The Simulation of the Water Temperature Rising Using ARIMA Models

DANA HALMOVA[1], PAVLA PEKAROVA[1], JAN PEKAR[2], KATARINA KUCAROVA[3]
[1] Institute of Hydrology
Slovak Academy of Sciences
Racianska 75, 831 02 Bratislava
SLOVAKIA
[2] Comenius University in Bratislava
Faculty of Mathematics, Physics and Informatics
SLOVAKIA
[3] Ministry of Environment of the Slovak Republic
Bratislava
SLOVAKIA
halmova@uh.savba.sk, http://www.ih.savba.sk/

Abstract: - The methodological approach to measuring the water temperature was historically developing. The economic importance of knowledge on flowing water temperature and thus the responsibility of the observer for the proper and reliable measurements has been known for over a century. In Slovakia, the water temperature in streams is measured according to sectorial technical environmental standards (Measurement of water levels, water temperature and ice phenomena on the surface flows) of 2005. Water temperature plays a key role from environmental, biochemical as well as chemical point of view. Increase in water temperature, e.g. during extreme and long-lasting heat waves and drought, can cause undesirable chemical and biochemical reactions.

In the study we have focused on water temperature simulation in twenty one streams in the Slovak part of the Morava River basin. The aim was to assess the impact of the expected air temperature increase to a temperature rise of water in the streams. While processing the data, we used the time series of the average daily water temperature in selected gauging stations in the Morava River basin and the average daily air temperature measured in Bratislava-airport, for the period 2006–2011.

Scenarios of extreme monthly air temperatures at the Bratislava-airport were compiled based on statistical analysis of daily air temperatures during 1951–2011. Extreme water temperatures were simulated based on a scenario of air temperature using several ARIMA models (Autoregressive Integrated models of Moving Averages). Results of the simulations show, that for increasing the maximum air temperature by 1°C, the water temperature may be increased by 0.7–0.9°C, depending on the model used.

Key-Words: ARIMA models, water temperature simulation, Water Framework Directive, climate change

1 Introduction

The water temperature is one of the main physical characteristics of the surface water. It directly influences the biota of the streams and adjacent land. The water temperature significantly influences other physical and chemical properties of the water. The productivity of the total water ecosystem does not only depend on the water temperature, but it is in great extend limited by the water temperature [1]. The factors that affect the water temperature can be generally divided into four groups [2]:

1. Atmospheric conditions - solar radiation, air temperature, wind speed, precipitation, evaporation, condensation...

2. Topographic conditions – altitude and latitude of the basin, flow orientation, coastal vegetation, subsoil...

3. The hydrological regime of flow - discharge, flow velocity and depth of stream, level and temperature of groundwater...

4. Anthropogenic activities in the basin - discharge of urban and industrial waste water, flow reduction [3], artificial reservoirs [4] and diversion canals and removal of riparian vegetation [5].

Several Slovak hydrologists addressed the statistical analysis of drought in watercourses in the East Slovakia, which are connected with the high water temperature in rivers [6]. The main objective of their work was to identify long-term trends in low flows in selected 63 stations in the East Slovakia during the period 1975–2012.

1.1 Methodology of water temperature measuring in Slovakia

The methodological approach to measuring the water temperature in Slovakia was historically developing. The first continual water temperature measurements started in 1921 on the Danube River at Bratislava. The water temperature was measured by observer. According to the source, the temperature of the water flow was measured daily, regularly at 7:00 am, or even in another time (hour) to a specific provision. The mercury thermometer with Celsius scale with a range from –12 to 40°C was used for the measurements of the water temperature in watercourses. Temperature was measured under the water surface, at a place designated for this purpose, at least 1.5 meters from the banks. Sampling point should not be: shadowed by vegetation, too shallow or deep and water should flow slightly. In case the access to water is difficult or impossible, the measurement is carried out in another suitable place, where it is necessary to observe at all times. The place of measurement must guarantee finding the average water temperature.

Nowadays, the measurements are executed according to the sectorial technical environmental standards [7]. According to that environmental standard, water temperature is measured usually in the morning at 7:00 am. Exception are the prognostic stations, where the water temperature is measured simultaneously with the water level at 6:00 am. In some stations for special purpose, the water temperature can be implemented in other terms or several times a day. A primary requirement for all measurements is to follow the frequency and time of measurements throughout the whole year.

In the context of sustainable protection and efficient use of water, considerable attention has focused on extremality in the hydrological regime of water. Sustainable protection and efficient use of water is based on the process of implementing the Water Framework Directive (WFD) [8] and is directly related to water quality and quantity, which are affected by climate change, with a direct impact on the established environmental goals. WFD introduced a new understanding and new terminology in the evaluation of water status.

Evaluation of the status is not related to the entity "flow", but it is based on the evaluation of "water bodies" and "stream types":

- “Water body” may be representative of the entire section of a watercourse, or may be part of it (entity = less than or corresponding to watercourse).
- “Stream type” is a grouping of watercourses into categories with similar internal characteristics (= entity associating several streams).

In the Slovak Republic (SR) there were defined 1763 surface water bodies and 22 stream types. Identification of different types of flows includes: the type of landscape (P - the Pannonian plain, K – the Carpathians), the altitude (1–4) and the size of stream: M - small, S - middle and V - large flow. With increasing altitude in small streams (P1M, P2M, and K2M) average and maximum water temperature decreases. The summary of numbers of water bodies, types and data from the Morava River basin is given in Table 1.

