Aplinkos tyrimai, inžinerija ir vadyba, 2014. Nr. 2(68), P. 15-24
Environmental Research, Engineering and Management, 2014. No. 2(68), P. 5-14-24
http://erem.ktu.lt

ISSN 1392-1649 (print)
ISSN 2029-2139 (online)

Prediction of River Water Temperature and its Dependence on Hydro-Meteorological Factors

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crossref http://dx.doi.org/10.5755/j01.erem.68.2.6178

(Received in April, 2014; accepted in June, 2014)

Rivers will be among the most sensitive of all ecosystems to the effects of climate change as they are heated by processes similar to those warming the Earth's atmosphere. The river water and air temperatures follow each other closely. The life cycle of lotic biota is regulated by two major physical factors: water temperature and hydraulic conditions. Any change in hydraulic pattern that leads to an alteration of the established thermal regime of a lotic ecosystem will ultimately lead to a dramatic change in the composition and survival of lotic biota. In order to assess the impacts of potential climate change on thermal regime of water bodies, it is important to know the long range forecasts for various climatic parameters. For this purpose the modelling of water discharge and forecasting of future changes are performed. This paper provides the long-term changes in the Lithuanian river water temperature according to two models and emissions scenarios. This paper evaluates the changes of warm season (May-October) water temperature and heat runoff of Lithuanian rivers (Nemunas, Merkys and Dubysa) with different thermal regimes at the end of the 21st century (2071–2100) comparing to the climate normal period (1961-1990) using two climate change models (ECHAM5 and HadCM3 global climate models and the A2 and B1 emissions scenarios) and hydrological modelling (HBV model).

Keywords: *river, climatic parameters, water temperature, forecast, HBV*

1. Introduction

There is a growing consensus among environmental scientists that the Earth experiences a gradual increase in temperature. According to the World Meteorological Organization, (WMO), over the 20th century the global average surface temperature has increased by more than 0.6*℃* above the long-term average, and the period of 2001-2010 was the warmest decade on record since modern meteorological records began around the year 1850 (WMO 2013). According to the Climate Atlas of Lithuanian Hydrometeorological Service (Lithuanian Hydrometeorological Service 2013) average annual air temperature in Lithuania in 1981-2010 was 6.9*℃* (standard climatic normal of 1961–1990 was 6.2*℃*). The warmest decade on record was 2001-2010. The year 2008 was the warmest on record, with positive anomaly of 2.1*℃*.

There are persuasive reasons for believing that rivers will be among the most sensitive of all ecosystems to the effects of climate change. They are heated by processes similar to those warming the Earth's atmosphere, and hence river water and air temperatures follow each other closely (Caissie 2006). In addition to these thermal effects, river ecosystems are directly influenced by water discharge of the river, precipitation and other hydrometeorological influences. Climate change increasingly modifies the temporal variability of a river flow; consequently ecological effects will be unavoidable.

The life cycles of lotic biota appear to be regulated by two major physical factors: water temperature and hydraulic conditions (Gore *et al.* 2008). Synthetic measure of water discharge and water temperature of the river – heat runoff (heat content in the river water) is useful to define the characteristics of a watershed's in response to climate change (Liu and Yang 2011). Any change in hydraulic pattern that leads to an alteration of the established thermal regime of a lotic ecosystem will ultimately lead to a dramatic change in the composition and survival of lotic biota (Gore *et al.* 2008). Water temperature influences distribution, growth rate, activity of all organisms living in the aquatic ecosystems. Temperature is a key environmental variable for fish and other ectotherms (cold-blooded), and a major component of climate change (Davidson and Hazlewood 2005). Ectothermic organisms dominate in aquatic communities and rising water temperatures can directly affect the metabolism and development of many lotic species (Durance and Ormerod 2007). Temperature also affects fundamental ecological factors, such as oxygen concentration, production, and decomposition. Rising water temperature and related changes in ice cover, oxygen levels and water circulation have already contributed to earlier migrations of fish in rivers (Wagner 2008).

Applications of different models for simulation and prediction of river water temperature have been widely reported in the literature (Smith 1981; Mackey and Berrie 1991; Webb and Walsh 2004; Ahmadi-Nedushan *et al.* 2007). The stochastic modelling of daily mean water temperatures on the Moisie River located in Quebec, Canada was presented in (Ahmadi-Nedushan *et al.* 2007). Two different methods (simple linear regression equations and empirical equation) of predicting river temperatures over a wide range of time scales were detailed in (Smith 1981). The research of the UK river water temperature suggests that global climate warming would cause river water temperatures to increase during the 21st century. Temperature increase would be very different depending on the climate change scenarios (Webb and Walsh 2004). The water temperatures of four English chalk streams, which have a large groundwater component in their discharge, were studied in (Mackey and Berrie 1991). Simple linear regression models were used to describe mean monthly water temperature as a function of mean monthly air temperature.

