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# The Influence of Reservoirs on Water Temperature in the Downstream Part of an Open Watercourse: A Case Study at Botovo Station on the Drava River

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**Abstract:** The air temperature trends measured at the central meteorological station Varaždin and the water temperature measured at the Botovo station on the Drava River were analyzed from 1 January 1969 to 31 December 2021. Analyses were performed for three different time scales: year, month, and day. Mann–Kendall testing statistically determined the significant trends over the analyzed period and found increasing air and water temperatures. From 1975 to 1989, three reservoirs of different volumes and water surface areas were built. The Botovo water measuring station is 11 km from the third largest reservoir and 28 km from the mouth. Applying the day-to-day (*DTD*) method, we determined that the variations in the daily air temperatures are significantly higher than the simultaneous variations in the daily water temperatures. Also, the rise in water temperatures at the downstream water measuring station Botovo was influenced by the construction of reservoirs. The commissioning of the second reservoir in 1982 caused a significant rise in water temperature at the Botovo station. Trends in water temperature increase during all months of the year were statistically significant, while air temperature trends were statistically significant during the warm parts of the year.

**Keywords:** air temperature; day-to-day temperature variability; lower Drava River (Croatia); water temperature

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## 1. Introduction

We are in a time of global climate change, which has most clearly manifested as an increase in air temperature. This process, which has been intensifying in recent decades, mainly causes negative consequences on numerous aspects of the environmental and social systems. It causes an increase in water temperature in open watercourses, which represent vital and vulnerable ecosystems. Open watercourses are the lifeblood of landscapes and watersheds [1]. The consequences of warming the water in open watercourses are felt in the ecosystems connected with them but are also reflected through human activity in numerous socio-social processes.

When analyzing water temperature variations in open watercourses, it is essential to consider the fact that they are most significantly affected by groundwater inflow, evaporation, return water radiation, atmospheric radiation, solar radiation, and vegetative-topographic radiation. The listed factors are responsible for about 90% of the heat flow in rivers (e.g., [2–4]). Apart from global warming, some of the listed properties can be significantly affected by anthropogenic interventions, such as the construction of dams and the formation of reservoirs, as well as the regulation of watercourse beds, the pumping of groundwater, and changes in land use around watercourses, etc.

Changes in the water temperature of open watercourses represent one of the most significant indicators of changes in the environment. Water temperature significantly affects numerous physical properties and chemical and biochemical reactions in the river system. Its influence is particularly significant on water quality and, as a consequence, on biological processes (e.g., [5,6], etc.). The development, distribution, and ecology of aquatic organisms depend on the water temperature in open watercourses [7,8]. The life cycle of river organisms is regulated by the temperature of the river water in combination with hydrological and hydraulic conditions. Water temperature and day length affect the coordination of egg laying, the maturation of larvae, and the protection and development of adults in open watercourses. Aquatic plant and animal species develop depending on the water temperature regime. Since the building of dams can significantly impact downstream water quality and quantity, it is obligatory to control the flow and minimize the water temperature concerning spillway operations. Advanced machine learning is suitable for such analysis [9] due to its suitability.

Interest in studying the impact of the development of water temperature processes in open watercourses concerns numerous ecological and other aspects that have proliferated in recent decades (e.g., [10–20], etc.). Open watercourses are under pressure from global climate change and aggressive and poorly controlled anthropogenic interventions. The impossibility of observing the minimum biological flow, as well as the minimum required water flow/level, does not contribute to the ecological functioning of the ecosystem. An increase in water temperature in open watercourses can potentially cause several negative consequences, some of which will be listed below. Natural and anthropogenic interventions cause a reduction in the flow of small waters and an extension of the drying period in numerous open watercourses. In these cases, the increase in water temperature affects the deterioration of water quality and the habitats associated with it and reduces the possibility of using water for human needs. Reducing the flow of water causes more intensive heating affect from the dilution capacity, which reconciles the concentration of pollutants entering the watercourse. An increase in water temperature reduces the ability to dissolve oxygen and increases the toxicity of contaminants (for example, heavy metals and organophosphates) for fish and other species that live in the freshwater of open watercourses. Freshwater organisms may be exposed to increased stress, especially during low summer water. The concentration of microbiological pollutants can be increased, affecting the cost of treatment for drinking water production.

This paper analyzes the changes in water temperature over various time scales (year, month, and day) of the Drava River, measured at the water measuring station Botovo from 1969–2021. The work aims to establish how and to what extent the rising air temperature influenced the trend of rising water temperatures and at what time the construction of the three reservoirs upstream at the water measuring station Botovo occurred. The authors of [21] applied an artificial neural network method to model the Drava River's relationship between water and air temperature [22]. They used the neural network method to forecast the daily water temperatures of the Drava River at the Botovo and Donji Miholjac stations. Analyzing a series of water temperatures on rivers in the Danube basin in Croatia [23] pointed to a significant rise in water temperatures along the lower, lowland course of the Drava River, beginning at the end of the 1980s. The authors of [24] used linear regression, stochastic modeling (or nonlinear regression), and multilayer perceptron (MLP) feed-forward neural networks to analyze the connection between the mean daily water temperature of the Drava River and the mean daily air temperature. Mean daily air temperatures were taken from the meteorological stations of Koprivnica, Virovitica, Donji Miholjac, and Osijek. Average daily water temperatures of the Drava River were taken from the hydrological measuring stations Botovo, Terezino Polje, Donji Miholjac, and Osijek. The authors determined that the multilayer perceptron (MLP) feed-forward neural network model best estimates and predicts the mean daily water temperatures of the Drava River.

The above is the motivation for finding a suitable method by which the connections of the mentioned temperatures will be reliably defined, taking into account natural and anthropogenic influences, which are inevitable and not always easy to detect, i.e., to take directly. For this purpose, day-to-day (*DTD*) methodology was applied. Such a method was not applied to the analyzed locations, i.e., the analyzed case study regarding the analysis of the average air and water temperature.

## 2. Materials

The Drava River rises in the Dolomites (Italian Alps) at an altitude of 1228 m above sea level (m asl). It is interesting to note that in various literary sources, the length of the Drava River is reported to be between 725 km and 750 km, resulting from numerous engineering operations carried out on its course during the last two centuries. The Drava River connects the Alps with the Pannonian Plain [25]. From the source to the mouth of the Danube, in addition to a large number of regulatory interventions, a total of 22 hydropower plants with associated dams and reservoirs have been built so far, which has significantly influenced the change in its natural hydrological, thermal, and ecological regime. From a hydrological point of view, it is possible to define the following three sections of the Drava River: (1) the upper, upstream, mountainous section, where most dams and reservoirs are built; (2) the middle part of the course where the Drava receives the most tributaries; (3) the lower, downstream, lowland part of the stream.

This paper will analyze the changes in water temperature measured at the water measuring station Botovo from 1969 to 2021. The station is located in the lower, downstream, lowland section of the Drava. Figure 1 shows the analyzed part of the Drava stream with the indicated positions: (1) hydroelectric power plant (HE1, HE2, HE3); (2) associated reservoirs (A1, A2, A3); (3) main meteorological stations (GMP) Varaždin (altitude: 167 m asl, latitude: 46°16′58″, longitude: 16°21′50″); (4) water measuring station Botovo (altitude 121.55 m asl).


