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THE IMPACT OF CHANGES IN AIR TEMPERATURE UPON THE THERMAL REGIME OF THE RIVER VISTULA IN TORUŃ (POLAND) OVER THE YEARS 1961-2012

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Abstract
The research examines changes in the thermal regime in the lower section of the River Vistula over the period of 52 years and the relationship between this phenomenon and the course of air temperature. The calculations were based on two tests, which led to drawing sounder conclusions on changes in water temperature in time series. It was found that the trend of the mean annual air temperature was positive (0.29°C·10^{-1} years). The same referred to the mean yearly water temperature (0.26°C·10^{-1} years). Both the trends are statistically significant. However, different values of the trends of water temperature changes, as well as ranges of extreme temperatures, were observed in the particular months and seasons of the year. Special attention was drawn to the big rate of the increase in the mean monthly minimum temperature in spring and summer (up to 0.85°C·10^{-1} years in May).

Keywords: water temperature, air temperature, climate change, Vistula River

1 INTRODUCTION

Temperature belongs to the most important properties of surface waters. Its values determine the course of most physical chemical and biological phenomena and processes taking place in rivers. Atmospheric conditions, then water volume and inflow, geological conditions, land relief and a type of the streambed with bottom sediments are among numerous factors affecting water temperature in rivers. Furthermore, in some cases it may also be influenced by anthropopressure. Factors influencing the temperature of river waters were discussed by Caissie (2006), among others. During climatic changes a series of studies aim to document their influence upon various elements of the natural environment, including fluvial waters. So far investigations have focused mainly on rivers running in the western and southern parts of Europe, in North America, and Australia. In most cases water temperature increased, though the rate of growth varied (e.g. the Danube 0.6°C·10^{-1} years alongside the mean increase in air temperature in Vienna 0.8°C·10^{-1} according to Pekarov et. al., 2008). Many research works claim the fastest increase in water temperature was observed during the cold season of the year. This, however, refers to rivers which do not freeze up during winters.

This work examines the scale of changes in the thermal regime prevailing in the lower (lowland) section of the River Vistula over the period of 52 years (1961-2012). It also looks at the relationship between this phenomenon and the course of air temperature. The calculations and analyses were conducted on the grounds of data coming from the hydrological station in Toruń, which is located at 735 kilometre of the river. At this point, the area of the Vistula drainage basin covers 181 000 km^2, and the mean flow is 986 m^3·s^{-1}. In winter there are ice phenomena in the river, often with the formation of the ice-cover. Taking this fact into account, the River Vistula differs from most rivers analysed in the professional literature with respect to changes in its thermal regime.

2 METHODS

This study was prepared on the grounds of the results of the measurements of water temperature in the River Vistula conducted in Toruń at 6 UTC every day and the values of the mean monthly air temperature recorded at the Toruń meteorological station in the years 1961-2012. The measurements were carried out by the Institute of Meteorology and Water Management – National Research Institute.

Statistical analyses accounted for the linear regression parametric test (Pearson's coefficient provided test statistics), and the Mann-Kendall non-parametric test (in which the Kendall's sum S divided by the root of variance served as test statistics).

$$S = \sum_{i=t}^{n} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i)$$

where sng(x) = 1 when x>0, 0 when x=0, when x<0

x – dentoes individual data series, n- denotes the total number of years in a time series.

The application of two tests made it possible to obtain a more convincing proof of undergoing changes in water temperature in a time series. If contrary results were obtained (one showing an existing trend and the other not) such a time series was considered without a trend. Out of all the time series such a situation occurred in 2 cases. A method of the rescaled adjusted partial sums (RAPS) of series in relation to the multiyear value was also applied.

$$\text{RAPS } Y_k = \sum_{t=1}^{k} \frac{x_t - \bar{x}}{\sigma_x} \qquad k \in (1,2,\ldots n)$$

x_t - element of the studied series, $\bar{x}$ - mean value of the studied series, σ_x - mean deviation of the series values, n- number of observations.

The RAPS method made it possible to detect trends and fluctuations in some fragments of a time series. Consequently, two fundamental sub-periods with different values of water temperature were distinguished: the years 1961-1986 with noticeably lower water temperature values, and the years 1987-2010 with higher values.