The hydrological regime of Lithuanian rivers which are the main fresh water source is well studied therefore the thermal regime reveals a lack of broader researches. River water temperature modelling and prediction have never been done in Lithuania. This paper provides the long-term changes in the Lithuanian river water temperature according to two models and emissions scenarios.

The aim of this work is to quantify how climate change will affect warm season (May-October) stream discharge, water temperature and its synthetic measure – heat runoff in Lithuanian rivers (Nemunas, Merkys and Dubysa) with different thermal regimes at the end of the 21st century (2071–2100) using climate change models and hydrological modelling.

2. Study area

The rivers Nemunas, Merkys and Dubysa (Fig. 1) were the study objects selected for the analysis of water temperatures and river heat runoff projections. According to Jablonskis and Jurgelėnaitė (2010) Lithuanian rivers were classified according to their water temperature in water gauging stations (WGS). The different rivers and streams or their reaches were classified into warm-water (t≥14.9*°C*), cool-water (13.4*°C*<t<14.9*°C*), and cold-water (t≤13.4*°C*) areas based on their warm season (May-October) average water temperature of standard normal period (1961–1990). The rivers Nemunas, Merkys and Dubysa belong to the different groups of water temperature: the Nemunas at Smalininkai – as a warm-water river, the Dubysa at Lyduvėnai – as a cool-water river and the Merkys at Puvočiai – as a cold-water river.

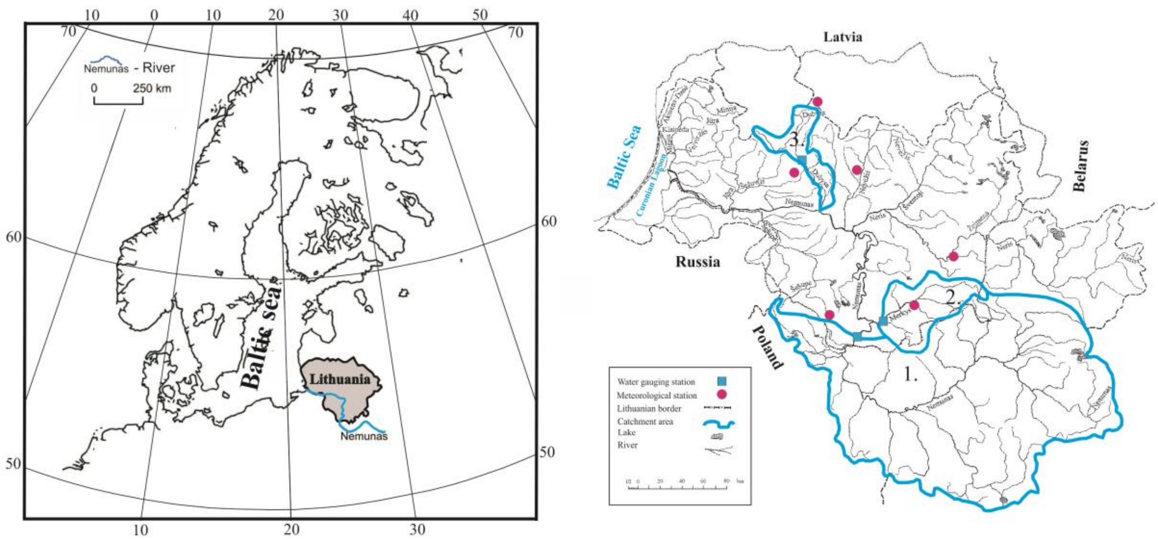

Fig. 1. Study sites and hydrometeorological observation network

The main catchments' characteristics are presented in Table 1. The Nemunas is the largest Lithuanian river whose basin covers 72% of Lithuania's territory. The Nemunas is fed by spring snowmelt (40% of the annual run-off), groundwater (35%) and rainfall (25%). The Merkys is the right tributary that enters the Nemunas in its middle reach. Ground water accounts for 63% in the annual runoff of the Merkys at Puvočiai. The Dubysa - right tributary of the Nemunas joins the Nemunas in its lower reaches. The river is fed by snowmelt waters (35%), rainfall (36%) and groundwater (29%).

