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Assessment of time course of water and air temperature in the locality of the Turček reservoir during its operation in the period 2005–2019

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In the future, during the ongoing climate change, water reservoirs will play an important role in the provision of raw water for the subsequent production of drinking water for the inhabitants of Slovakia. The Turček water reservoir is the fifth largest water reservoir in Slovakia with a total volume of 9.9 mil. m^3, which is used for the production of drinking water for the towns Prievidza, Žiar nad Hronom, Handlová and a connection to the water mains of the Žarnovica district is also planned. The paper deals with the trend analysis of water and air temperatures data for a selected period of time (2005–2019). We used the non-parametric Mann-Kendall test, which is one of the most widely used nonparametric tests to detect significant trends over time. The results of this test answer the question if there existed a significant trend for mentioned temperatures in this locality or not. Analysis confirmed that it is not possible to determine a significant trend at the significance level of 5%. Anyway, value of annual air temperature increased by 0.57°C during the study period 2005–2019.

KEY WORDS: climate change, air temperature, water temperature, Turček water reservoir, trend analysis

Introduction

Slovakia is the country with rich water resources. Both the surface water and the groundwater resources ensure the current and also potential needs of the country in the future. However, they are distributed unequally over the Slovak territory. The distribution depends on natural conditions – mostly on geomorphologic, geological, hydrogeological and climatic ones (Zeleňáková and Fendeková, 2018; Rončák and Šurda, 2019).

Water resources are limited and are facing issues that are caused by over-exploitation, continuous human pressure and also climate changing, which could have serious consequences on quality of water (Shevah, 2015), an essential resource for human health, ecosystems and the economy. Degradation of water quality can result in human exposure to harmful diseases and toxic chemicals (Hu and Cheng, 2013), reduced productivity and diversity of ecosystems and damage to aquaculture, agriculture and other water-related industries (Kaiblinger et al., 2009).

Reservoirs are important sources of drinking water in most parts of the world. Like other water body, reservoirs are also impacted by climate change. This is reflected, for example, in changes of physical properties such as increasing surface water temperature, decreasing ice cover duration, changing stratification or in biological effects such as changes in the phytoplankton community and in increasing risk of cyanobacteria blooms. Climate change also amplifies processes leading to eutrophication of water bodies which might reinforce global warming. (Feldbauer et al., 2020). Reservoirs respond differently to climate change compared to lakes because storage and outflow are actively managed (Hayes et al., 2017; Bednárová et al., 2021). The operational parameters associated with reservoir control are: the withdrawal rate or quantity, the withdrawal schedule, and the withdrawal depth. The withdrawal depth directly influences storage or dissipation of heat and material, thermal stability, and thus resistance to mixing (Kennedy, 1999). In drinking water reservoirs, adaptation of withdrawal depth is used as a tool to optimize raw water quality for drinking water production (Cáceres et al., 2018).

The aim of this study is to analyze the time course of water temperature and air temperature in this locality as a starting point for assessing the possible impacts of climate change on the water quality in this water body.

Water reservoirs for drinking water production in Slovakia

Water reservoirs intended for the supply of water to the inhabitants have their peculiarities – specific operating conditions that allow raw water to be treated and converted into drinking water. So far, eight water reservoirs have been built in Slovakia, the basic data of which are given in Table 1 (Slovak association of water experts, 2020).

As can be seen from the Table 1 all these reservoirs were built in the 20th century during the period of years 1965 – 1998 with the exception of the Rozgrund reservoir (it was built in the 18th century). From a historical point of view, the Rozgrund reservoir deserves primary and special attention. It was built in the years 1743–1744. The project was elaborated by Samuel Mikovíni in 1741 and under his leadership the construction was also realized (Slovak association of water experts, 2020).

Trends of climate changes in Slovakia

By the document of the Ministry of Environment of the Slovak Republic (MESR, 2018), the climate change in Slovakia during the period 1881–2017, was manifested as follows:

- the average annual air temperature increased by about 1.73°C;
- spatially different trend of annual total atmospheric precipitation on average by about 0.5% (in the south of the Slovak Republic the decrease was sometimes more than 10%, in the north and northeast seldom total precipitation increased by 3%); decrease in relative humidity (in the south of Slovakia since 1900 by 5%, to other territory less);
- a decrease of values of all snow cover characteristics up to an altitude of 1000m at almost the whole territory of the Slovak Republic (in spite of this, an increasing was recorded at a higher altitude);
- increase of potential evaporation and decrease of soil moisture - characteristics of water evaporation from soil and plants, soil moisture, sunlight confirm that especially the south of Slovakia gradually dries out.