Table 1 Summary of numbers of water bodies, types and data from the Morava River basin

type	Number of water bodies of particular type	Number of VS of particular type with TVO measurements	Number of obtained data sets of VS with temperature measurements
P1M	58	4	4
P1S	4	6	5
M1(P1V)	2	6	3
P2M	18	3	3
K2M	20	6	6
Total	102	25	21

TVO – water temperature, VS – gauging station

2 Description of the Morava River basin

The Morava River is a left tributary of the Danube. The Morava River basin is mostly located in the Czech Republic. Catchment area of the Morava River at estuary into the Danube is about 26 580 km^2, of which is only 2 282 km^2 in Slovakia, representing 8.6% of the whole catchment area and 4.65% of the Slovak Republic area (Table 2), (Fig. 1).

In terms of water balance, sub-basin of Morava is the catchment of lowest rainfall (614 mm) as well as lowest outflow (109 mm), in the Danube basin. The Morava River basin is characterized by a drainage system with the maximum average monthly flows during the Spring season (March and April), and the smallest average monthly discharges in the Summer - Autumn seasons (August and September).

The regime of low water levels is an important phase of the hydrological cycle, which is associated with the occurrence of minimum flows. Low flows are concentrated during two periods: Summer-Autumn period with a minimum in the months of August to October, and the winter depression usually with a minimum in January.

Table 2 Basic characteristics of the gauging profiles

Gauging station	Sastin-Straze	Myjava	Borinka
Catchment	Morava	Morava	Morava
River name	Myjava	Myjava	Stupavka
Catchment area [km^2]	640.04	32.53	35.74
Catchment altitude [m a.s.l.]			
• Min.	167.56	324.53	217.81
• Max.	820	820	651.91
• Average	303.62	472.54	462.67
Average slope [°]	5.96	8.66	9.24
Density of the river network [$km.km^2$]	1.22	1.48	1.38
Forest coverage [%]	34.92	41.4	84.66
Average annual discharge [$m^3.s^{-1}$]	2.51	0.22	0.35

Fig. 1 The Slovak part of the Morava River basin, study area.

2.1 Water temperature at river cross-section

Figure 2 shows the relation between the mean annual water temperature (*To*) of the Morava River at station Zahorska Ves and the mean annual air temperature (*Ta*) at Bratislava–airport station, 1956–2011. The mean annual temperatures of both series are identical since the year 1991. The mean annual water temperature corresponds to the mean annual temperature of the environment through which the river flows. The air temperature increased in the period 1971–1998. In case of water temperature the increase was much more moderate in last twenty years.

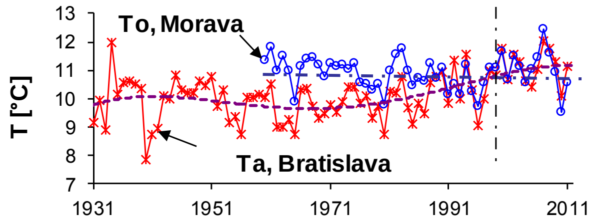


Fig. 2 Long-term trend of the mean annual air temperature (*Ta*) in Bratislava (1931–2011) and of the mean annual water temperature (*To*) of the Morava River at station Zahorska Ves (1955–2011).

Since the period of introducing the automatic measuring stations, the mean annual air and water temperatures are identical and the relation between them is very close (Fig. 2). The long-term water temperature trend of the Morava River was evaluated from the series of mean annual water temperature (*To*) and maximal annual water temperature (*To, max*) in the period 1956–2010. The mean annual water temperature of the Morava River was decreasing in 1956–1996, but the trend is increasing since 1996. The series of maximal annual water temperature does not show neither increasing nor decreasing trend, [9].

In accordance with an applicable standard, the water temperature is measured below the surface, usually at the site of water gauge. Location of measurements should be selected on the basis of temperature measurement of the entire river cross-section. The water temperature may not be the same throughout the river cross-section. The measurement site must guarantee detection of the average water temperature. Part of the suitable cross-section detection is upstream field survey in order to determine whether there are not discharged other waters into the river that will affect the river temperature regime. In place of the water temperature measurement, the water must flow still. The water temperature is measured at least 0.5 m far away from the bank. The water temperature in the stream is affected by several factors:

1) The nature of the stream: flow velocity, flow depth, channel shape, riparian vegetation, altitude, size, flow, etc.,
2) The climate conditions,
3) The anthropogenic factors.

The experimental measurements of water temperature in the transverse profile Morava: Moravsky Svaty Jan (Fig. 3) was performed to determine the differences in water temperature.

Fig. 3 Gauging profile Morava: Moravsky sv. Jan, the bridge at Moravsky sv. Jan.

Probes with a three-minute entry of water temperature, water level and conductivity were used for measurements. The probes were fixed on a steel wire with weights and were triggered off the bridge into the Morava River from the left bank in 5 meter intervals. The bridge is not situated perpendicular to the Morava River and the length of the bridge over the stream in Moravsky Svaty Jan is 70 meters. The course of water temperature measured on 29.09.2011 at gauging profile Morava: Moravsky Svaty Jan in depths of 0.3 m and 1 m is illustrated in Fig. 4. The experiment started at 10:43 am and ended at about 11:24 am. The average daily water temperature according to SHMI (Slovak Hydrometeorological Institute) measurements was 17.6°C.