Table 1. Characteristics of the Nemunas, Merkys and Dubysa rivers

River	Water gauging station	Catchment's area, km^2	Hydrometeorological characteristics				Land cover, %			
			Average annual discharge, m^3/s	Specific discharge, l/s km^2	Average annual precipitation, mm	Average annual water temperature, °C (1961–1990)	lakes	forests	wetlands	other
Nemunas	Druskininkai	37400	208	5.57	650–700	16.0	1.0	24.6	4.5	69.9
Merkys	Puvočiai	4300	31.2	7.25	600–650	13.3	0.9	40.0	10.0	49.1
Dubysa	Lyduvėnai	1070	8.29	7.75	700–750	14.2	0.8	13.0	3.7	82.5

3. Materials and methods

The daily discharge and monthly water temperature data of Druskininkai, Puvočiai and Lyduvėnai water gauging stations (WGS) as well as air temperature and precipitation data of Vilnius, Varėna, Lazdijai, Raseiniai, Šiauliai and Dotnuva meteorological stations (MS) (Fig. 1) for the period of 1961–1990 were used in this study. The river water temperature predictions were carried out according to the ECHAM5 and HadCM3 global climate models and the A2 and B1 emissions scenarios during the period of 2071-2100. Climate scenarios data are stored in the database of *World Data Center* for Climate (WDCC) in Hamburg, Germany (http://cera-www.dkrz.de/WDCC/ui/Index.jsp). Global model output data (air temperature and precipitation) are prepared for the grids where the cell sizes are 1.865° latitude × 1.875° longitude for ECHAM5 model, and 2.5 × 3.75° for HadCM3 model (Thomas *et al.* 2009; Chou 2012). The obtained projection results were compared to the data of 30-year (1961–1990) climate normal period (climatological standard normal or baseline period). Correlation between the river water temperature and discharge or climatic parameters (air temperature and precipitation) was estimated for the period of 2071–2100.

3.1. Water temperature prediction

Relationships between average monthly water temperatures of the warm season of the Nemunas, Merkys and Dubysa rivers and air temperatures of the closest meteorological stations were calculated for the period of 1961–1990. Strong correlations between water and air temperatures were estimated: water temperature of the Nemunas at Druskininkai well correlated with air temperature at Lazdijai MS (R=0.98), water temperature of the Merkys at Puvočiai – with air temperature at Varėna MS (R=0.99) and water temperature of the Dubysa at Lyduvėnai – with measured air temperature at Šiauliai MS (R=0.98) (Fig. 2). Linear equations (presented in Fig. 2) and air temperature projections by global climate models (ECHAM5 and HadCM3) and emission scenarios (A2 and B1) in selected MS were used for the prediction of the average monthly river water temperatures for the period of 2071-2100.

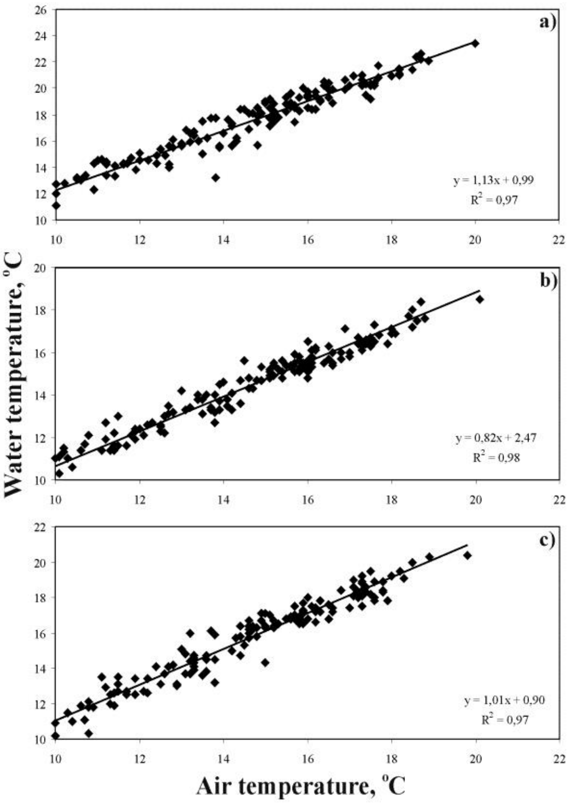

Fig. 2. Correlations between the air temperatures in MS and the river water temperatures in WGS in 1961-1990: a) Lazdijai MS – the Nemunas at Druskininkai; b) Varėna MS –the Merkys at Puvočiai; c) Šiauliai MS –the Dubysa at Lyduvėnai

3.2. Modelling of the water discharge of the Nemunas, Merkys and Dubysa rivers using HBV model

Simulations of the water discharges of the Nemunas at Druskininkai, the Merkys at Puvočiai, and the Dubysa at Lyduvėnai were performed for the period of 2071–2100 with a HBV model, which is often used to simulate discharge response to a changing climate. The semi–distributed conceptual HBV model was developed at the Swedish Meteorological and Hydrological Institute (Bergstrom 1995). The observed meteorological and the regional climate model results (daily air temperature and precipitation), transferred to meteorological station sites, were used for the hydrological modelling. The main model routines are calculation of precipitation and snow accumulation, snow fall distribution, and runoff generation. These routines have components of snow accumulation, interception storage, soil moisture storage capacity, groundwater storage and runoff response, soil and lake evaporation. The general equation of the HBV model (Integrated Hydrological Modelling System 2005) is:

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + V] \tag{1}$$

where:
P - precipitation;
E - evapotranspiration;
Q - water discharge;
SP - snow pack;
UZ - upper groundwater zone;
LZ - lower groundwater zone;
V - lake or dam volume.