Global warming has manifested itself in Slovakia by maintaining the average annual air temperature over the last 100 years by 1.1°C. These data were observed in the oldest Slovak weather station in Hurbanovo, in which the monitoring has been ongoing since 1871 and continuously since 1901. The period of the warmest 12 years was recorded in the early 1990s. At the same time, atmospheric precipitation increased by an average of 5.6%.

Regional differences were recognized between the southern and northern parts of the Slovakia territory. In the south of Slovakia the decrease was 10%, while in the north and northeast it was 5%. The manifestation of climate change is primarily a reduction of relative humidity (up to 5%). Similarly, the snow cover decreased in almost the whole territory of Slovakia (SHMI, 2021).

Impacts of climate change on water quality

Impacts of climate change on water quality with regards to the water reservoirs for supply of the population with drinking water were described and summarized by (Hosaka, 2009) as follows:

- Increase in frequency of turbid water inflow due to increase in heavy rain;
- Stagnation of circulation in reservoir due to global warming;
- Increased risk of toxic chemicals in raw water due to increase in vermin;
- Increase in production of trihalomethane due to water temperature rise;
- Increased risk in pathogenic microorganisms in tap water due to water temperature rise.

Future climate change scenarios also foresee a decrease in water quality due to higher concentrations of pollutants and sediments, through reduced dilution as a result of less water in the rivers and reservoirs. Larger runoff events in winter due to more extreme rainfall events may lead to higher sediment and nutrient loads into streams and reservoirs (Whitehead et al., 2009).

The synergistic effect of a decrease in atmospheric precipitation and an increase in temperature disrupts the natural water cycle. Long-term river flows have been on a declining trend since 1980, with the exception of the Danube River. Already in 1997 it was estimated by (Marečková et al., 1997) that by the scenarios for the time horizons of 2010, 2030 and 2075, the capacity of surface water reserves will decrease to 12.05, 11.05 and 9.42 billion m^3, with the reduction of flows by 4, 12 and 25%. Due to global warming, the surface water temperature of a reservoir in winter does not lower as much as it had before, and as a result, it does not complete circulation in the reservoir bottom. Therefore, nutrition salts elute from sediments at the reservoir bottom, deteriorating the water quality and resulting in phenomena such as water-bloom (Hosaka, 2009). Such phenomenon is already observed in several lakes and reservoirs.

Table 1. Summary of water reservoirs in Slovakia used as a source of drinking water (source: Slovak association of water experts, 2020)

Reservoir	Basin	Total volume [mil.m^3]	Year of commissioning
Rozgrund	Hron	0.5	1774
Hriňová	Hron	7.6	1965
Klenovec	Slaná	6.7	1974
Bukovec	Bodva	21.4	1976
Starina	Bodrog	47	1988
Nová Bystrica	Váh	31.6	1989
Málinec	Ipeľ	21.5	1993
Turček	Váh	9.9	1998
Tichý potok	Poprad	24	?

Material and methods

Description of study area

The Turček reservoir is located at the confluence of the Turiec and the Ružový streams above the village of Turček village (48°45'50.4"N 18°56'13.2"E). The dam profile is situated in the valley below the confluence of both streams. The width of the valley is approximately 120 m and the altitude in the dam profile localization is 719 m a.s.l. The dam of the Turček reservoir is sprinkled, the length of the crown of the dam is 287.6 m and its height is 59 m (Chmelár, 1998). The total volume of the reservoir is 10.6 mil. m^3, while its storage content is 9.9 mil. m^3, (the reservoir is filled twice a year) and the constant volume is 0.3 mil. m^3 of water. The average amount of water supplied to the water treatment plant is 15.8 mil. m^3/year. The total catchment area is 29.5 km^2.