The measurements of individual physical and chemical water quality indicators in selected gauging profiles Morava: Moravsky Svaty Jan (Fig. 3) and Morava Hohenau (Fig. 5) are conducted in accordance with the intergovernmental treaty on the regulation of water management issues on transboundary waters from 1967.

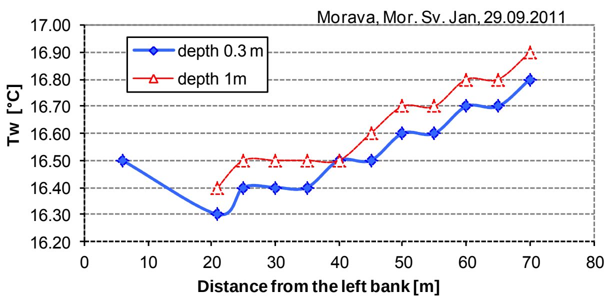


Fig. 4 Experimental water temperature measurement at gauging station Morava: Moravsky Svaty Jan, 29.09.2011, blue line: measurement in depth 0.3m and red line: measurement in depth 1m.

Fig. 5 Morava: Hohenau, Austrian gauging profile, the right bank (approx. 100 m downstream of the bridge at Moravsky sv. Jan).

3 Methods – autoregressive models

Many activities regarding water resource systems require a forecast and an accurate prediction helps to optimize other issues. A time series (TS) is a sequence of observations of a variable, which should be predicted for one or more periods ahead. One of the main TS models is ARMA (Auto-Regressive Moving Averages), and one of its variations is ARIMA (Auto-Regressive Integrated Moving Average), ARIMA is considered the most effective ARMA method. This method is exploited in various sectors: Frausto-Solis et al. used this method for short-term streamflow forecast [10]; Hernandez et al. used this method for testing the randomness of the results of three lotteries and to check if there were any patterns, studying them as time series [11]; Popescu et al. used this method for simulation prognosis of heat demand taking into consideration two components: the space heating and domestic warm water heat demand [12].

Linear autoregressive models represent the very suitable means to describe the periodic time series with strong stochastic character. They are simple autoregressive models of the processes AR (p), MA (q) and the combination of ARMA (p, q) as well as the integrated form ARIMA (p, d, q). ARIMA model has several advantages. It is highly flexible, fast responding and adapts to changing the nature of the test process. The model is able to model the stochastic seasonality, and even trend, better than the classical time series analysis [13]–[20].

Effect of air temperature increase on the water temperature plays an important role in relation to the development and implementation of effective measures for the protection of water resources and ensuring a sufficient amount of quality water.

Obviously, the extreme air temperature increase is reflected in the growth of the water temperature in the streams. This expected increase can be evaluated using models that enable the prediction of the time-series, in this case the water temperature, on the basis of the air temperature.
For this purpose, several autoregressive ARIMA models have been tested with two additional regression components (regressors) - air temperature and flow rates in the flow. Priority attention in this work is concentrated on the maximum temperature. Models have therefore been designed for maximum average daily air temperature and maximum average daily water temperature in monthly step.

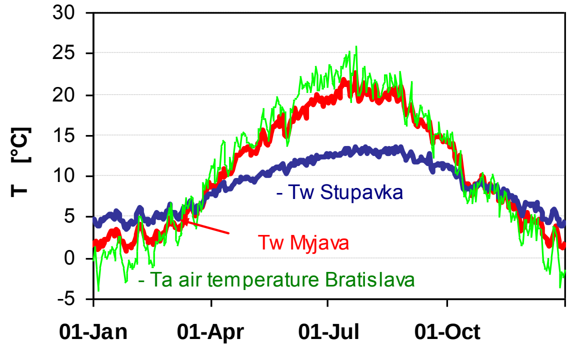
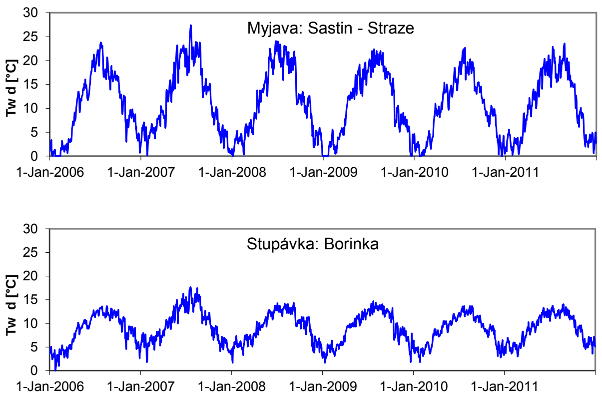


Fig. 7 Comparison of the long-term daily means of the water and air temperature for the time period 2006–2011.