3 RESULTS

3.1 Air temperature

The analysed section of the River Vistula is located in the central part of the European Lowland, in the zone of the temperate climate (between maritime and continental climates). Over the years 1961-2012 the mean air temperature at the Toruń station was 8.1°C. The lowest yearly temperature (6.3°C) was recorded in 1965, whereas, the highest one (9.8°C) in 2000. July was the warmest month (with the mean value of 18.4°C), while January was the coldest (with the mean value of -2.2°C). In the particular years the values of the mean temperature in winter months varied significantly (Fig. 1).

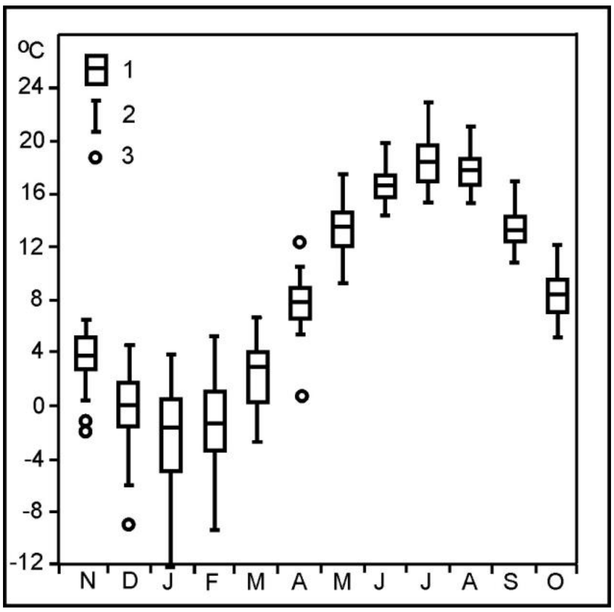

Figure 1. Differentiation of the monthly mean air temperature in Toruń over the years 1961-2012. Symbols: 1-range between first and third quartile; 2-range limited by 1 quartile deviation; 3-outliers under 1.5 quartile deviation

The difference between the mean temperature values recorded in January over the years 1961-2012 equalled 16.1ºC (from –12.2ºC in 1963 to 3.9ºC in 2007), and in February 13.1ºC (from –9.3ºC in 1986 to 3.9ºC in 1998 and 2002). On the other hand, the difference was definitely smaller in summer months. In August it was 5.9ºC, i.e. from 15.2ºC in 1987 to 21.1ºC in 2002. Over the analysed period a statistically significant positive trend of the mean yearly air temperature was observed (0.29ºC·10^{-1} years). Positive, and statistically significant, trends of the mean air temperature were also recorded in April, May, July and August, during the entire spring and summer seasons, in fact (Tab. 1).

Table 1. Monthly, seasonal and annual changes in the mean air temperature (ºC·10^{-1} years) over the years 1961-2012 (the values of statistically significant trends are underlined and in bold)

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Aut	Win	Spr	Sum	Year
0.04	0.30	0.51	0.31	0.43	<u>**0.51**</u>	<u>**0.34**</u>	-0.03	<u>**0.43**</u>	<u>**0.44**</u>	0.18	0.00	0.07	0.36	<u>**0.43**</u>	<u>**0.28**</u>	<u>**0.29**</u>

3.2 Water temperature

Over the years 1961-2012 the mean yearly water temperature in the River Vistula at the hydrological station in Toruń was 10.2ºC . Its lowest value (9.1ºC) was recorded in 1980 and its highest value (11.6ºC) was observed in 2007. The highest mean water temperature was noted in July (20.5ºC), whereas, the lowest value (0.9ºC) was observed in January and February. The values of the mean temperature showed rather small diversity (merely 1 - 2ºC) in winter months (January-February) of the particular years. However, in some years (1989, 1990, 2002, 2008) the mean monthly water temperature increased exceptionally up to 4.6ºC in January and February. Considerably bigger diversity was documented in March, May and July (Fig. 2). The mean yearly maximum water temperature in the River Vistula was 23.6ºC. Its biggest diversity (over 10ºC) was observed in March, April and May (Fig. 3). Similarly to air temperature, a statistically significant positive trend of the mean yearly water temperature (0.26ºC·10^{-1} years) was observed in the years 1961-2012. Statistically significant positive trends of the mean monthly water temperature were noted in December, April, May, July and August, during all the year seasons, in fact (Tab. 2).

