculated different rate of warming above 22 °C critical temperature are shown by Figure 5. The differences between duration curves for the climate analogy and for the present climate can be considered as the changes in daily water temperature due the climate warming.

The average duration expressed in day number above any given water temperature can be obtained for different rate of summer temperature rise from the duration curves in Fig. 5. Thereafter, a relationship may be constructed how the average duration above any given water temperature has been increasing with the rising summer air temperature (Figure 6). For example the duration of days with water temperature above 20 °C would increase from 40 days at present climate to 60 day in future if the climate is warming by 1 °C. Similarly, the number of days with water temperature above 22 °C threshold value, would increase from 12 days presently to 28 days in future by 1°C rise in air temperature in summer season.

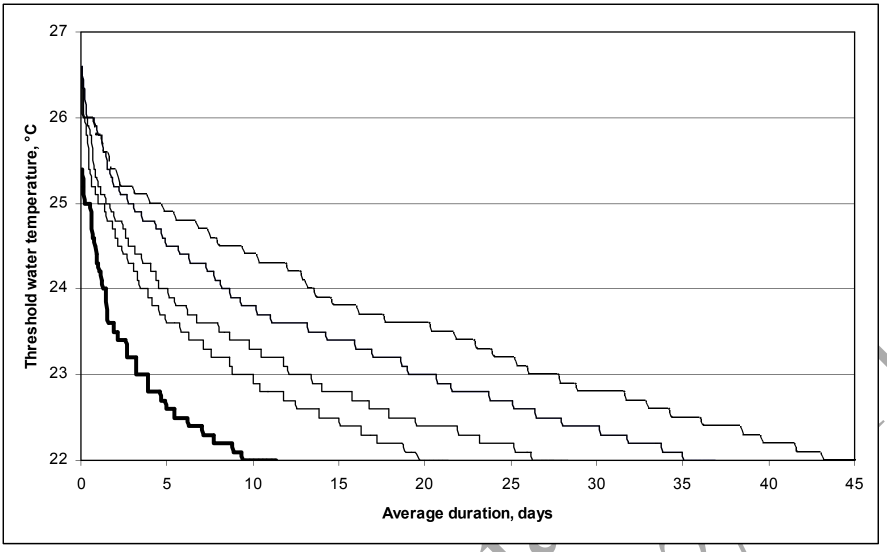

Figure 5. The expected change of average duration curves from present climate (fat line) to future climates (slight lines) supposing different rate of rise (from left to right 0,5, 1,0, 1,5, 2,0 °C respectively) in average summer temperature.

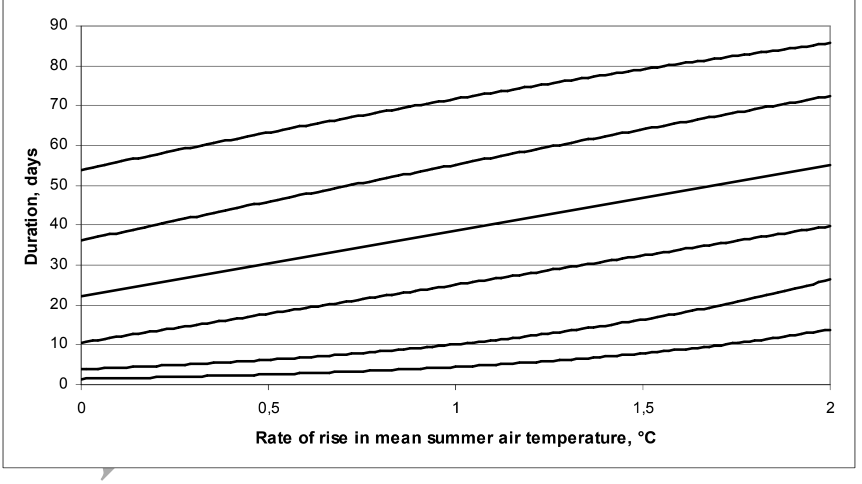

Figure 6. Change of duration with water temperature above given threshold (from 19 °C for upper line to 24 °C for down line) depending on the rate of rise in mean summer temperature.

Discussion

The analysis of historical records confirm that water temperature has been rise during the last decades. The rise is closely correlated with warming of climate, especially with increase of air temperature in summer months. The climate scenarios for Hungary predict further warming of climate, so the water temperatures are expected to be increased in future. In the paper a simple method was shown for prediction of expected change in daily water temperature. The method has some uncertainties. The greatest uncertainty is that climate analogy of predicted future climate in the past can be selected only limited uncertainty using the historical records. Despite the uncertainties we can conclude that increase in duration of days with water temperature above critical value would lead the worsening conditions for introduction of used cooling water from power station into the Danube River. Moreover, we can conclude if the climate would warm in the future the water temperature also would further rise and would have had an impact on the river ecology.

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