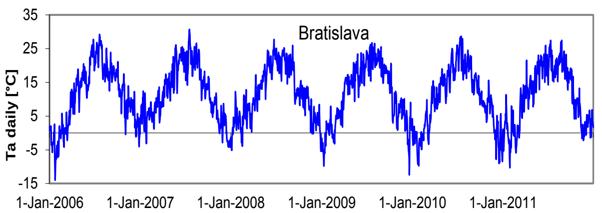
4 Results

4.1 Water temperature data analysis

In this study we will present results from two stations in the Morava River basin: Myjava: Sastin-Straze and Stupavka: Borinka. We used time series of daily water temperature (Fig. 6) measured during the period 2006–2011. The average daily water temperature was calculated from hourly data.
Annual basic statistical characteristics computed from the daily water temperature are in Table 3.



a)



b)
Fig. 6 (a) Measured daily water temperature Tw at stations Myjava: Sastin-Straze and Stupavka: Borinka, and (b) mean daily air temperature Ta at Bratislava (period 2006–2011).

Temperature of Stupavka at Borinka small brook is highly influenced by groundwater temperature (Fig. 7), while large river temperature of Myjava is highly influenced by air temperature. You can see the time delay between air and water temperature of Stupavka. On the Fig. 8 there are shown histograms of daily water temperature time series from Myjava: Sastin – Straze and Stupavka: Borinka rivers. Due to the amount of heat required for the passage of water from the solid state to the liquid, the water temperatures typically have a bimodal histogram.

Table 3 Basic statistical characteristics of the water temperature in gauging stations Myjava: Sastin-Straze (a) and Stupavka: Borinka (b)

a) Myjava: Sastin-Straze

	2006	2007	2008	2009	2010	2011
Tmin	0.00	0.20	0.00	0.00	0.00	0.20
Taver	10.43	11.95	11.60	10.90	10.03	10.84
Tmax	23.80	27.40	24.10	22.40	22.70	23.60
p99	23.40	26.02	23.47	22.00	22.11	22.84
TQd30	20.12	22.41	21.60	20.20	18.80	19.90
p50	11.30	10.60	11.60	12.10	9.90	10.40
Td330	1.09	3.39	3.10	1.10	1.30	2.39
p01	0.00	0.63	0.00	0.00	0.00	0.56
cs	0.01	0.25	0.14	-0.07	-0.01	0.05
cv	0.66	0.60	0.60	0.63	0.63	0.62

b) Stupavka: Borinka

	2006	2007	2008	2009	2010	2011
Tmin	0.00	1.80	1.70	1.70	1.80	3.00
Taver	8.41	9.73	9.18	8.94	8.44	8.90
Tmax	13.70	17.70	14.40	14.70	13.70	14.10
p99	13.34	17.31	14.14	14.14	13.60	13.84
TQd30	12.60	15.20	13.40	13.30	12.50	12.70
p50	9.00	9.30	9.50	9.40	8.80	9.00
Td330	3.50	5.19	5.10	4.19	4.00	4.90
p01	0.96	3.50	3.27	2.00	3.00	3.60
cs	-0.39	0.22	-0.12	-0.24	-0.23	-0.14
cv	0.41	0.38	0.34	0.38	0.36	0.34

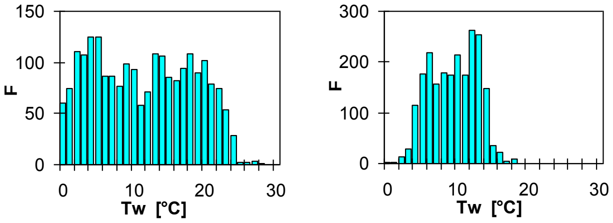


Fig. 8 Histograms of the daily water temperature (time period 2006–2011): left) Myjava–Sastin Straze; right) Stupavka–Borinka.

The choice of the time period (2006–2011) was associated with a gradual transition to the automatic hourly hydrological data collection since 2003 and thus better comparability of water temperature measurements. That period includes the period of hydrological and climatic extremes (drought, high floods).

4.2 Input data to the models

Input data for the autoregressive models are monthly series of maximum average daily water temperature in selected rivers in the Morava River basin (Myjava: Sastin-Straze and Stupavka: Borinka). Selected hydrometric stations represent two types of rivers (medium and small) and in their surrounding area there was not located significant source of anthropogenic effects.
As a regressor the monthly series of maximum average daily air temperature in the Bratislava-airport station were used.

4.3 Choice of the autoregressive models

The process of model selection is presented on data from gauging station Myjava: Sastin-Straze for the period 2006–2010. Following autoregressive models were tested (with air temperature as regressor):
(A) ARIMA(1,0,1)x(1,0,1)12 + 1 regressor;
(B) ARIMA(1,0,0) + 1 regressor;
(C) ARIMA(1,0,0) with constant + 1 regressor;
(D) ARIMA(1,0,1) + 1 regressor;
(E) ARIMA(1,0,1) with constant + 1 regressor.
Procedure for autoregressive models testing is shown on the model simulation (A). When testing other model simulations (B)–(E), we proceeded by analogy. The regressor was the monthly maximum of mean daily air temperature at station Bratislava–airport for the same time period. The resulting parameters of the model simulation (A) ARIMA (1,0,1)x(1,0,1)12+1 regressor are given in Table 4.
The marginal significance levels of each model parameter (P-value) were less than 0.05, so any parameter of the model has not to be excluded.