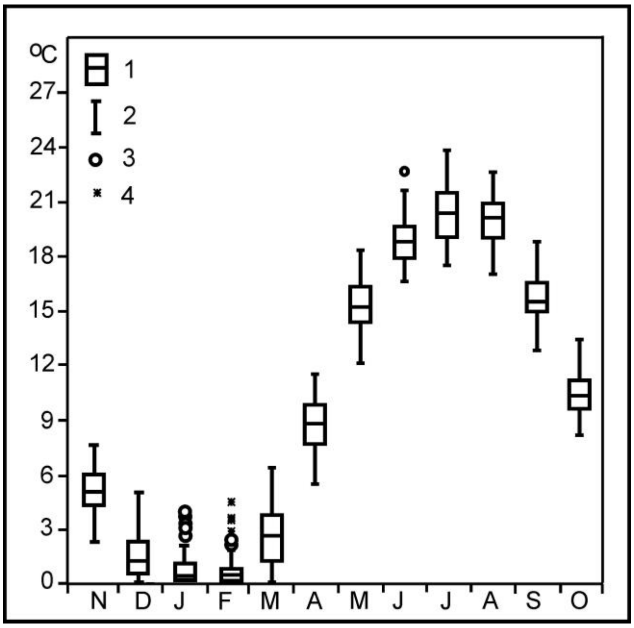

Figure 2. Differentiation of the monthly mean water temperature in Vistula River in Toruń over the years 1961-2012. Symbols: 1-range between first and third quartile; 2-range limited by 1 quartile deviation; 3-outliers under 1.5 quartile deviation; 4-extremes over 1.5 quartile deviation

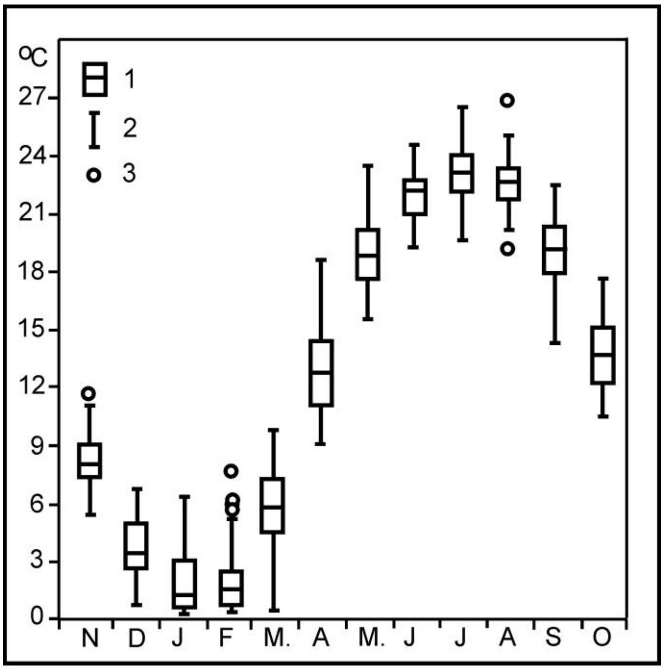

Figure 3. Differentiation of the monthly maximal water temperature in Vistula River in Toruń over the years 1961-2012. Symbols as in tab. 1

Table 2. Monthly, seasonal and annual changes in the mean temperature of the River Vistula water ($^oC \cdot 10^{-1}$ years) over the years 1961-2012 (the values of statistically significant trends are underlined and in bold)

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Aut	Win	Spr	Sum	Year
0.18	**0.22**	0.19	0.14	0.28	**0.36**	**0.45**	0.12	**0.39**	**0.46**	0.20	0.17	**0.18**	**0.18**	**0.36**	**0.32**	**0.26**

The biggest increase in water temperature in the Vistula occurred in the case of the mean monthly minimum temperature, particularly in spring and summer (Tab. 3). In May the positive trend reached the record value of $0.85^oC \cdot 10^{-1}$ years, and in August it was slightly lower ($0.67^oC \cdot 10^{-1}$ years). Considerably lower values of water temperature increase were recorded in the case of the mean monthly maximum water temperature. Its biggest increase took place in March ($0.51^oC \cdot 10^{-1}$ years), then in April, May and October, that is only in four months of the year (Tab. 3).