Theoretical background of data processing

The Mann-Kendall nonparametric test (M-K test) is one of the most widely used nonparametric tests for significant trends detection in a time series. Nonparametric tests are more suitable for detection of the trends in the hydrological time series, which are usually irregular with many extremes (Hamed, 2008; Yue et al., 2003; Gilbert, 1987 cited by Bačová Mitková and Halmová, 2021).

This statistical method was also well described in Wang et al. (2020):

The Mann–Kendall trend test (Mann, 1945; Kendall, 1975) is based on the correlation between the ranks and sequences of a time series. For a given time series $\{X_i, i = 1, 2…, n\}$, the null hypothesis *H0* assumes it is independently distributed, and the alternative hypothesis *H1* is that there exists a monotonic trend. The test statistic *S* is given by:

$$S = \sum_{i=0}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \tag{1}$$

where

X_i and X_j – are the values of sequence *i*, *j*;

n – is the length of the time series;

$$sgn(\theta) = \begin{cases} 1, \ if\theta < 0 \\ 0, \ if\theta = 0 \\ -1, \ if\theta \geq 0 \end{cases} \tag{2}$$

Mann (1945) and Kendall (1975) have documented that the statistic *S* is approximately normally distributed when $n \geq 8$, with the mean and the variance of statistics *S* as follows:

$$E(S) = 0 \tag{3}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} T_i i(i-1)(2i+5)}{18} \tag{4}$$

where

T_i – is the number of data in the tied group;

m – is the number of groups of tied ranks.

The standardized test statistic *Z* is computed by

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{5}$$

The standardized MK statistic *Z* follows the standard normal distribution with *E*(*Z*)=0 and *V*(*Z*)=1, and the null hypothesis is rejected if the absolute value of *Z* is larger than the theoretical value $Z_{1-\alpha/2}$ (for two-tailed test) or $Z_{1-\alpha}$ (for one-tailed test), where α is the statistical significance level concerned.

Results and discussions

Time series of data (type of weather, precipitations, inflows, outflows, temperature of air and water, etc.) were obtained from the operator of this reservoir – Slovenský vodohospodársky podnik, š.p. (Slovak Water Management Enterprise, state enterprise). These data are monitored and recorded every day at 6:30 AM, in some cases even several times per day. This study analyses trend of temperature of water and air in the Turček reservoir locality.

All data were digitized and processed in spreadsheet software and analysis was performed through XLSTAT. The overall course of mean monthly air and water temperatures and trend lines for the whole period 2005–2019 can be seen in Fig. 1. The course of the mean monthly temperature values in the period 2005–2019 is shown in Fig. 2 for each month separately.

As it can be seen, the value of average annual temperature of water oscillated in the period 2005–2017 between 2.2–3.8°C, only in the last two years is starting to rise more rapidly. The value of average annual temperature of air fluctuated in the range of 2°C, but no longer is lasting steeper increase visible. However, both parameters show a gradual increase in values, temperature of air slightly steeper than water temperature. What can be also seen from Fig. 1 is the fact that the change in trend between these parameters occurs with postponement on 3 years in average.

M-K trend test

The M-K trend test with 5% level of significance was used for detection of the significance in long-term trends of air and water temperature (Fig. 2). This significance level means that there is a 5% probability that we make a mistake if we reject the hypothesis *H0* (*H0* = There is no trend in the series).

Table 2 summarizes results of the Mann-Kendal trend test such as *S*, *VAR(S)*, *Z*, *p*-value for each month in seasons: November–January, February–April, May–July, August–October.

Table 3 shows results of MK test for two seasons into

which the year was divided: 1. from November to April and 2. from May to October.
The results of the M-K analysis in the Fig. 2 and summarized in tables showed that there was no significant trend in the majority of months using the 5% significance level. The data analysis in this study shows decreasing air temperature trends in January, May, July, and September, the rest of the months have a rising trend. The most significant trend at 5% significance level is in July (negative) and in August (positive). The total mean