Hydrometeorological information of the period of 1961–1990 (as a climate normal period) was used for the model creation. The period of 1961–1975 was selected for the model calibration, whereas the period of 1976–1990 was used for validation. Calibration process has to be performed until the correlation coefficient R is the greatest and the total deviation is the least.

In order to use these prognostic climate data to predict the river discharge, meteorological information from the mesh points, which were used in global models, had to be transferred to the meteorological station locations. For this purpose, the methodology developed at the Department of Hydrology and Climatology of Vilnius University (Rimkus *et al.* 2007) was applied. Output data of climate change models (P and T) are presented at a monthly time scale, while a hydrological modelling requires daily average values. The Delta method was used to recalculate the monthly average air temperature and precipitation data to the daily values. The calculation was performed using the following equations:

$$T_s = T_i + (T_{m.s} - T_{m.i}) \tag{2}$$

$$P_s = P_i \frac{P_{m.s}}{P_{m.i}} \tag{3}$$

where:

T_i, P_i, - daily values of measured water temperature (*ºC*) and precipitation (mm);

$P_{m.i}$, $T_{m.i}$ - average monthly values for the climatological normal period (1961-1990);

$P_{m.s}$, $T_{m.s}$ - average monthly water temperature and precipitation values according to the regional climate change scenarios;

3.3. Heat runoff prediction

Heat runoff (*J*) of the rivers Nemunas at Druskininkai, the Merkys at Puvočiai and the Dubysa at Lyduvėnai was calculated according to equation (Odrova 1984):

$$\Theta = c \cdot \rho \cdot Q \cdot t \cdot T \tag{4}$$

where:
Θ - heat runoff (J or cal);
t - the average water temperature (°C);
Q - water discharge (m^3/s);
T - time interval (s);
c - specific heat capacity of water (J/g °C);
ρ - water density (kg/m^3).

Heat capacity and density of water were taken as constant values (ρ = 1, c = 4.186 J/g ºC*).*

Predicted water temperatures of the investigated rivers were assessed by the relationship between the water temperature and air temperature of the closest meteorological stations (Fig. 2). Water discharges were forecast according to climate scenarios using the hydrological models. According to average monthly water discharge and water temperature data, the average monthly heat runoff for the warm season (May-October) was calculated, evaluating different month duration in seconds. The heat runoff for individual years was calculated as the mean of average monthly values during the warm season (May-October).

Average annual means of the water temperature and heat runoff were established for the warm (May-October) season because at that time the most intensive vital activities take place in the water bodies.

4. Results and discussions

4.1. Correlation among water temperature and other hydrometeorological factors

It was found that the correlations between the water and air temperatures were very strong in the period of 1961–1990 (Fig. 2). Correlations between the water temperature and precipitation or water discharge were not strong in the period of 2071–2100 (Table 2). Weak positive correlations were obtained between water temperature and precipitation, whereas weak negative relationships were between the water temperature and discharge. The strongest correlation was identified for the River Dubysa at Lyduvėnai. This can be explained by the fact that the small rivers are more dependent on climatic factors (water heats up more quickly or cools down more rapidly) compared to the larger rivers (for example, the River Nemunas).

Table 2. Correlation between projected water temperatures and precipitation or river discharges for 2070-2100 (under ECHAM5 and HadCM3 GCM as well as A2 and B1 ES)

River-WGS	Correlation	
	T_W-P	T_W-Q
Nemunas-Druskininkai	0.06-0.43	0-(-0.18)
Merkys-Puvočiai	0.01-0.42	(-0.03)-(-0.17)
Dubysa-Lyduvėnai	0.10-0.32	(-0.2)-(-0.35)