**Figure 1.** (**a**) Map of the analyzed area (purple ellipse) with marked positions for the reservoirs: A1, A2, A3, hydroelectric power plant: HE1, HE2, HE3, (**b**) central meteorological station (GMP) Varaždin, (**c**) the water measuring station (VP) Botovo on the Drava River, with their pictures [26–28].

Table 1 lists the aerial distances between individual localities used in the analyses performed in this paper. It should be noted that the shortest aerial distance is between the most oversized reservoir, A3, and the water measuring station, Botovo. In comparison, the distance measured along the Drava riverbed is significantly longer and amounts to 28 km.

**Table 1.** Aerial distances between individual locations.

| L (km) | Drava Botovo | GMP Varaždin | A1 | A2 | A3 |
|---|---|---|---|---|---|
| Drava Botovo | - | 29 | 36 | 22 | 11 (28 *) |
| GMP Varaždin | | - | 16 | 3.2 | 18 |
| A1 | | | - | 9.8 | 26.8 |
| A2 | | | | - | 5.2 |
| A3 | | | | | - |

Since the paper examines the influence of the reservoirs on the change in water temperature in the Drava at the water measuring station Botovo, Table 2 lists the essential characteristics (start of operation, volume, water surface area, and maximum level).

**Table 2.** Basic characteristics of reservoirs on the Drava are shown in Figure 1.

| | A1 | A2 | A3 |
|---|---|---|---|
| Starting of the work (years) | 1975 | 1982 | 1989 |
| Volume ($10^6$ $m^3$) | 8.0 | 51.0 | 93.5 |
| Area ($km^2$) | 3.0 | 10.5 | 16.6 |
| Max. altitude (m asl) | 191.0 | 168.0 | 149.6 |

The construction of the dams and the reservoirs formed by them (and the operation of hydroelectric power plants) significantly influenced the change in the sediment transport regime [29]. On the downstream stretch of the Drava River, at about 150 km, the flow of suspended sediment has been drastically reduced [3,26].

Data on air temperatures at the central meteorological station Varaždin and water temperature and flow at the water measuring station Botovo were obtained from the State Hydrometeorological Institute in Zagreb.

## 3. Methods

Linear trends were calculated for the available time series of air temperature GMP Varaždin, water temperature, and flow of the Drava near Botovo. The linear trend equation is defined as:

$$T = (a \times t) + b \quad (1)$$

where $T$ represents the mean monthly or annual value of the analyzed parameter in the year, $t$, while $a$ and $b$ are linear regression coefficients calculated by the least squares method; the coefficient $a$ represents the slope of the regression line, for which the dimension is °C during the analyzed time. As such, it is an indicator of the average intensity of the trend of rising or falling values of the analyzed series. For the linear trends, the squared values of the linear correlation coefficients, $R^2$, were also calculated. The sign of the linear correlation coefficient, $R$, indicates the direction of the linear relationship. A negative value indicates the trend is decreasing, while a positive value indicates an increasing trend.

The statistical significance of linear trends was checked by the Mann–Kendall (M-K) nonparametric test [30,31]. The Mann–Kendall package for Python was used in [32]. The null hypothesis for this test is that there is no statistically significant monotonic trend in the analyzed time series. An alternative hypothesis is that there is a trend. In this paper, the probability value, $p < 0.01$, was used as a criterion for accepting the alternative hypothesis (the existence of a statistically significant linear trend).

$F$-testing and $t$-testing [33] were used to determine the statistical significance of the differences between the average values of two adjacent subperiods. The $F$-test was used to test the equality of variances of the two normally-distributed populations (two subsets). In contrast, the $t$-test was used to assess whether the two time subsets' average values were statistically (significantly) different. In both tests, a probability value of $p < 0.01$ was chosen as the level for accepting the hypothesis, meaning that the average values of the subseries are statistically significantly different.

When analyzing temperature variation during consecutive days within a year, the article used the day-to-day (*DTD*) method (e.g., [34–46]). The technique is used to detect subtle variations in air temperature that occur as a result of numerous natural and mainly anthropogenic factors, such as climate change, urbanization, land use change, industrialization, change in local hydrological conditions due to the construction of dams, the formation of reservoirs, etc. By comparing them, it is possible to determine the differences in the reaction of these two media to the factors that occur in the analyzed area shown in Figure 1.

The article uses the following equation for the calculation of the *DTD* variations of air and water temperatures:

$$DTD = \Sigma \mid T_i - T_{i-1} \mid /(n - 1) \quad (2)$$

where Σ denotes the sum of all included *n* data, and represents a counter of the days during the considered time, and ∣ ∣ indicates the absolute value of the difference in daily air or water temperatures. The *DTD* variations of mean daily air temperatures measured at GMP Varaždin, $T_V$, and daily Drava water temperatures measured at the water measuring station Botovo, $T_{DB}$, from 1 January 1969 to 31 December 2021, were calculated.

The so-called Day-to-Day (*DTD*) method quantifies subtle climatic variations in temperatures between two adjacent days over one year. The method is considered very useful for analyzing climate variability. It has been shown that changes in *DTD* values over time can significantly affect various ecological and social processes. As the process of global warming intensifies, the *DTD* method has a particular quantitative definition and explains the causes and possible consequences of climate processes. Understanding the *DTD* variety in daily air and water temperatures over the analyzed period (1969–2021) at the GMP Varaždin and water measuring station Botovo can be helpful for more effective preparation for the near future climatic and other changes in the analyzed region, especially on the Drava River itself.

## 4. Results

### *4.1. Year as a Time Increment of Analysis*

#### 4.1.1. Air and Water Temperature

Columns 1, 2, and 3 of Table 3 list the characteristic annual values (minimum, average, and maximum), the linear correlation coefficient squares, $R^2$, the Mann–Kendall test probabilities, $p$, the series of yearly water temperatures of the Drava near Botovo, $T_{DB}$, the series of air temperature GMP Varaždin, $T_V$, and the series of their differences, $\Delta T = T_{DB} - T_V$, measured in the period 1969–2021.

Figure 2 shows a series of mean annual water temperatures for the Drava River, measured at the station Botovo (blue color), $T_{DB}$, and air temperatures measured at GMP Varaždin (green color), $T_V$, from 1969–2021. The regression lines are plotted with their numerical values and the squared values of the linear correlation coefficients, $R^2$. The MK test confirms that the growth trends are statistically significant in both series since the probabilities are $p < 0.01$. The direction of increasing water temperature is observed to be greater than the trend of rising air temperature.

Figure 3 shows the differences in mean annual water and air temperature, $\Delta T = T_{DB} - T_V$, from 1969 and 2021. This presentation indicates a significantly different development of the analyzed temperatures during a period of 53 years (1969–2021).