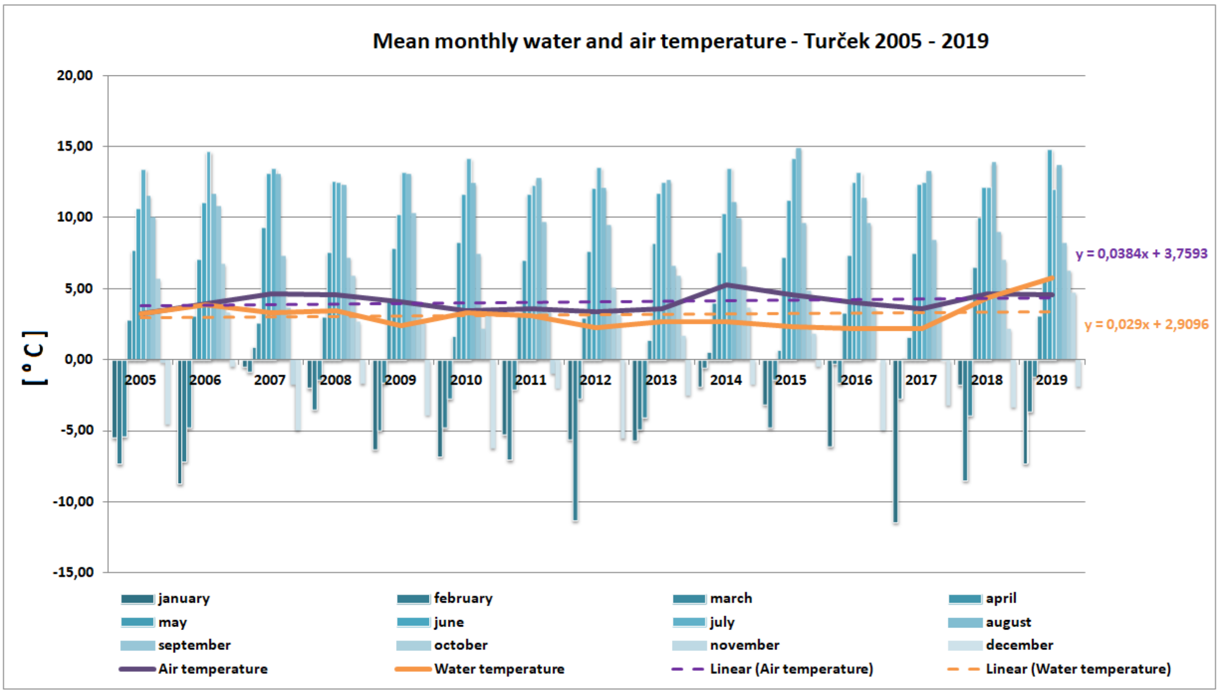


Fig. 1. Time course of Mean monthly air and water temperatures in the period 2005–2019.

Table 2. Results of M-K trend analysis for mean monthly air and water temperatures, significance 5%

Mann-Kendall trend test results						
1. November–January	**Air XI.**	**Water XI.**	**Air XII.**	**Water XII.**	**Air I.**	**Water I.**
Kendall's tau	0.134	0.181	0.077	0.162	-0.086	-0.314
S	14.000	19.000	8.000	17.000	-9.000	-33.000
VAR(S)	407.333	408.333	407.333	408.333	408.333	408.333
p-value (Two-tailed)	0.519	0.373	0.729	0.428	0.692	0.113
Z	0.644	0.891	0.347	0.792	-0.396	-1.584
1. February–April	**Air II.**	**Water II.**	**Air III.**	**Water III.**	**Air IV.**	**Water IV.**
Kendall's tau	0.191	-0.077	0.183	0.105	0.048	0.067
S	20.000	-8.000	19.000	11.000	5.000	7.000
VAR(S)	407.333	407.333	406.333	408.333	408.333	408.333
p-value (Two-tailed)	0.346	0.729	0.372	0.621	0.843	0.767
Z	0.941	-0.347	0.893	0.495	0.198	0.297
2. May–July	**Air V.**	**Water V.**	**Air VI.**	**Water VI.**	**Air VII.**	**Water VII.**
Kendall's tau	-0.162	-0.086	0.287	-0.067	-0.387	-0.010
S	-17.000	-9.000	30.000	-7.000	-40.000	-1.000
VAR(S)	408.333	408.333	407.333	408.333	404.667	408.333
p-value (Two-tailed)	0.428	0.692	0.151	0.767	0.053	1.000
Z	-0.792	-0.396	1.437	-0.297	-1.939	0.000
2. August–October	**Air VIII.**	**Water VIII.**	**Air IX.**	**Water IX.**	**Air X.**	**Water X.**
Kendall's tau	0.314	-0.257	-0.219	-0.276	0.115	-0.181
S	33.000	-27.000	-23.000	-29.000	12.000	-19.000
VAR(S)	408.333	408.333	408.333	408.333	407.333	408.333
p-value (Two-tailed)	0.113	0.198	0.276	0.166	0.586	0.373
Z	1.584	-1.287	-1.089	-1.386	0.545	-0.891