Table 3. Monthly and annual changes in the mean monthly minimum and maximum temperature of the River Vistula water ($^oC \cdot 10^{-1}$ years) over the years 1961-2012 (the values of statistically significant trends are underlined and in bold)

Water temperature	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Year
Minimal	0.25	0.11	0.00	0.03	0.08	**0.59**	**0.85**	**0.49**	**0.50**	**0.67**	**0.45**	0.13	0.00
Maximal	0.12	0.21	0.27	0.30	**0.51**	**0.43**	**0.33**	-0.19	0.15	0.23	0.16	**0.38**	0.14

In the course of the mean yearly water temperature in the Vistula over the years 1961-2012 two sub-periods can be distinguished . The first period covers the years 1961-1986, and does not show any significant changes in the course of the mean yearly water temperature, whereas the other period (after 1987) was very noticeable with the average increase rate of $0.44^oC \cdot 10^{-1}$ years (Fig. 4). The occurrence of two sub-periods with different values of water temperature can be proven by the results of the analysis carried out by a method of accumulated differences of the mean yearly temperature from the mean value for the multiyear period 1961-2012. From 1961 to 1986 water temperature was observed to decline with respect to the mean value for the entire study period. In 1987 the trend changed due to the increase in water temperature (Fig. 5).

As a result, the mean temperature of the River Vistula was higher by 1.1^oC at the end of the second period (1987-2012) as compared to the first period (1961-1987).

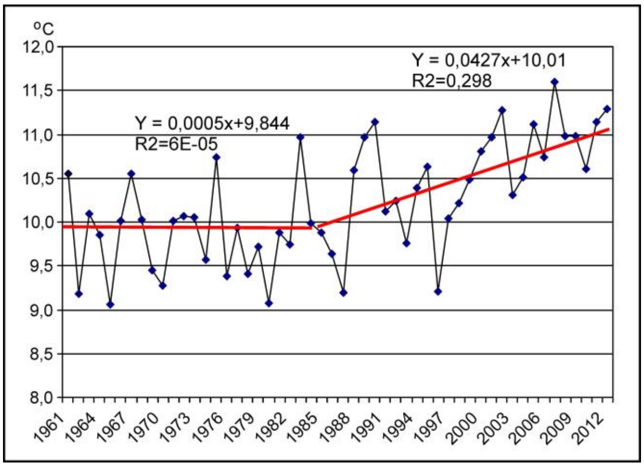

Figure 4. Course of the mean yearly water temperature in Vistula River in Toruń over the years 1961-2012

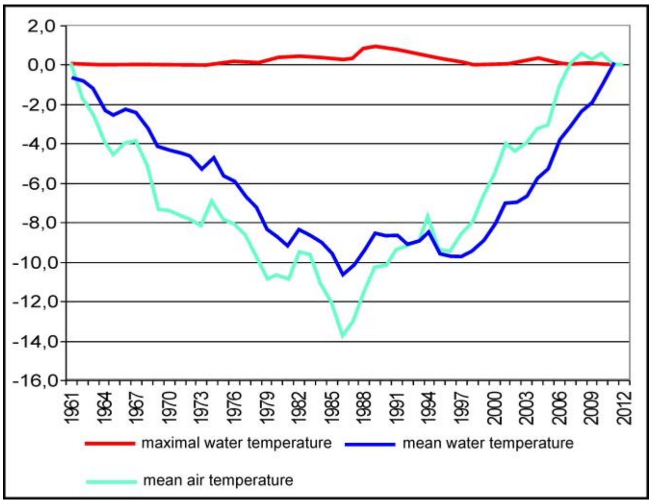

Figure 5. Accumulated deviations of the maximal yearly water temperature, mean yearly water temperature and mean yearly air temperature from the period 1961-2012

4 DISCUSSION

Undoubtedly, air temperature constitutes the main factor determining the increase in water temperature in rivers (Webb et al., 2003). This dependence was tested through the analysis of the relationships between air temperature and water temperature. The correlation between air and water temperature was found to be high, and equaled (depending on a studied period) from r = 0.58 to r = 0.91. The values are most often higher than r = 0.80 (Tab.4). The presented results of the analyses and calculations lead to a conclusion that apart from the unquestionable increase in water temperature of the River Vistula, air temperature also has miscellaneous influence upon water temperature in the particular seasons of the year. Its smallest influence is marked in winter when ice phenomena occur in the river, including the formation of the ice cover. During winter there is little diversity of water temperature, whereas air temperature varies significantly (see Fig. 1). The currently observed increase in air temperature during winter occurs mainly in the range of its negative values. Therefore, this does not lead to the increase in water temperature. More and more frequently there were sudden water temperature increases of even up to 4 and 5^{o}C during the so-called "warm winters", particularly at the turn of the 20th and 21st centuries (see Fig. 2). If air temperature increases further in the winter season, the thermal regime of the River Vistula and other rivers flowing in the transitional zone of the temperate climate is likely to change considerably.