**Table 3.** Characteristic (minimum, average, maximum) annual values, squares of linear correlation coefficient of series, $R^2$, probabilities of the Mann–Kendall test, $p$, series of yearly water temperatures of the Drava near Botovo, $T_{DB}$, series of air temperature GMP Varaždin, $T_V$, series of their differences, $\Delta T = T_{DB} - T_V$, series of Day-to-Day water temperature of the Drava near Botovo, $DTD_{DB}$, series of Day-to-Day air temperature of GMP Varaždin, $DTD_V$, series of their differences, $\Delta D_{TD} = (DTD_V - DTD_{DB})$, series of mean flows of the Drava near Botovo, $Q$, in the period 1969–2021.

| | $T_{DB}$ | $T_V$ | $\Delta T$ | $DTD_{DB}$ | $DTD_V$ | $\Delta DTD$ | $Q$ |
|---|---|---|---|---|---|---|---|
| | °C | | | | | | m$^3$/s |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **minimum** | 8.85 | 8.98 | −0.81 | 0.17 | 1.59 | 1.12 | 327 |
| **average** | 10.99 | 10.67 | 0.32 | 0.045 | 1.95 | 1.49 | 490 |
| **maximum** | 13.04 | 12.31 | 1.15 | 0.65 | 2.31 | 2.15 | 739 |
| $R^2$ | 0.7253 | 0.5833 | 0.1668 | −0.542 | 0.0428 | 0.329 | −0.0146 |
| $p$ | $p < 0.01$ | $p < 0.01$ | $p < 0.01$ | $p < 0.01$ | $p > 0.01$ | $p < 0.01$ | $p > 0.01$ |

Note(s): Cases where the analyzed sequences show a statistically significant trend at the $p < 0.01$ level are marked with a yellow background.

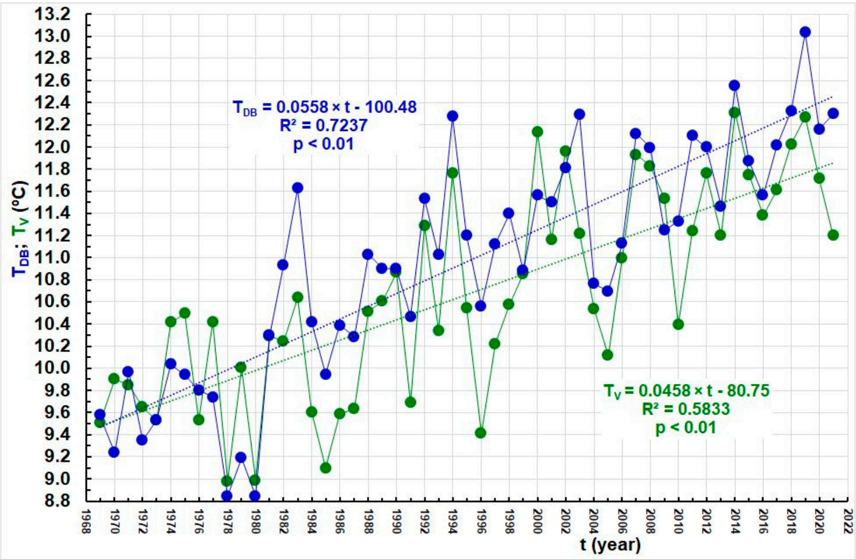


**Figure 2.** Series of mean annual water temperatures of the Drava at the station Botovo, $T_{DB}$, and air temperatures at the GMP Varaždin, $T_V$, from 1969–2021.

In the subperiod from 1969–1981, the mean annual air temperatures were, on average, 0.247 °C higher than the water temperatures, and the differences ranged between −0.814 °C (1979) and 0.273 °C (1976). The situation changed drastically in the recent subperiod from 1982–2021, when water temperatures, on average, became higher than air temperatures by 0.507 °C; the differences ranged from 0.028 °C (1999) to 1.151 °C (1996). During this subperiod, the mean annual water temperatures were consistently higher than the mean annual air temperatures.

Figure 4 shows two subseries of mean annual water temperatures of the Drava at the station Botovo, $T_{DB}$, and air temperatures at the GMP Varaždin, $T_V$, for the two previously defined subperiods: (1) 1969–1981 and (2) 1982–2021. In the first subperiod (1969–1981), a statistically insignificant downward trend can be observed for both of the analyzed subseries. In the recent subperiod (1982–2021), statistically significant increases in water and air temperature are observable, with the subrange of water temperature being slightly higher than those of the subrange of air temperature.

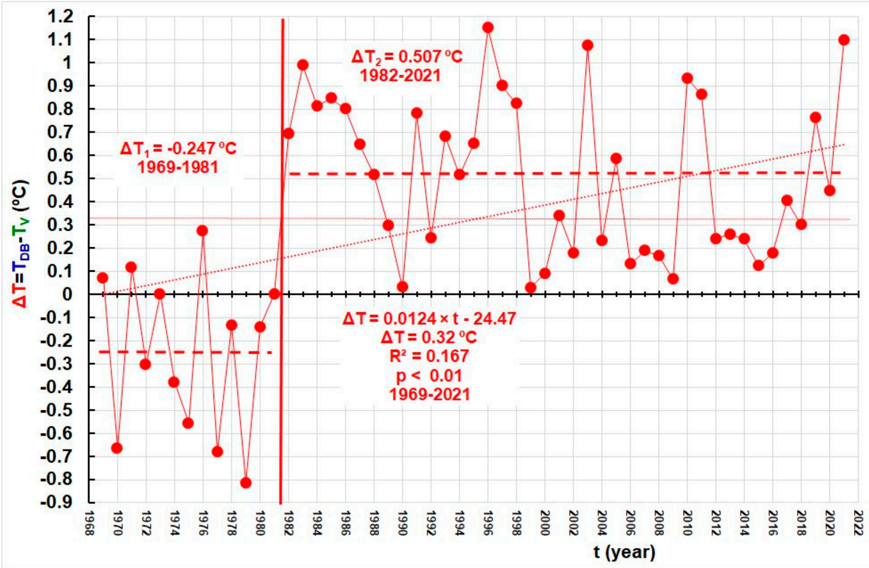


**Figure 3.** Series of differences in mean annual water and air temperatures, $\Delta T = T_{DB} - T_V$, from 1969–2021.

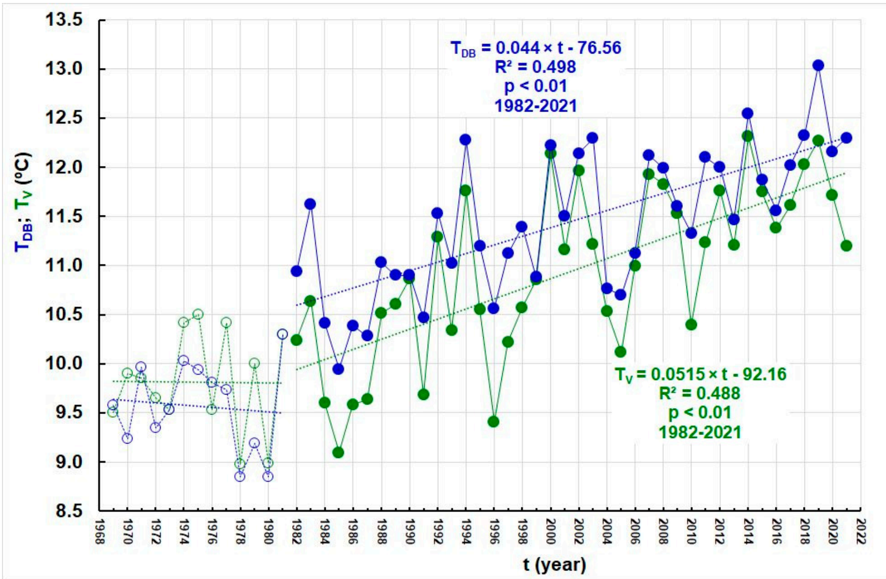


**Figure 4.** Two subseries of mean annual water temperatures of the Drava at the Botovo station, $T_{DB}$, and air temperatures at the GMP Varaždin, $T_V$, during the subperiods (1) 1969–1981 and (2) 1982–2021.