4.2. Changes of air temperature comparing the period of 2071-2100 with baseline period

Projected air temperature changes of the warm season (May-October) for the period of 2071-2100 are presented in Figure 3. The obtained results were compared with the data of the climate normal period (1961-(1990) and the increase in the air temperature of the warm period was identified in 2071-2100. Comparing to the climate normals, the maximum increase in air temperature is projected under the HadCM3 model A2 climate change scenario: air temperature is going to increase by 4.5*°C* at Šiauliai MS, 4.1*°C* - Lazdijai MS, 3.9*°C* - Varėna MS. The smallest changes in air temperature are projected under the ECHAM5 model and B1 scenario: air temperature is supposed to increase by 1.7*°C* at Šiauliai MS, 1.4*°C* - Lazdijai MS, 1.6*°C* - Varėna MS comparing to the climate normals. According to the data of all three MS, July is projected to be the hottest month (as well as during the period of climatic normals) with the exception of HadCM3 model and B1 emissions scenario. Under this scenario, August is projected to be the warmest month. Under the HadCM3 model and A2 emissions scenario, the average air temperature of July will be: Šiauliai MS – 21.6*°C*, Lazdijai MS – 21.3*°C*, Varėna MS - 20.9*°C*. Comparing to the air temperature data of the baseline period of 1961-1990, July average temperature will rise by 4.8*°C* (29%), 4.3*°C* (25%) and 4.0*°C* (24%), respectively.

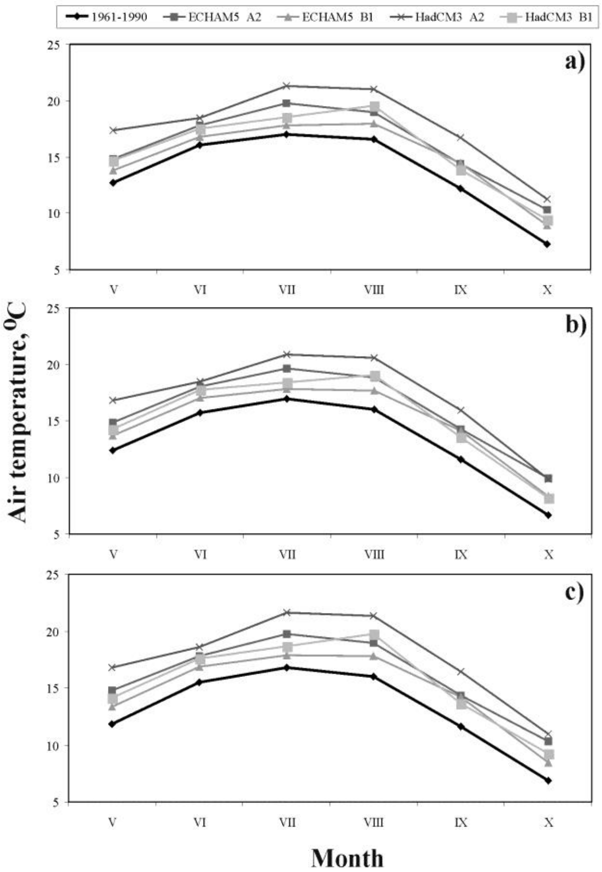

Fig. 3. Average monthly air temperatures in 1961-1990 and predicted temperatures in 2071-2100 according to 4 climate scenarios: a) Lazdijai MS, b) Varėna MS, c) Šiauliai MS

4.3. Water temperature analysis according to the climate scenarios

Regression equations (Fig. 2) were used to obtain the future water temperatures in Table 3. Prognostic air temperature data from global climate models (ECHAM5 and HadCM3) and emissions scenarios (A2 and B1) and relationships between the water and air temperature data (Fig. 2) during the climate normal period (1961–1990) were used for river water temperature prediction. Predicted warm season water temperatures of the Nemunas, Merkys and Dubysa rivers for 2071–2100 are presented in the Table 3.

Table 3. Water temperature changes in the Nemunas, Merkys and Dubysa rivers for 2071-2100 comparing with the period of 1961-1990

River	WGS	1961-1990	Predicted average water temperature of warm season, °C for 2071-2100			
			ECHAM5 A2	ECHAM5 B1	HadCM3 A2	HadCM3 B1
Nemunas	Druskininkai	16.0	19.0	17.9	20.9	18.6
			19%	12%	31%	16%
Merkys	Puvočiai	13.3	15.5	14.6	16.4	14.9
			16%	10%	23%	12%
Dubysa	Lyduvėnai	14.2	17.1	15.9	18.8	16.6
			20%	12%	32%	17%

The warm season water temperature in investigated rivers is expected to increase in 2071-2100 comparing to the baseline period under all analyzed climate models and emission scenarios. Water temperature maximum increase is predicted under HadCM3 A2 (Table 3). Average water temperature of the River Nemunas at Druskininkai for 2071-2100 is expected to rise to 20.9*°C*, which is 4.9*°C* (31%) higher than the water temperature of the baseline period, and the water temperature of the River Dubysa should increase mostly - by 4.6*°C* (32%), while the minimum increase is likely to be in the River Merkys at Puvočiai - 3.1°*C* (23%). The lowest water temperature of the warm season was predicted under ECHAM5 B1 climate scenario (Table 3). Comparing with the water temperature of the baseline period the water temperature of 2071-2100 should be higher by 1.9*°C* (12%) in the River Nemunas, 1.7*°C* (12%) in the River Dubysa and 1.3*°C* (10%) in the River Merkys.