monthly air temperature for the period 2005–2019 shows a temperature increasing by 0.57°C.

In the case of water temperature the situation is very similar. Analysis of month data shows that there was no significant trend in the majority of months using the 5% significance level. Increasing trend occurs in March, April, November and December, in July no trend exists and in the rest months there are decreasing trends for the research period. The most significant trend at 5% significance level is in January (negative) and in November (positive). Total rise of water temperature is 0.33°C/period.

M-K trend test results for two different seasons of the year show that in the period November–April (could be named as a winter period) the more significant trend exists for air temperature with positive value. On the other side, for the period May–October (could be named as a summer period) the more significant trend occures for water temperature with negative value.

According to the Report on the state of the environment of the Slovak Republic (2017), since 1951 the annual air temperature in Liptovský Hrádok (640 m above sea level – a.s.l.) represents a statistically significant upward trend in the linear trend until 2017 (an increase of 2.0°C). Liptovský Hrádok is located at a similar altitude as Turček, so it is presented here to compare what trends in air temperature are in similar localities.

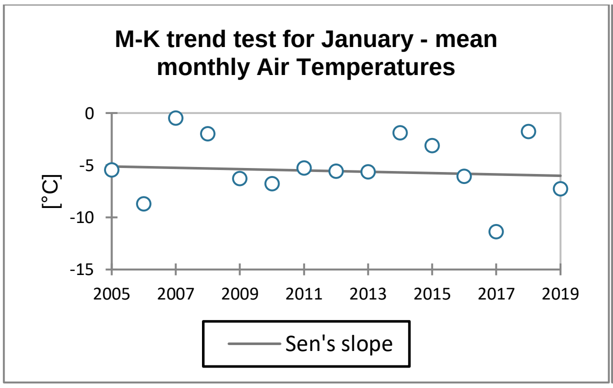
In the study made by Ceppi et al. (2012), where the trend analysis of air temperatures in Switzerland from 1959 to 2008 was desribed, all seasonal trends are positive and mostly significant with an annual average warming rate of 0.35°C/decade (~1.6 times the northern hemispheric warming rate), ranging from 0.17°C in autumn to 0.48°C/decade in summer. Altitude-dependent trends are found in autumn and early winter where the trends are stronger at low altitudes (<800 m a.s.l.), and in spring where slightly stronger trends are found at altitudes close to the snow line.

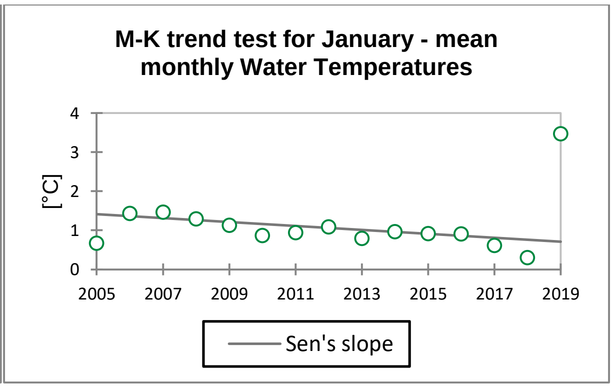
Ohmura (2012) points to temperature trends in different regions of the Earth, for example trends 0.37°C/decade at Choibalsan (Mongolia, 747 m a.s.l.) for last 40 years (1970–2010) for comparison in our case the air temperature rises by 0.57°C in 15 years as our values are not affected by older values when the air temperature was lower, 0.09°C/decade for Hami (China, 739 m a.s.l.) for period 1959–2005, these data are used as an example of the globally rising trend of air temperature at a similar altitude as Turček. Summing up the analyses of the 18 groups of stations in 10 regions, there is a general tendency that the amplitude of climate change is larger at high altitudes in comparison with low lands.