### 4.1.2. Day-to-Day (*DTD*) Method

Columns 4, 5, and 6 of Table 3 contain the values for the minimum, average, and maximum annual series, day after day, for water temperature, $DTD_{DB}$, air temperature, $DTD_V$, their differences, $\Delta DT_D$, the squares of the linear correlation coefficient, $R^2$, and Mann–Kendall test probabilities, $p$, from 1969–2021. Graphical representations of a series of annual values of *DTD* of the water temperatures measured at the water measuring station Botovo (blue color), $DTD_{DB}$, annual values of *DTD* for the air temperatures measured at GMP Varaždin (green color), $DTD_V$, and their differences (red color), $\Delta DTD = DTD_{DB} - DTD_V$, from 1 January 1969–31 December 2021, are shown in Figure 5. Lines of linear regression are drawn for each series, and their analytical expressions, squares of correlation coefficients ($R^2$), are also presented.

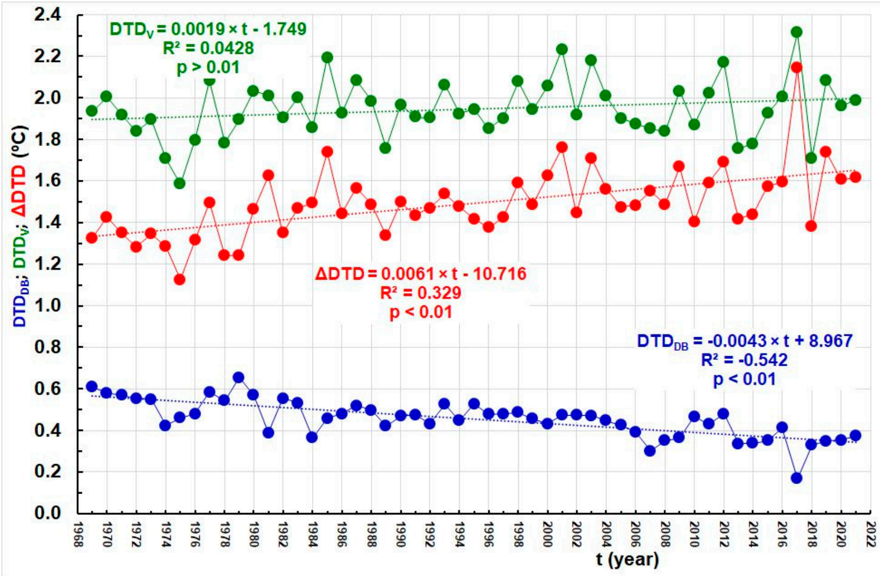


**Figure 5.** Series of annual values of water temperatures day-to-day, $DTD_{DB}$, air temperature, day after day, $DTD_V$, and their differences, $\Delta DTD = DTD_{DB} - DTD_V$, from 1969–2021.

The $DTD_V$ values for air are significantly higher than the $DTD_{DB}$ values for water, which is understandable given that they are different media. However, what is important to note is that the trend of the $DTD_V$ series (of air temperature) shows a statistically insignificant increase ($p > 0.01$), while the trend of the $DTD_{DB}$ series (of water temperatures) shows a statistically significant increase ($p < 0.01$). The result is that the trend of their differences, ΔDTD, shows a statistically significant increase ($p < 0.01$). From this, it can be concluded that the Drava water downstream of the reservoirs heats up faster than the surrounding air, which indicates a need for careful monitoring and explanation of this process, which could have negative consequences in the low-lying part of the Drava River downstream of the A3 reservoir.

### *4.2. A Month as a Time Increment of Analysis*

The more subtle behavior of the relationship between the analyzed temperatures will be performed in this subchapter by using the month as the time increment of analysis. Table 4 shows the characteristic monthly values (minimum, average, and maximum) of the series of mean monthly water temperatures of Drava Botovo, $T_{DB}$, the series of mean monthly air temperatures of Varaždin, $T_V$, and the series of their differences, $\Delta T = T_{DB} - T_V$, from 1969–2021.

From the graphic representation in Figure 6, it is possible to see that, during the period from 1969–2021, the average air temperatures at GMP Varaždin, $T_V$, were higher than the average water temperatures at the water measuring station Botovo, $T_{DB}$, from April to August, while they were lower in the period from September to March. In June, the air temperatures were, on average, 2.11 °C higher, while in December, they were 2.40 °C lower.

Table 5 shows the values of the square of the correlation coefficient, $R^2$, and the probability of the Mann–Kendall test, $p$, for the series of mean monthly water temperatures of Drava Botovo, $T_{DB}$, the series of mean monthly air temperatures of Varaždin, $T_V$, and the series of their differences, $\Delta T = T_{DB} - T_V$, from 1969–2021.

**Table 4.** Characteristic monthly values (minimum, average, and maximum) of the series of mean monthly water temperatures of Drava Botovo, $T_{DB}$, the series of mean monthly air temperatures of Varaždin, $T_V$, and the series of their differences, $\Delta T = T_{DB} - T_V$, from 1969–2021.

| | $T_{DB}$ | | | $T_V$ | | | $\Delta T$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Min.** | **Aver.** | **Max.** | **Min.** | **Aver.** | **Max.** | **Min.** | **Aver.** | **Max.** |
| **January** | 0.1 | 2.49 | 6.6 | −6.0 | 0.17 | 5.8 | −1.2 | 2.32 | 6.9 |
| **February** | 0.4 | 3.45 | 7.5 | −4.5 | 1.92 | 7.1 | −1.1 | 1.53 | 5.7 |
| **March** | 3.5 | 6.21 | 9.4 | 0.4 | 6.10 | 9.9 | −2.7 | 0.11 | 3.1 |
| **April** | 7.2 | 10.17 | 13.0 | 8.0 | 10.83 | 15.1 | −3.4 | −0.66 | 1.7 |
| **May** | 10.9 | 14.03 | 16.7 | 12.2 | 15.67 | 18.7 | −3.8 | −1.64 | 0.7 |
| **June** | 14.5 | 17.08 | 21.3 | 16.7 | 19.19 | 23.8 | −4.0 | −2.11 | −0.6 |
| **July** | 15.5 | 19.23 | 22.4 | 17.8 | 20.80 | 23.0 | −3.5 | −1.57 | 0.9 |
| **August** | 16.3 | 19.59 | 23.5 | 16.3 | 20.00 | 24.5 | −2.5 | −0.42 | 1.7 |
| **September** | 12.9 | 16.33 | 19.5 | 12.3 | 15.56 | 18.4 | −1.8 | 0.77 | 5 |
| **October** | 8.1 | 11.90 | 15.7 | 6.6 | 10.46 | 13.8 | −0.3 | 1.44 | 4.1 |
| **November** | 3.5 | 7.35 | 10.3 | 0.8 | 5.56 | 9.5 | −2.0 | 1.79 | 5.1 |
| **December** | 0.3 | 3.65 | 6.2 | −3.2 | 1.25 | 4.7 | −0.5 | 2.40 | 5.2 |