The changes of water temperature were found for individual months (Fig. 4). The highest water temperature in the Rivers Nemunas and Merkys will be under the A2 scenario in July, while under the B1 scenario – in August (Fig. 4, a-b). Analyzing the River Dubysa water temperatures different regularities were identified. Under the ECHAM5 model, regardless of the emission scenarios, the water will warm up most in July (Fig. 4, c). Meanwhile, under the HadCM3 model the warmest water in the River Dubysa will be in July under A2 scenario, while under B1 scenario - in August. The results suggest that the summer water temperature in 3 Lithuanian rivers could increase by 10-12% for a low emission scenario (ECHAM5 B1) and by 23-32% for a high emission scenario (HadCM3 A2), by the 2071–2100. Comparing the predicted water temperatures in the studied rivers, more significant differences were found between A2 and B1 emissions scenarios of the HadCM3 and lower differences between the same scenarios of ECHAM5 model.

Analysis of the results showed the maximum changes in average water temperature of the warm season in the Nemunas and Dubysa rivers (2.9-3.0*°C* higher than the temperature of the baseline period), and the least changes in the River Merkys (2.1*°C* higher than the temperature of the baseline period) in 2071-2100.

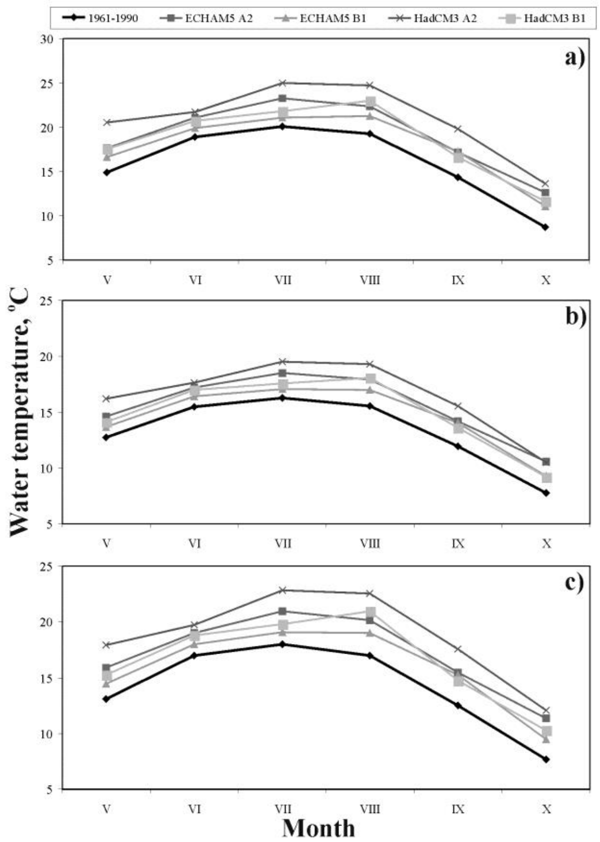

Fig. 4. Predicted water temperatures in Lithuanian rivers for 2071-2100: a) the Nemunas at Druskininkai, b) the Merkys at Puvočiai, c) the Dubysa at Lyduvėnai.

4.4. Water discharge changes according to the climate scenarios

The correlation coefficient between simulated and calculated discharges for the calibration period (1961–1975) in the Nemunas at Druskininkai was R=0.81, in the Merkys at Puvočiai – 0.84 and in the Dubysa at Lyduvėnai – 0.86. The correlation coefficient for the validation period (1976–1990) was R=0.83, 0.80 and 0.80. Considering the model calibration and validation results, it can be concluded that the model is suitable to make forecast of the Nemunas, Merkys and Dubysa runoff in the 21st century. Results of water discharge simulation (Table 4, Fig. 5) show that in 2071-2100 the warm season water discharge of the River Nemunas and the River Merkys will decrease under both models and emission scenarios, compared with the discharge of the climate normal period. During the same period the warm season water discharge in the River Dubysa will slightly increase (1% –11%), except the projected one under the HadCM3 A2 scenario (water discharge will decrease by 13%).