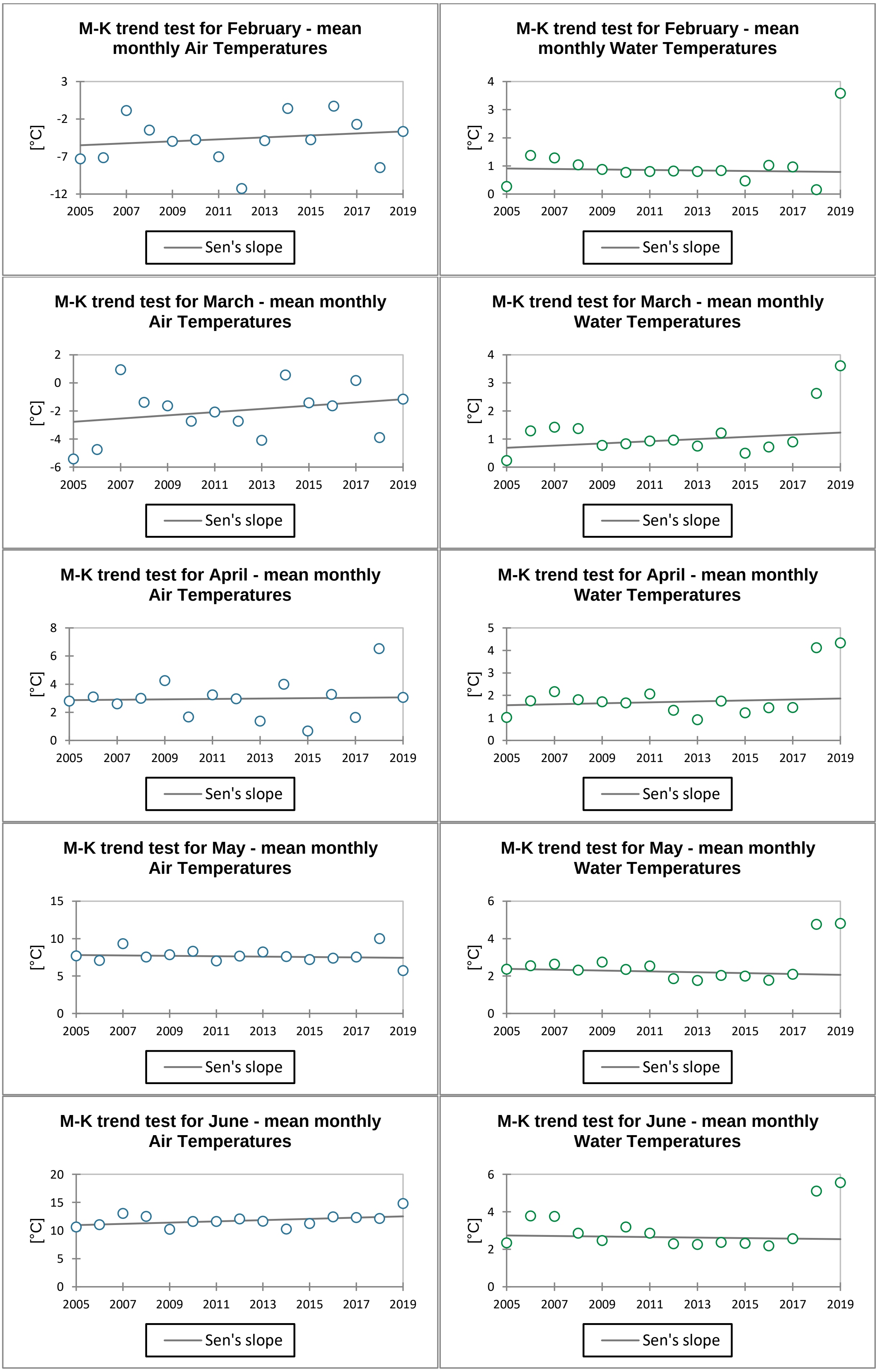
Bačová Mitková and Halmová (2021) used Mann-Kendall's analysis on hydrological and climatic indicators in the Váh river basin. Their results show an increasing trend of air temperature for Liptovský Hrádok. According to their results, the trend of rising air temperature from 2005–2014 is around 0.25°C, but it is necessary to add that it is valid for the period of analysis from1951 to 2014. Although our research period is 2005–2019, our results show the upward trend, too. Also according to a report from Enviroportal (2016), the air temperature in Liptovský Hrádok increased by 0.3°C in the period 2005–2015. On the other hand, annual air temperature data from the meteorological station Liesek