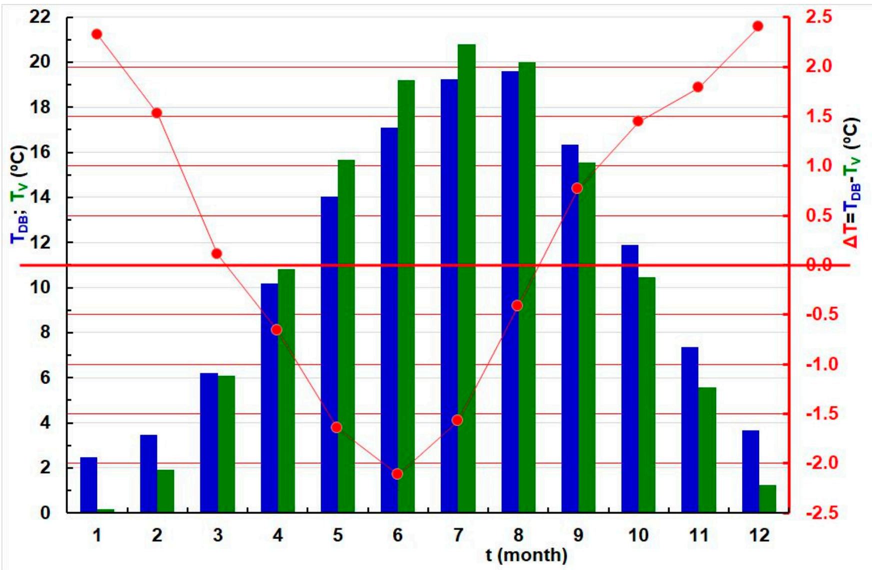


**Figure 6.** Histograms of the average monthly water temperatures of the Drava at the Botovo station (blue color), $T_{DB}$, and the air temperatures of Varaždin (green color), $T_V$, with a line graph of their differences (red color), $\Delta T = T_{DB} - T_V$, from 1969–2021.

It is important to note that increasing trends were observed in all months for all three analyzed parameters. However, while the increasing trends are statistically significant for all months with regards to the water temperature series, $T_{DB}$, for the air temperature series, they are statistically insignificant in February, March, May, and September. The squares of the linear correlation coefficients, $R^2$, for the water temperature series are significantly higher than those for the air temperatures in all months except June and July. The series of monthly differences in all months show a slight and statistically insignificant upward trend, except for the month of September.

**Table 5.** Values of the square of the correlation coefficient, $R^2$, and the probability of the Mann–Kendall test, $p$, for the series of mean monthly water temperatures of Drava Botovo, $T_{DB}$, the series of mean monthly air temperatures of Varaždin, $T_V$, and the series of their differences, $\Delta T = T_{DB} - T_V$, from 1969–2021.

| | $T_{DB}$ | | $T_V$ | | $\Delta T$ | |
|---|---|---|---|---|---|---|
| | $R^2$ | $p$ | $R^2$ | $p$ | $R^2$ | $p$ |
| January | 0.419 | $p < 0.01$ | 0.089 | $p < 0.01$ | 0.088 | $p > 0.01$ |
| February | 0.235 | $p < 0.01$ | 0.054 | $p > 0.01$ | 0.007 | $p > 0.01$ |
| March | 0.268 | $p < 0.01$ | 0.081 | $p > 0.01$ | 0.028 | $p > 0.01$ |
| April | 0.542 | $p < 0.01$ | 0.323 | $p < 0.01$ | 0.041 | $p > 0.01$ |
| May | 0.194 | $p < 0.01$ | 0.037 | $p > 0.01$ | 0.096 | $p > 0.01$ |
| June | 0.286 | $p < 0.01$ | 0.407 | $p < 0.01$ | 0.090 | $p > 0.01$ |
| July | 0.312 | $p < 0.01$ | 0.441 | $p < 0.01$ | 0.000 | $p > 0.01$ |
| August | 0.304 | $p < 0.01$ | 0.286 | $p < 0.01$ | 0.008 | $p > 0.01$ |
| September | 0.264 | $p < 0.01$ | 0.088 | $p > 0.01$ | 0.148 | $p < 0.01$ |
| October | 0.463 | $p < 0.01$ | 0.212 | $p < 0.01$ | 0.061 | $p > 0.01$ |
| November | 0.546 | $p < 0.01$ | 0.113 | $p < 0.01$ | 0.081 | $p > 0.01$ |
| December | 0.506 | $p < 0.01$ | 0.125 | $p < 0.01$ | 0.081 | $p > 0.01$ |

Note(s): The yellow background indicates the months when the upward trend is statistically significant at the $p < 0.01$ level.

In Section 4.1.1., which covers air and water temperature (Figures 3 and 4), different behavior for the annual water and air temperatures for the two subperiods ((1) 1969–1981; (2) 1982–2021) were determined. Therefore, the monthly values were continuously analyzed to determine the behavior differences during the months of the year.

Figure 7 shows the histograms of average monthly water temperatures of the Drava at the station Botovo, $T_{DB}$, during the two subperiods: 1969–1981 (light blue color) and 1982–2021 (dark blue color). The line graph of their differences, $\Delta T_{DB}$, for the two subperiods above is shown in red. The average water temperatures during the recent subperiod for all 12 months are higher than during the first subperiod. The slightest difference was observed in June, when it was 1.30 °C, while the biggest difference appeared in December, at 2.34 °C.

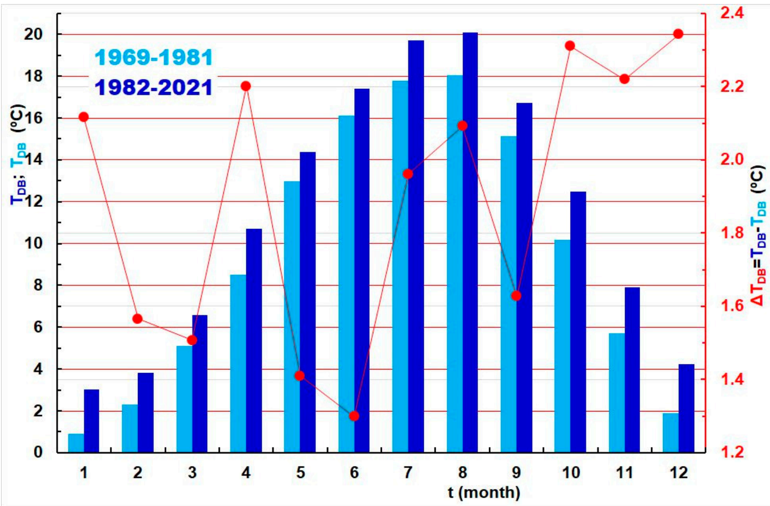


**Figure 7.** Histograms of average monthly water temperatures of the Drava at the station Botovo, $T_{DB}$, during the two subperiods: 1969–1981 (light blue color) and 1982–2021 (dark blue color). A line graph of their differences, $\Delta T_{DB}$, for the two subperiods above is shown in red.

Figure 8 shows the histograms of the average monthly air temperatures in Varaždin, $T_V$, during the two subperiods: 1969–1981 (light green color) and 1982–2021 (dark green color). The line graph of their differences, $\Delta T_V$, for the two subperiods above is shown in red. The average air temperatures during all months of the recent subperiod are higher than during the first subperiod. The smallest difference was observed in February, when it was 0.09 °C, while the biggest difference appeared in August, at 1.83 °C.