Table 4 Parameters of the model ARIMA (1,0,1) x (1,0,1) 12 + 1 regressor *Tam Br* (air temperature Bratislava Airport)

Parameter	Estimate	Stnd. Error	T-test	P-value
AR(1)	0.101838	0.0419494	2.42764	0.017850
MA(1)	-0.490689	0.1147440	-4.27637	0.000061
SAR(1)	0.112752	0.0334248	3.37329	0.001230
SMA(1)	-0.707946	0.0794354	-8.91222	0.000000
Tam Br	0.661843	0.0295140	22.42470	0.000000

Where: AR (1) - autoregressive component, MA (1) - moving average model, SAR (1) - seasonal autoregressive component, SMA (1) - Component of the seasonal moving averages, *Tam Br* - air temperature at the Bratislava-airport, Estimate - Preliminary calculation, Stnd. Error - standard deviation, *T*-test verification of normal distribution, *P*-value - significance level; thereby the higher value of *P* indicates the lower dependency. *P*-values less than 0.05 indicate a significant dependence.

Table 5 Comparison of predictions for the 5 selected models

Model	RMSE	RUNS	RUNM	AUTO	MEAN	VAR
(A)	1.11349	OK	OK	**	OK	OK
(B)	1.58388	OK	**	***	OK	***
(C)	1.45784	OK	**	OK	OK	**
(D)	1.43085	OK	OK	**	OK	OK
(E)	1.38074	OK	OK	OK	OK	OK

Where: RMSE = residual standard deviation; RUNS = number of rising and falling courses; RUNM = number of traces above and below the median; AUTO = Box-Pierce test of auto-correlative course; MEAN = t-test; VAR = F-test; OK = not significant ($p \geq 0.10$), * = 90% limit/interval of reliability/confidence interval, ** = 95% limit/interval of reliability/confidence interval, *** = 99% limit/interval of reliability/confidence interval.

The comparison of the prediction results for selected 5 models is in Table 5. On Fig. 9 there are depicted observed and modeled temperatures by model A.
The models were verified such a way that a period of parameters calibration was reduced by one year (2006–2010), and the last year 2011 (12 values) was used for model verification.

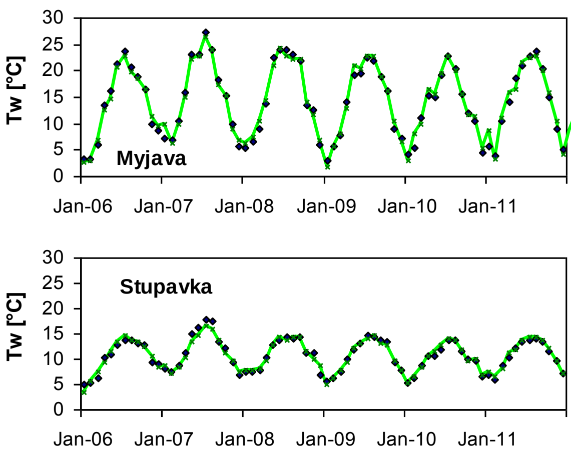


Fig. 9 Comparison of observed (points) and modeled maximum monthly water temperatures.

4.4 Evaluation of the forecast errors

If the model of the time series is known, we need to know how it fits the measured data. This is why differences between measured data yt and those predicted at time t (ŷt), i.e. residuals yt - ŷt = et, t = 1, 2, ..., N, are evaluated. Then the quality of the model, i.e., whether we can accept it, can be estimated by the following interpolation criteria [19]:

Absolute errors:

- Mean error

$$ME = \frac{1}{N}\sum(y_t - \hat{y}_t) \quad (1)$$

- Mean squared error

$$MSE = \frac{1}{N}\sum(y_t - \hat{y}_t)^2 \quad (2)$$

- Root mean squared error

$$RMSE = \sqrt{MSE} \quad (3)$$

- Mean absolute error

$$MAE = \frac{1}{N}\sum|y_t - \hat{y}_t|| \quad (4)$$

Relative errors:

- Mean absolute percentage error

$$MAPE = \frac{1}{N}\sum\left|{(y_t - \hat{y}_t)}/{y_t}\right|.100\% \quad (5)$$

- mean percentage error

$$MPE = \frac{1}{N}\sum\frac{(y_t - \hat{y}_t)}{y_t}.100\% \quad (6).$$

The values of selected criteria of accuracy for the test ARIMA models A–E are given in Table 6. Based on the results we can state that the most suitable models for the specified criteria are the A and E models.

Table 6 Overview of the different accuracy criteria for models A–E

Model	MSE	MAE	MAPE	ME	MPE
(A)	1.23985	0.85732	9.44931	-0.0803246	-1.92328
(B)	2.50869	1.23905	14.5216	-0.261001	-6.61318
(C)	2.12529	1.08533	12.4658	-0.0185187	-0.64766
(D)	2.04732	1.08048	12.6994	-0.175505	-4.70249
(E)	1.90645	1.02908	12.1770	-0.0365269	-1.31357

5 Results of simulations

5.1 Maximum monthly air temperature scenario

The objective of the simulation was to predict the effect of increasing of the maximum monthly air temperature to a maximum monthly water temperature of selected types of flows. For this purpose it was necessary to create a scenario of maximum monthly air temperatures at the Bratislava-airport using measured series of the daily air temperatures during the period 1951–2010, (Fig. 10).