Table 3. **Results of M-K trend analysis for significance 5%**

M-K trend test results for 2 periods XI.–IV., V.–X.				
periods	**November–April**		**May–October**	
temperatures	*Air*	*Water*	*Air*	*Water*
Kendall's tau	0.200	-0.010	0.105	-0.257
S	21.000	-1.000	11.000	-27.000
Z	0.989744	0	0.494872	-1.28667
VAR(S)	408.333	408.333	408.333	408.333
p-value (Two-tailed)	0.322	1.000	0.621	0.198






M-K trend test for February - mean monthly Air Temperatures
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Sen's slope
M-K trend test for February - mean monthly Water Temperatures
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Sen's slope
M-K trend test for March - mean monthly Air Temperatures
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M-K trend test for March - mean monthly Water Temperatures
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M-K trend test for April - mean monthly Air Temperatures
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M-K trend test for April - mean monthly Water Temperatures
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M-K trend test for May - mean monthly Air Temperatures
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M-K trend test for May - mean monthly Water Temperatures
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M-K trend test for June - mean monthly Air Temperatures
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M-K trend test for June - mean monthly Water Temperatures
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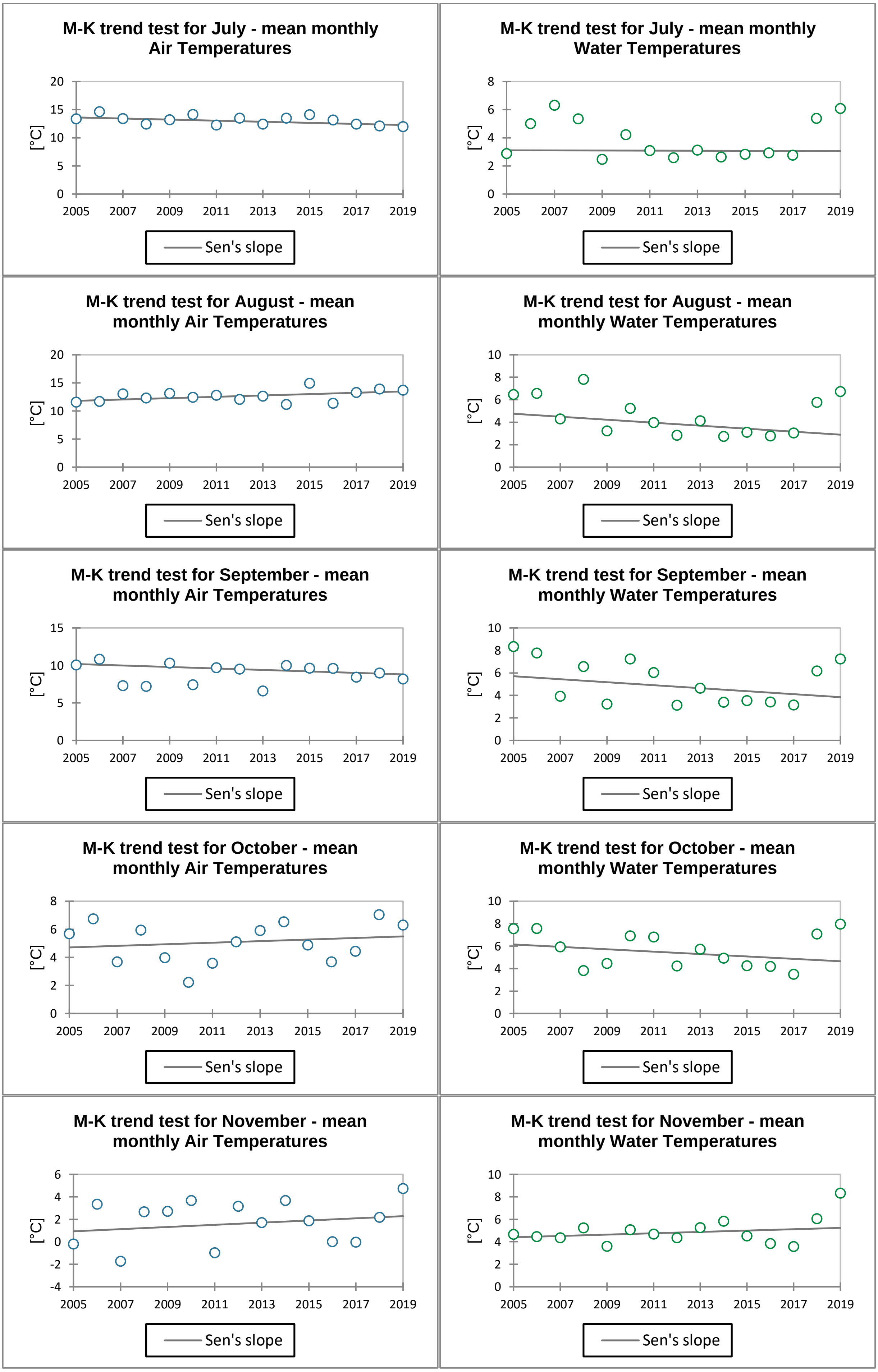
M-K trend test for July - mean monthly Air Temperatures
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M-K trend test for July - mean monthly Water Temperatures
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M-K trend test for August - mean monthly Air Temperatures
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M-K trend test for August - mean monthly Water Temperatures
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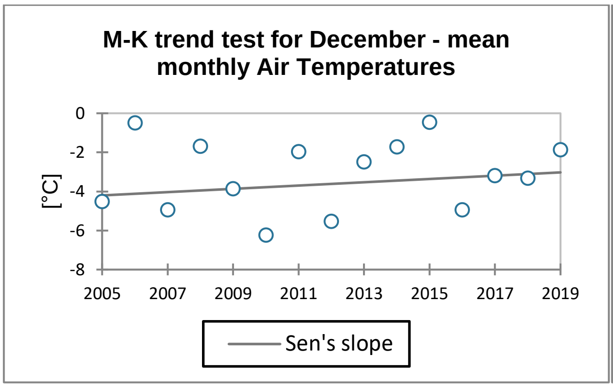