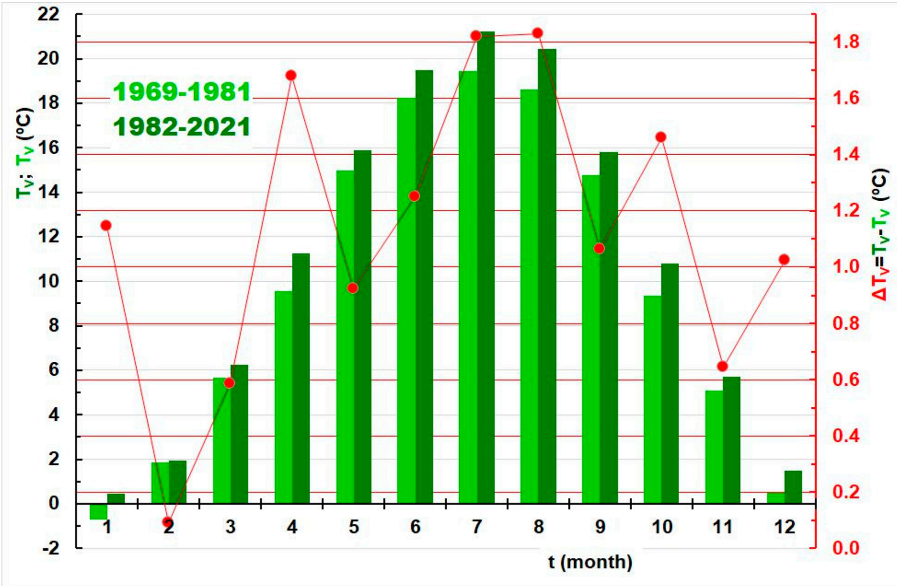


**Figure 8.** Histograms of average monthly air temperatures in Varaždin, $T_V$, during the two subperiods: 1969–1981 (light green color) and 1982–2021 (dark green color). A line graph of their differences, $\Delta T_V$, during the two subperiods above is shown in red.

Figure 9 shows the histograms of the average monthly differences in the water temperature of the Drava at the station Botovo, $T_{DB}$, and the air temperature at Varaždin, $T_V$, $\Delta T = T_{DB} - T_V$, during the two subperiods: 1969–1981 (grey color) and 1982–2021 (black). A line graph of their differences, $\Delta\Delta T$, during the two subperiods above is shown in red. This analysis indicates the regularity of the behavior of the differences, $\Delta\Delta T$. In the first subperiod (1969–1981), the differences, ΔΔT, are more significant during the cold part of the year (October–March), while they are lower in the warm part of the year (April–September). The highest value, $\Delta\Delta T$, with a measurement of 1.58 °C, was observed in November, and the lowest of 0.05 °C was observed in June.

Table 6 contains the average values of the subseries of monthly water temperatures for the Drava near Botovo (1969–1981 and 1982–2021), $T_{DB}$, the subseries of air temperature at Varaždin, $T_V$, and the subseries of their differences, $\Delta T = T_{DB} - T_V$, and the probability *t*-test, *p*. Cases where the analyzed subsets show a statistically significant difference at the $p < 0.01$ level are marked with a yellow background. The difference is statistically significant during all months for water temperature, while for the air temperatures, it is significant mainly in the warm part of the year (April, June, July, August, and October). In the case of the series of monthly differences, $\Delta T$, the statistically significant differences between the monthly values occur only in February, November, and December.

Figure 10 shows the relationship between the average monthly water temperatures of the Drava at the Botovo station (abscissa axis), $T_{DB}$, and the average daily air temperatures at Varaždin (ordinate axis), $T_V$, during the following two subperiods: (1) 1969–1981 (Gray) and (2) 1982–2021 (black). There is a clear difference in temperature behavior during the two analyzed subperiods, which can be traced as a shift relative to the bisector of the first quadrant (axis X = Y).

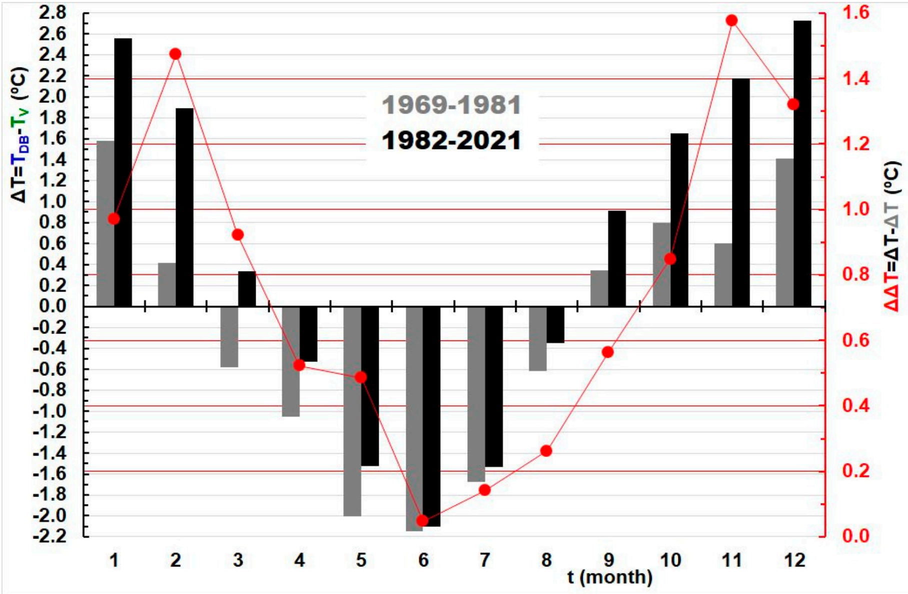


**Figure 9.** Histograms of average monthly differences in water temperature of the Drava at the station Botovo, $T_{DB}$, and the air temperature at Varaždin, $T_V$, $\Delta T = T_{DB} - T_V$, during the two subperiods: 1969–1981 (grey color) and 1982–2021 (black color). A line graph of their differences, $\Delta\Delta T$, during the two subperiods above is shown in red.

**Table 6.** Average values of the subseries of monthly water temperatures of the Drava near Botovo (1969–1981 and 1982–2021), $T_{DB}$, the subseries of Varaždin air temperature, $T_V$, and the subseries of their differences, $\Delta T = T_{DB} - T_V$, and the probability of the *t*-test, *p*.