Following scenarios of maximum monthly air temperature were created (Table 7):

1. The first scenario (Scen1) represents the maxima of monthly maximum air temperature during 60-years period 1951–2010;
2. The second scenario (Scen1 + 1) was created adding 1°C to Scen1;
3. The third scenario (Scen1 + 2) was created adding 2°C to Scen1.

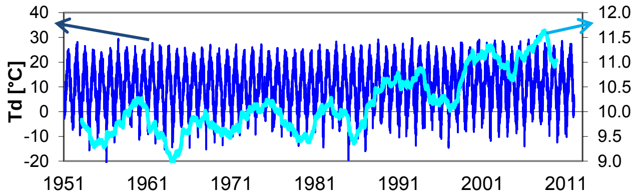


Fig. 10 Average daily air temperature at Bratislava–airport station, period 1951–2011; and 4-years moving averages of the daily values (light line).

Table 7 Scenarios of monthly maximum daily air temperature for Bratislava–airport station

month	1	2	3	4	5	6	7	8	9	10	11	12	max
Scen1, max	14.2	15.7	18.0	21.5	26.7	28.5	30.7	29.7	25.9	21.1	18.4	14.1	30.7
Scen1+1	15.2	16.7	19.0	22.5	27.7	29.5	31.7	30.7	26.9	22.1	19.4	15.1	31.7
Scen1+2	16.2	17.7	20.0	23.5	28.7	30.5	32.7	31.7	27.9	23.1	20.4	16.1	32.7

5.2 Results of maximum daily water temperature simulation

The simulation results of the maximum monthly water temperatures of the Myjava River at Sastin-Straze station according to two autoregressive models for one air temperature scenarios Scen1 + 1 show that in case of maximum air temperature increase by 1°C the water temperature will rise by 0.7°C according to model A and 0.9°C according to model E. The upper 95% limit represents the extreme water temperatures that could be achieved.

The results of the maximum monthly water temperature simulation in the gauging station Myjava: Sastin-Straze according to two AR models and for air temperature scenario Scen1 + 1 are shown in detail in Table 8 and for air temperature scenario Scen1 + 2 in Figure 11.

Table 8 Results of maximum daily water temperature simulation To in Myjava River based on scenario Scen1 + 1 according to two models

	Model A ARIMA(1,0,1)x(1,0,1)12 + 1 regressor			Model E ARIMA(1,0,1) with constant + 1 regressor		
month	To[˚C]	To, upper limit [˚C]	To, lower limit [˚C]	To[˚C]	To, upper limit [˚C]	To, lower limit [˚C]
1	8.4	10.2	6.6	8.8	10.3	7.4
2	9.1	11.3	6.8	9.8	11.5	8.2
3	10.5	12.8	8.1	10.8	12.5	9.2
4	11.9	14.2	9.6	12.2	13.8	10.5
5	14.3	16.7	12.0	14.1	15.8	12.5
6	15.9	18.2	13.5	15.3	17.0	13.7
7	17.2	19.5	14.8	16.4	18.0	14.7
8	17.5	19.8	15.1	16.4	18.1	14.8
9	16.5	18.8	14.1	15.4	17.0	13.7
10	14.5	16.8	12.1	13.6	15.3	12.0
11	12.7	15.1	10.4	12.3	13.9	10.6
12	10.7	13.0	8.3	10.6	12.2	8.9

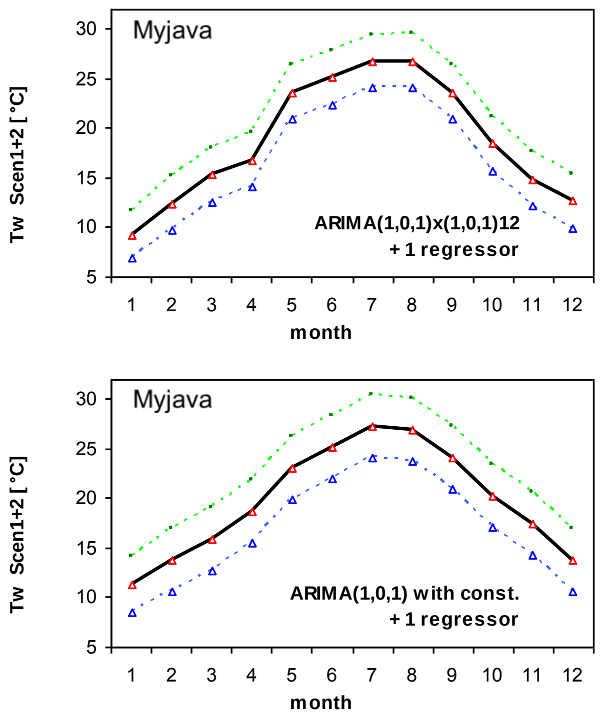


Fig. 11 Results of maximum daily water temperature simulation in gauging station: Myjava: Sastin-Straze based on scenarios Scen1 + 2 (black line) according to two models A and E; upper (green line) and lower (blue line) 95% limits.

The results of the maximum monthly water temperature simulation in the gauging station Stupavka: Borinka according to two AR models and for air temperature scenario Scen1 + 1 are shown in detail in Table 9 and for air temperature scenario Scen1 + 2 in Figure 12.