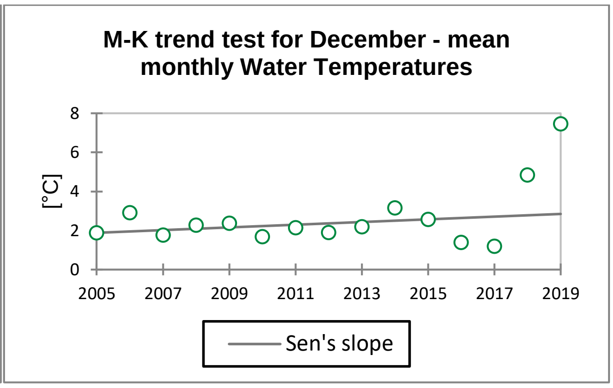

Fig. 2. Mann-Kendall trend test for mean monthly water and air temperatures, significance=5%.

(692 m a.s.l.) show a rising temperature trend of 0.98°C for the period 2006–2019 and for the station Poprad–Gánovce (694 m a.s.l.) air temperature trend increases by 0.8°C for the period 2011–2020. According to data from these 2 meteorological stations, we can see from the trends that average air temperature in Turček is lower.

Conclusion

The overall trend for water and air temperature is rising during studied period. As we can see in various studies in various parts of the world with a similar altitude as the Turček locality, air temperatures are rising in general although some months have decreasing trends. More significance levels should be used for more telling results, because no significant trend was received at the 5% significance level. Each calculated *p*-value was greater than the significance value alpha, which means that we cannot reject the null hypothesis that there is no trend in the data. Air temperature increased by 0.57°C during the study period 2005–2019.

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