| Months | Subperiods | $T_{db}$ | | $T_v$ | | $\Delta t$ | |
|---|---|---|---|---|---|---|---|
| | | Average | *p* | Average | *p* | Average | *p* |
| January | 1969–1981 | 0.89 | $p < 0.01$ | −0.69 | $p > 0.01$ | 1.58 | $p > 0.01$ |
| | 1982–2021 | 3.01 | | 0.45 | | 2.56 | |
| February | 1969–1981 | 2.27 | $p < 0.01$ | 1.85 | $p > 0.01$ | 0.42 | $p < 0.01$ |
| | 1982–2021 | 3.84 | | 1.95 | | 1.89 | |
| March | 1969–1981 | 5.08 | $p < 0.01$ | 5.66 | $p > 0.01$ | −0.58 | $p > 0.01$ |
| | 1982–2021 | 6.58 | | 6.25 | | 0.34 | |
| April | 1969–1981 | 8.51 | $p < 0.01$ | 9.56 | $p < 0.01$ | 1.05 | $p > 0.01$ |
| | 1982–2021 | 10.71 | | 11.24 | | −0.53 | |
| May | 1969–1981 | 12.96 | $p < 0.01$ | 14.97 | $p > 0.01$ | −2.01 | $p > 0.01$ |
| | 1982–2021 | 14.37 | | 15.89 | | −1.52 | |
| June | 1969–1981 | 16.10 | $p < 0.01$ | 18.25 | $p < 0.01$ | −2.15 | $p > 0.01$ |
| | 1982–2021 | 17.40 | | 19.50 | | −2.10 | |
| July | 1969–1981 | 17.75 | $p < 0.01$ | 19.42 | $p < 0.01$ | −1.68 | $p > 0.01$ |
| | 1982–2021 | 19.71 | | 21.24 | | −1.53 | |
| August | 1969–1981 | 18.01 | $p < 0.01$ | 18.62 | $p < 0.01$ | −0.62 | $p > 0.01$ |
| | 1982–2021 | 20.10 | | 20.45 | | −0.35 | |
| September | 1969–1981 | 15.10 | $p < 0.01$ | 14.75 | $p > 0.01$ | 0.35 | $p > 0.01$ |
| | 1982–2021 | 16.73 | | 15.82 | | 0.91 | |
| October | 1969–1981 | 10.15 | $p < 0.01$ | 9.35 | $p < 0.01$ | 0.80 | $p > 0.01$ |
| | 1982–2021 | 12.46 | | 10.82 | | 1.65 | |
| November | 1969–1981 | 5.68 | $p < 0.01$ | 5.08 | $p > 0.01$ | 0.60 | $p < 0.01$ |
| | 1982–2021 | 7.90 | | 5.72 | | 2.18 | |
| December | 1969–1981 | 1.88 | $p < 0.01$ | 0.48 | $p > 0.01$ | 1.41 | $p < 0.01$ |
| | 1982–2021 | 4.23 | | 1,50 | | 2.73 | |

Note(s): The yellow background indicates the months when the upward trend is statistically significant at the $p < 0.01$ level.

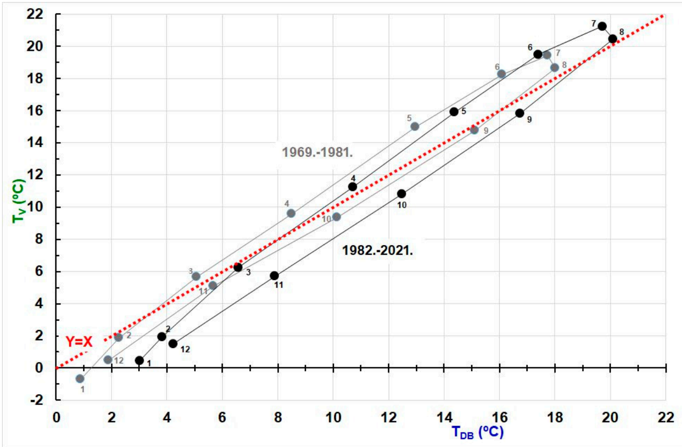


**Figure 10.** Graphic representation of the relationship between the average monthly water temperatures of the Drava at the Botovo station (abscissa axis), $T_{DB}$, and the average daily air temperatures at Varaždin (ordinate axis), $T_V$, during the following two subperiods: (1) 1969–1981 (Gray color) and (2) 1982–2021 (black).

### *4.3. Day as a Time Increment of the Analysis*

Variations in the daily air temperature during the year are significantly higher than the variations in water temperature, which can be seen in Figure 11A,B, which show their data during the first available year, 1969 (Figure 11A), and the last available year, 2021 (Figure 11B). The mean daily air temperature measured at GMP Varaždin; TV is marked in green, the daily water temperature measured at the water measuring station Botovo, TDB, is marked in blue, while their differences, $\Delta T = T_{DB} - T_V$, are marked in red.

It is necessary to note that, in 1969, during the winter months, water temperatures of 0 °C were measured on as many as 42 days, while in 2021, this water temperature was not calculated for a single day. During the first 12-year subperiod (1969–1981), water temperatures of 0 °C occurred on average 31.3 days per year, with a maximum of 43 days in 1971. In the recent 40-year subperiod (1982–2021), water temperatures of 0 °C occurred on average 0.55 days per year. At most, it appeared for eight days in 1985, and for 30 years, it did not appear for a single day.

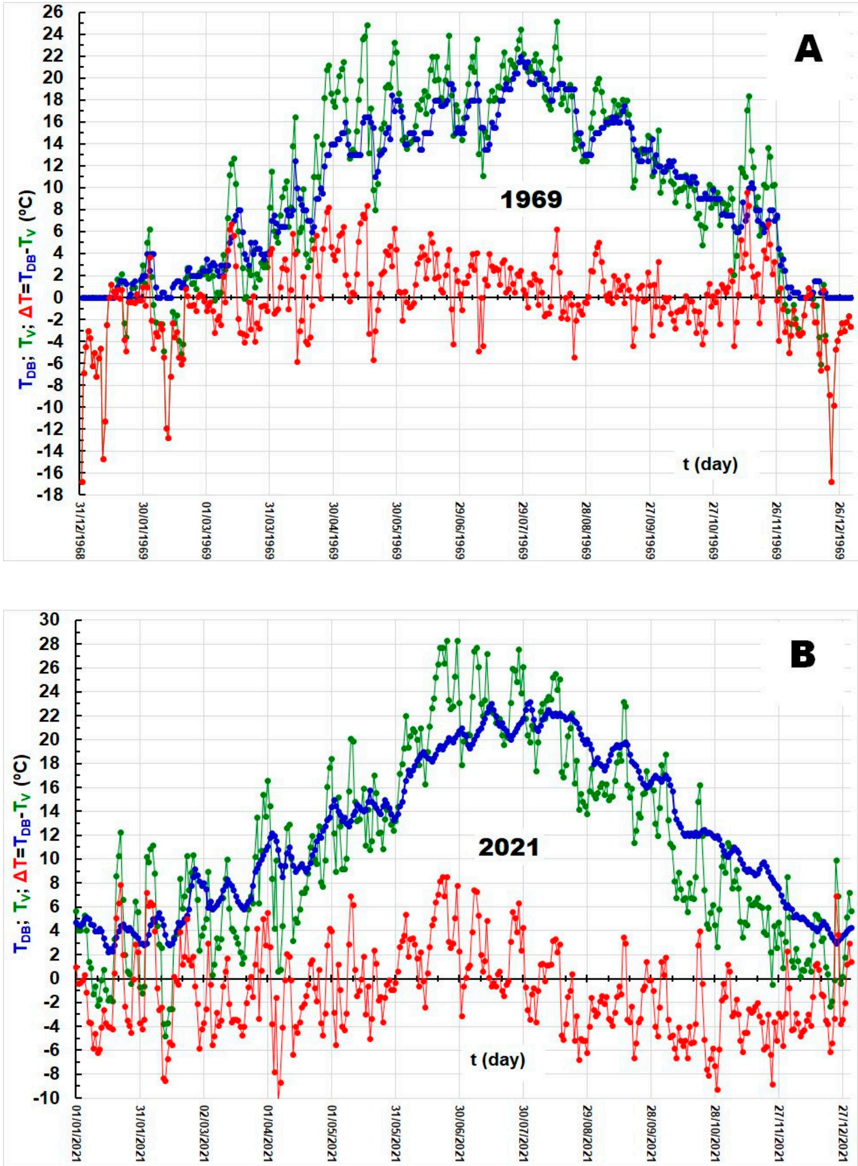


**Figure 11.** Series of daily water temperatures of the Drava at Botovo station (blue color), $T_{DB}$, average daily air temperatures at Varaždin (green color), $T_V$, and their differences (red color), $\Delta T = T_{DB} - T_V$, during 1969 (**A**) and 2021 (**B**).