Table 4. Changes of the warm season water discharge in the period of 2071–2100 comparing with the baseline period

River	WGS	Average discharge, m³/s in 1961-1990	Average discharge, m³/s in 2071-2100			
			ECHAM5 A2	ECHAM5 B1	HadCM3 A2	HadCM3 B1
Nemunas	Druskininkai	171	135	148	126	152
			-19%	-21%	-26%	-11%
Merkys	Puvočiai	27.6	21.2	22.3	19.3	22.9
			-23%	-19%	-30%	-17%
Dubysa	Lyduvėnai	4.66	4.71	5.16	4.07	5.02
			1%	11%	-13%	8%

Predicted discharge changes for 2071-2100 are very diverse. The hydrological modelling results show a decrease in the River Nemunas water discharge under both models and emission scenarios comparing the period of 2071-2100 with the baseline period of 1960–1990. Decrease in water discharge will be more significant in May (from 25% to 43%), while water discharge changes in August are projected to be the least. According to different models and emission scenarios it will be lower (from 1% to 10%) or slightly higher (1%) than the water discharge of the baseline period (Fig. 5 a). The reason of decrease in water discharge could be the increase in evapotranspiration due to higher air temperatures and changes in precipitation.

Projected water discharge of the River Merkys in 2071-2100 will decrease for all climate models compared to the baseline period. The largest decrease in the River Merkys discharge will occur in May (from 18% to 36%) and the lowest one - in August (from 14% to 20%) (Fig. 5 b).

In the River Dubysa water discharge will be lower for 2071–2100 relative to 1961–1990 only in May (from 9% to 32%) and October (from 6% to 30%). River discharge is expected to be higher (from 4% to 49%) in June, July and August, and close to the baseline period discharge (fig. 5 c) in September.

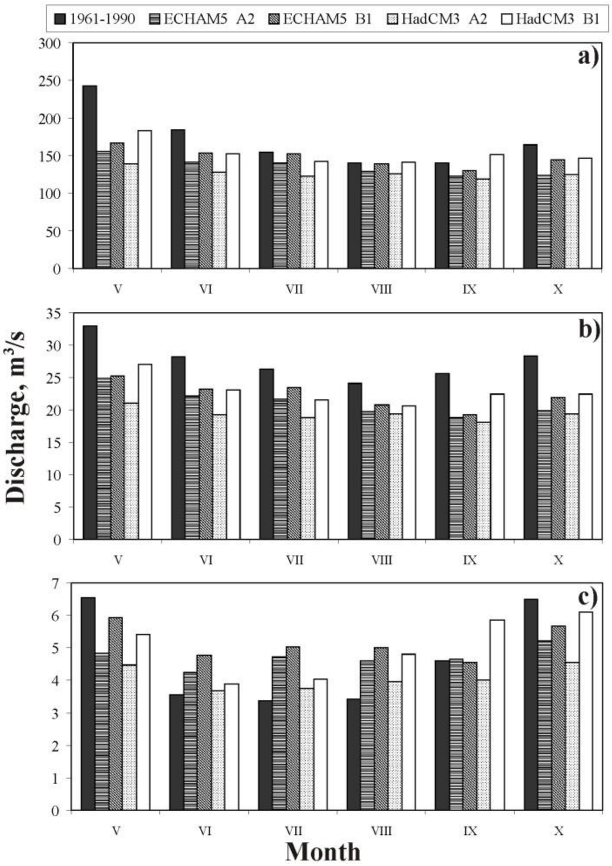

Fig. 5. Average monthly water discharges in 1961-1990 and temperature projections according to 4 climate models in 2071-2100 in a) the River Nemunas at Smalininkai, b) the River Merkys at Puvočiai, c) the River Dubysa at Lyduvėnai

4.5. Heat runoff changes according to the climate scenarios

River heat runoff is influenced by two major hydro-meteorological factors: water discharge and air temperature which determine the thermal state of the water. Using the developed hydrological models, decrease in discharge of 18.0% in the River Nemunas and 22.4% in the River Merkys, and an increase in discharges of 1.7% in the River Dubysa were identified for the last 30-year period of the 21st century compared to the baseline period. Based on the output data of the global climate scenarios (ECHAM5, HadCM3 under the A2 and B1 emissions scenarios), the average water temperature is projected to rise in 2071-2100 compared with the baseline period: in the River Nemunas – by 3.1*°C*, in the River Dubysa – 2.9*°C* and Merkys – 2.1*°C*. These water discharge and water temperature changes will result in a change of river heat runoff: in the River Nemunas and the River Merkys it will decrease (except for HadCM3 B1 climate scenario), and in the River Dubysa it will increase at the end of 21st century compared to the climate normal period (Table 5).