Table 9 Results of maximum daily water temperature simulation To in Stupavka brook based on scenario Scen1 + 1 according to two models

	Model A ARIMA(1,0,1)x(1,0,1)12 + 1 regressor			Model E ARIMA(1,0,1) with constant + 1 regressor		
month	To[˚C]	To, upper limit [˚C]	To, lower limit [˚C]	To[˚C]	To, upper limit [˚C]	To, lower limit [˚C]
1	8.6	11.0	6.2	10.6	13.4	7.9
2	11.7	14.4	9.0	12.8	16.0	9.7
3	14.6	17.3	11.9	14.9	18.1	11.8
4	16.0	18.7	13.3	17.9	21.0	14.7
5	22.9	25.6	20.2	22.2	25.3	19.0
6	24.4	27.1	21.7	24.3	27.5	21.2
7	26.0	28.7	23.3	26.4	29.5	23.2
8	26.0	28.8	23.3	26.1	29.2	22.9
9	22.9	25.6	20.2	23.3	26.4	20.1
10	17.7	20.5	15.0	19.3	22.4	16.1
11	14.1	16.8	11.4	16.5	19.7	13.4
12	12.0	14.7	9.2	12.9	16.1	9.7

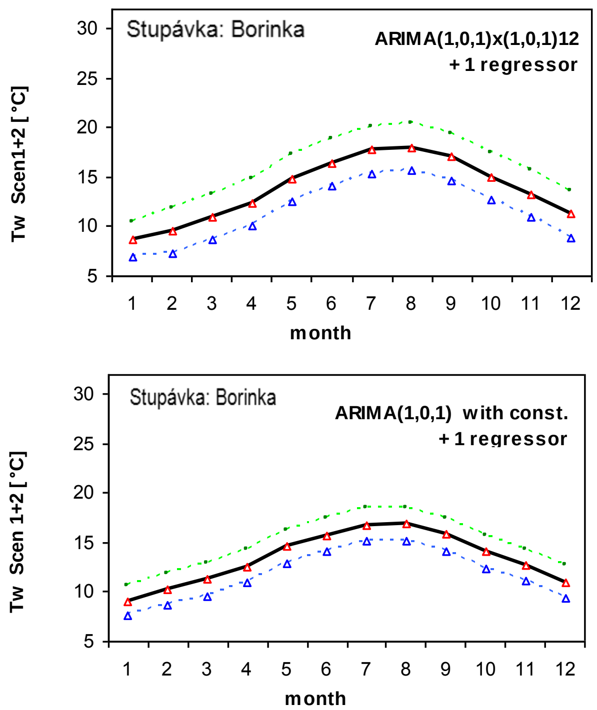


Fig. 12 Results of maximum daily water temperature simulation in gauging station: Stupavka: Borinka based on scenarios Scen1 + 2 (black line) according to two models A and E; upper (green line) and lower (blue line) 95% limits.

The Morava River basin has been chosen as a pilot area. Two hydrometric stations were selected within this area. The aim was to assess the effects resulting from possible air warming to water temperature rise. For this purpose three scenarios of extreme monthly air temperatures at the Bratislava-airport were prepared. No significant difference was found between small, medium and large rivers. It should be noted that this example is a case study processed based on selected criteria for two hydrometric stations where the air temperature as regressor has priority. When testing the water flow (discharge) as regressor, no significant dependence of water flow and water temperature was modeled. This may be caused by high dependence of water temperature on air temperature, which was more dominant than the dependence of water temperature on flow. The water temperature increases with increasing air temperature and flow rates mostly decline (particularly during dry summer months). It is possible that, for a constant flow rate test vs. scenarios of temperature fluctuations, the mutual regression could show a stronger dependence for small, medium and large flows.

6 Conclusion

The paper is focused on one of the most recent topics: regime of water temperature in streams in the context of climate change.

The monitoring of water temperature in streams and rivers in Slovakia has been successively transferred to the automatic continuous measurement, so the accuracy and the quality of the measurements were rapidly improving. In the national database managed by the Slovak Hydrometeorological Institute there is currently being archived daily average water temperature, calculated from hourly measurements of water temperature in the rivers. These data give a very wide range of processing and analysis of the water temperature development in the Slovak rivers.

The European Commission (EC) issued a document entitled „A Blueprint to Safeguard Europe's Water Resources“ on 14.11.2012. This conception defines and also offers solutions to the problems related to the protection of water resources. Individual sections of the approved concept address the problem areas and suggest ways forward in relation to land use/ecological status, chemical status and water pollution, water efficiency, vulnerability and cross-cutting issues. But it should be kept in mind that these are all inter-connected aspects of water management and the proposed measures will contribute to multiple goals. For instance, water efficiency and vulnerability measures are expected to have positive impacts on ecological and chemical status and vice versa. Great attention is given to current challenges: climate change - extremality (floods, droughts and water shortages).

Water temperature plays a key role from environmental, biochemical as well as chemical point of view. Increase in water temperature, e.g. during extreme and long-lasting heat waves and drought, can cause undesirable chemical and biochemical reactions. The adverse reactions may primary or secondary affect the quality as well as status of surface water, and possibly groundwater as well. For its high correlation with air temperature, water temperature belongs to the parameters for which there are not directly proposed measures for its reduction.