## 5. Conclusions

The relationship between water temperatures in rivers and the surrounding air temperature depends on the size of the water body, variable hydrological conditions (flow, water speed, etc.), and different river shapes and bed dimensions that change over time, depending on anthropogenic interventions. Previously performed analyses point to the conclusion that the first built and smallest reservoir, A1, did not have any influence on the change in temperature of the Drava water at the water measuring station Botovo.

Based on the previously detailed results of the analysis of the water temperature trends of the Drava River at the water measuring station Botovo and the air temperature at GMP Varaždin, it can be concluded that they have intensively increased. On an annual time scale, using the Mann–Kendall test, a statistically significant trend of increasing mean yearly water and air temperatures was determined at the $p < 0.01$ probability level, where the increase in air temperatures is milder than the increase in water temperatures.

The day-to-day (*DTD*) results indicated that the trend of increasing annual air temperature variations is not statistically significant. In contrast, that of the water temperature is statistically significant. The difference between them decreases, i.e., the water in the Drava River not only heats up faster than the surrounding air, but its variations between two adjacent days also increase.

The trends of an increase in monthly water temperatures for all months are statistically significant, while air temperatures are not statistically significant during February, March, May, and September. The increasing trends (of their differences) are statistically significant only in September. A comparative analysis of the monthly air and water temperatures indicates that the water temperature rises faster in the colder part of the year. An explanation for this is the nature of the climate in the observed area.

When comparing the air and water temperature data analyzed in this paper, it is necessary to consider several other facts. The mean daily air temperature at GMP Varaždin, $T_{sr}$, as well as at all climatological stations in Croatia, is determined by the following equation:

$$T_{sr} = [T_7 + T_{14} + (2 \times T_{21})]/4 \tag{3}$$

Whereby the $T_7$, $T_{14}$, and $T_{21}$ temperatures were measured at 7 am, 2 pm, and 9 pm local time, respectively. The water temperature at the water measuring station Botovo is calculated every day at 7:30 am. Although the daily variations in the water temperatures in the river are significantly minor than that of the air temperatures, when interpreting the results, one should not ignore the fact that the water temperatures in the river, if they were defined by Equation (3), were slightly higher than those available in this work, which points to a possible conclusion that, in reality, the water temperature in the Drava River is warming faster than was established by previous analyses based on the existing data.

Previously performed analyses undoubtedly point to the conclusion that the water temperature of the Drava River measured at the Botovo station warms up faster than the air temperature measured at the GMP, Varaždin. It is impossible without detailed additional information, which unfortunately has not been monitored, to determine precisely how statistically significant the increase in water temperature is for the period of 1982–2021, as is true for influencing factors such as global warming and the influence of reservoirs A2 and A3.

Column 7 of Table 3 contains the values of minimum (327 $m^3/s$), average (490 $m^3/s$), and maximum (739 $m^3/s$) annual flows of the Drava near Botovo for the period 1969–2021. There is a statistically insignificant downward trend for the average annual flow during the same period. At the same time, it must not be forgotten that the retention of water in reservoirs and the operation of hydroelectric power plants have influenced the change in the Drava River downstream hydrological regime and, therefore, also at the Botovo water measuring station. There was a flattening of the flow regime during the year. Figure 12 graphically shows the values of the standardized, average monthly flows of the Drava near Botovo, $Q_{stt}$, during the following two subperiods: (1) 1969–1981 (light purple color); (2) 1982–2021 (dark purple color), defined by the equation:

$$Q_{st,t} = (Q_{pr,t}/Q_{pr,g}) \tag{4}$$

where $Q_{st,t}$ is the standardized monthly flow during the month, $t$, $Q_{pr,t}$, is the average monthly flows during the analyzed month, and $t$, $Q_{pr,g}$, are the average annual flows in the analyzed subperiod. From September to January, the standardized average flows were higher in the recent subperiod than in the subperiod when the reservoirs were not built and when HE2 and HE3 were not in operation. From February to August, the standardized average flows are lower in the recent subperiod than in the subperiod covered by the previous analysis. The naturally glacial hydrological regime in the lower reaches of the Drava River has eased. There is a possibility, for which there are unfortunately no reliable measured indicators, that the changes in the hydrological regime during the year also influenced the increase in the intensity of the rise in water temperature.

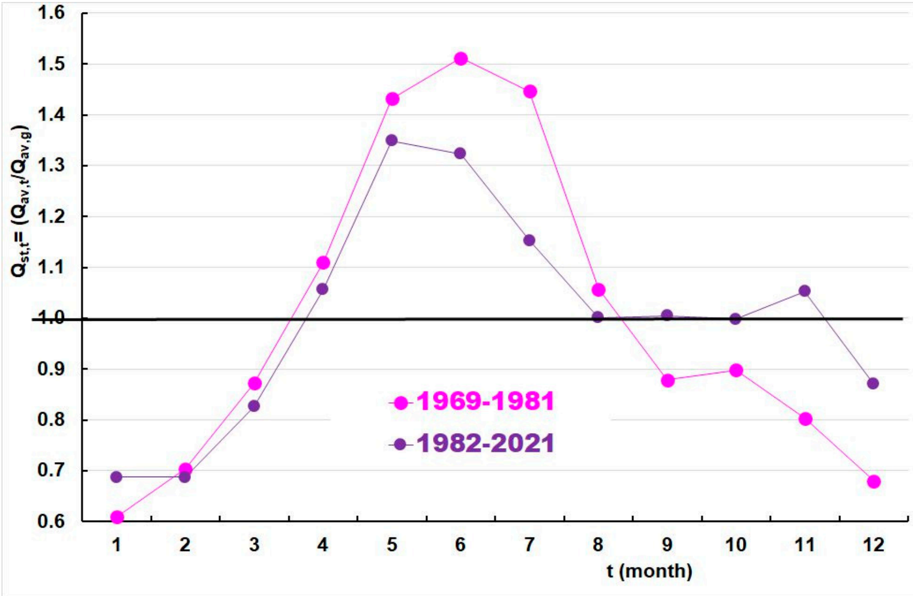


**Figure 12.** Graphical representation of the values of the standardized, average monthly flows of the Drava near Botovo, $Q_{st,t}$, during the following two subperiods: (1) 1969–1981 (light purple color); (2) 1982–2021 (dark purple color).

When explaining in more detail the increase in the temperature of the Drava water at the Botovo station and also at the downstream stations, Terezino Polje, Donji Miholjac, and Osijek [23], it is necessary to install modern measuring devices for continuous water temperature measurement at these locations. Such information would enable more detailed and reliable insight into the processes of water heating along the lowland course of the Drava River, which should help in the sustainable management of the water resources of this extremely important watercourse and the related ecosystems. This is particularly important because the significant increase in air and water temperature in the last 40 years (1982–2021) points to the conclusion that this process will continue and intensify.

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