Table 4. Correlation between the mean air temperature and water temperature in a particular month, season, and a year

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Aut	Win	Spr	Sum	Year
0.77	**0.70**	**0.58**	**0.71**	**0.90**	**0.64**	**0.84**	**0.85**	**0.95**	**0.84**	**0.82**	**0.83**	**0.78**	**0.70**	**0.91**	**0.91**	**0.81**

Over the years 1961-2012 the mean rate of the increase in water temperature in the River Vistula was 0.26ºC $\cdot 10^{-1}$ years, whereas in the shorter time period (1987-2012) it was as much as 0.44ºC$\cdot 10^{-1}$. Similar values were obtained in the case of other rivers, though it seems they depended on the length of the study period. For a comparison, in the period 1901 – 1990 in several rivers in Austria, including the River Danube, the increase in water temperature was from 0.05 to 0.11ºC$\cdot 10^{-1}$ years on average (Webb&Nobilis, 1995). In the years 1977 – 1990 the increase in water temperature the rivers in the Devon County ranged from 0.29 to 0.74 ºC$\cdot 10^{-1}$ years (Webb & Walling, 1992). Up to now the fastest rate of water temperature increase was recorded in the River Itchen (United Kingdom) in the years 1980 – 2006, which rose to 0.50ºC/10 years in winter, and 1.04ºC/10 years in summer (Durance and Omerod, 2007). In some areas water temperature in rivers did not rise, among others in the plain rivers flowing in Scotland (Langan et al., 2001).

In the case of the River Vistula the increase in water temperature was most noticeable in spring and summer months. It must be underlined, however, the rate of the increase in water temperature was slightly lower than air temperature, which results from bigger thermal stagnancy of water. Documenting the considerable increase rate of the mean monthly minimum temperature during spring and summer is undoubtedly among the most interesting effects of the investigations (see Tab. 3). The phenomenon proves a general assumption of a faster arrival of spring and summer in this part of Europe, as well as of undergoing climatic changes.

5 CONCLUSION

The thermal regime of rivers may be a good indicator of climatic changes occurring in a particular region. However, the analysis of the course of temperature in long time series must account for the possibility of various tendencies of the changes (or lack of changes) in shorter periods of time. In the case of the River Vistula nearly all changes in the thermal regime are the effect of nearly 30 years, i.e. the period starting from 1987.

The rate of the growth of water temperature in the Vistula varies significantly in the particular seasons of the year. The lowest rate of water temperature increase is recorded in winter and early spring. This phenomenon seems to be particularly characteristic of the rivers flowing in the temperate climatic zone, especially in the transitional and cold zone. In winter ice phenomena often develop in the rivers. Therefore, the rivers in the central part of the European Lowland differ from the rivers flowing in the western and southern parts of Europe.

REFERENCES

Caissie, D. 2006, The thermal regime of rivers: a review. *Freshwater Biology*, **51**, 1389-1406, DOI: 10.1111/j.1365-2427.2006.01597.x.

Durance I. & Omerod S.J. 2007, Climate change effects on upland stream macroinvertebrates over a 25-year period, *Global Change Biology*, **13**:5, 942-957, DOI: 10.1111/j.1365-2486.2007.01340.x.

Langan S.J., Johnston L., Donaghy M.J., Youngson A.F., Hay D.W., & Soulsby C. 2001, Variation in river water temperatures in an upland stream over a 30-year period, *The Science of the Total Environment*, **265**, 195-207, DOI:10.1016/S0048-9697(00)00659-8.

Webb B.W., Clack PD & Walling DE. 2003. Water-air temperature relationships in a Devon river system and the role of flow. *Hydrological Processes* 17 (15): 3069 – 3084.

Webb B.W. & Nobilis F. 1995, Long term water temperature trends in Austrian rivers, *Hydrological Sciences-Journal*, **40**:1, 83-96.

Webb, B.W. & D.E. Walling. 1992. Long term water temperature behaviour and trends in a Devon, UK, river system. *Hydrological Sciences* 37: 567-580.