Acknowledgement:

This work was supported by the VEGA project under the contract No. 2/0009/15 “Identification of changes in hydrological regime of streams and mutual relation of extreme hydrologic events in complex river system of the Danube basin” and it results from the project implementation of the “Centre of excellence for integrated flood protection of land” (ITMS 26240120004) supported by the Research & Development Operational Programme funded by the ERDF.

References:

[1] T. Derka, http://www.fns.uniba.sk/prifuk/skripta/kek/t2.htm, 1999.

[2] D. Caissie, The thermal regime of rivers: a review, *Freshwater Biology*, 51, 2006, pp. 1389-1406.

[3] B. A. Sinokrot and J. S. Gulliver, In-stream flow impact on river water temperatures, *Journal of Hydraulic Research*, 38, 2000, pp. 339-349.

[4] Lowney, C.L., Stream temperature variation in regulated rivers: evidence for a spatial pattern in daily minimum and maximum magnitudes, *Water Resources Research*, 36, 2000, pp. 2947-2955.

[5] S.L. Johnson, J.A. Jones, Stream temperature response to forest harvest and debris flows in western Cascades, Oregon, *Canadian Journal of Fisheries and Aquatic Science*, 57, 2000, pp. 30-39.

[6] M. Zelenakova, P. Purcz, T. Solakova, D. Simonova, Statistical Analysis of Low Flows in Eastern Slovakia, *Advances in Environmental Sciences, Development and Chemistry*, 2014, pp. 181-185.

[7] OTN ŽP 3103:05, 2005: Sectoral Technical Standard of environment. Quantity of surface water. The measurement of water levels, water

temperatures and ice phenomena on surface flows. Hydrology of surface water and groundwater. ISSN 1335-1567, 2005.

[8] WFD (Water Framework Directive) 2000/60/EC of the European Parliament and of the Council of the 23 October 2000, establishing a framework for Community action in the field of water policy.

[9] K. Kucarova, M. Valuchova, I. Bartik, K. Melova, R. Magulova, Evaluation of the ecological status of rivers in Slovakia, (in Slovak) Part 4: Podporné prvky kvality - fyzikálno-chemické a hydromorfologické, *Vodohospodársky spravodajca*, 11-12, 2008, ISSN: 0322-886X.

[10] J. Frausto-Solis, E. Pita, J. Lagunas, Short-term Streamflow Forecasting: ARIMA Vs Neural Networks, American Conference on Applied Mathematics (MATH '08), 2008, ISSN: 1790-5117, ISBN: 978-960-6766-47-3, pp. 402-407.

[11] A. Hernandez, F.R. Echeverria, E.B. Gonzalez, F. Pachano, Analysis of the results of lotteries using statistical methods and artificial neural networks, Proceedings of the 6th WSEAS Int. Conf. on NEURAL NETWORKS, Lisbon, Portugal, 2005, pp. 250-255.

[12] D. Popescu, F. Ungureanu, E. Serban, Simulation of Consumption in District Heating Systems, *Environmental Problems and Development*, ISSN: 1790-5095, ISBN: 978-60-474-023-9, 2008, pp. 50-55.

[13] G.E.P. Box, G.M. Jenkins, G.C. Reinsel, Time Series Analysis, Forecasting and Control, 3rd ed. Prentice Hall, Englewood Clifs, NJ., 1994.

[14] D. Damian, N. Patrascu, C.-G. Carstea, L. Patrascu, I.-G. Ratiu, N. DavidAVID, Time Series Applied in Romanian Economy, Proceedings of the 8th WSEAS Int. Conf. on Artificial Intelligence, Knowledge Engineering & Data Bases (AIKED '09), ISSN: 1790-5109, ISBN: 978-960-474-051-2, 2009, pp. 402-406

[15] M. Komornikova, J. Szolgay, D. Svetlikova, D. Szokeova, Combined deterministic - stochastic forecasting of monthly river flows, *Geophysical Research Abstracts*, *EGU General Assembly*, 10, EGU2008-A-05501, SRef-ID: 1607-7962/gra/EGU2008-A-05501, 2008.

[16] M. Komornikova, J. Szolgay, D. Svetlikova, D. Szokeova, S. Jurcak, A hybrid modeling framework for forecasting monthly reservoir inflows, *J. Hydrol. Hydromech.*, 56, 3, 2008, pp. 145-162.

[17] D. Svetlikova, M. Komonikova, S. Kohnova, J. Szolgay, K. Hlavcova, Analysis of discharge and rainfall time series in the region of the Kláštorské lúky wetland in Slovakia, XXIVth conference of the Danubian countries on the hydrological forecasting. Conference E-papers. Bled, 2008, 12 pp.

[18] T. Burt, F. Worrall, Non-stationarity in long time series: some curious reversals in the 'memory' effect, *Hydrological Processes*, 21, 2007, pp. 3529-3531.

[19] P. Pekarova, P. Miklanek, J. Pekar, Long-term prediction of the draughts in the Danube and Elbe basins: role of NAO and use of periodicities, In Pollution and Water Resources, Columbia University Seminar Proceedings: Environmental Protection of Central Europe and USA. vol. XL, 2010-2011. - Bratislava; Pécs: Institute of Hydrology SAS: Hungarian Academy of Sciences, 2011, pp. 208-236.

[20] J. Pekar, Autoregression models of gross domestic product, (in Slovak). UK Bratislava, Slovakia, 2004, 146 pp.