Table 5. Heat runoff changes (in %) in 2071-2100 compared with the baseline period

River-WGS	**Heat runoff change compared with the climate normal period, %**				
	ECHAM5 A2	**ECHAM5 B1**	**HadCM3 A2**	**HadCM3 B1**	**Average**
Nemunas – Druskininkai	-4.6	-3.4	-2.4	+3.2	-1.8
Merkys – Puvočiai	-9.6	-11.1	-12.7	-6.9	-10.1
Dubysa – Lyduvėnai	+29.3	+29.5	+22.6	+30.2	+27.9

The projected decrease in heat runoff in the rivers Nemunas and Merkys at the end of the 21st century could be explained by the considerably reduced water discharge (Table 4, Fig. 5, a and b) and less increased water temperature (Table 3, Fig. 4, a and b) of warm season in these rivers, i.e., an increase in the air temperature is unlikely to be compensated by water discharge decrease. In future increase in heat runoff of the River Dubysa will be determined by two main factors: the relatively small increase in water discharge (by 1.7% in average, Table 4) and increased water temperature (by 2.9*°C*, Table 3, Fig. 4, c), i.e.

the increase in water discharge and the temperature at the same time will be summarized and cause the higher heat runoff.

5. Conclusions

The strongest correlation (0.98–0.99) was estimated between the water temperatures of all investigated rivers (the Nemunas, the Merkys and the Dubysa) and air temperatures of the nearest MS. Much weaker positive correlation was found between the precipitation and the water temperature (0.01 to 0.43), and very weak inverse relationship – between the discharge and the water temperature (0 – (-0.35)).

Climate change is expected mostly to affect the runoff of smaller rivers (e.g. the Dubysa), especially increasing runoff in the summer months (June-August) from 4% to 49%, depending on the model and emissions scenario. Runoff of the larger rivers will decrease, especially runoff of the River Merkys (from 10% to 36%); the runoff of the River Nemunas is expected mainly to decrease in May (25-43%), smaller decrease rates are forecast in the summer months (1-30%).

In the end of the 21st century average water temperatures of the warm season in the Rivers Nemunas, Merkys and Dubysa will increase in comparison with the baseline period (1961-1990) by 1.9*°C*, 1.3*°C* and 1.7*°C*, respectively.

Climate change is supposed to have a minimum impact on those rivers, where the water temperature is low due to groundwater feeding. The inflow of cold groundwater to the channel has a cooling effect on the water temperature during the warm season. Insignificant water temperature changes were established in the River Merkys as groundwater accounts for 63% in the annual runoff of this river.

In the period of 2071-2100 the decreasing heat runoff of the larger rivers such as the Nemunas (an average decrease by 1.8%) and the Merkys (an average decrease by 10.1%) will be influenced by the decreasing water discharge, impact of which will not be able to offset the rising water temperature. In small rivers, such as the Dubysa, due to the increasing discharge and the rising water temperature heat runoff will rise (on average by 27.9%) compared with the climate normals period (1961-1990).

References

Ahmadi-Nedushan B., St-Hilaire A., Ouarda T.B.M.J., Bilodeau L., Robichaud E., Thiemonge N., Bobee B. (2007), Predicting river water temperatures using stochastic models: case study of the Moisie River (Quebec, Canada). Hydrological Processes, Vol. 21, No. 1, pp. 21–34. DOI: 10.1002/hyp.6353;

Bergstrom S. (1995), The HBV Model. In Singh, V.P. (ed.), Computer Models of Watershed Hydrology, pp. 443–476. ISBN 0918334918;

Caissie D. (2006), The thermal regime of rivers: a review. Freshwater Biology, Vol. 51, No. 8, p. 1389–1406. DOI:10.1111/j.1365-2427.2006.01597.x;

Chou S.C., Marengo J.A., Lyra A.A., Sueiro G., Pesquero J.F., Alves L.M., Chagas D.J., Gomes J.L., Bustamante J.F., Tavares P. (2012), Downscaling of South America present climate driven by 4-member HadCM3 runs. Climate dynamics, Vol. 38, No. 3–4, pp. 635–653. DOI: 10.1007/s00382-011-1002-8;

Davidson I.C., Hazlewood M.S. (2005), Effect of climate change on salmon fisheries. Environment Agency Science Report, pp. 62. ISBN: 1 84432 365 X;

Durance I., Ormerod S.J. (2007), Climate change effects on upland stream macroinvertebrates over a 25-year period. Global Change Biology, Vol. 13, No.5, pp. 942–957. DOI: 10.1111/j.1365-2486.2007.01340.x;

Gore J. A., Mead J., Penczak T., Higler L., Kemp J. (2008), Processes influencing aquatic fauna. *In* Harper, D, Zalewski, M, Pacini, N. (eds.), Ecohydrology: Processses Models and Case Studies, pp.62–87. ISBN 9781845930028;

Integrated Hydrological Modelling System. Manual. Version 5.8. 2005. SMHI;

Jablonskis J., Jurgelėnaitė A. (2010), Water temperature Peculiarities of Lithuanian Rivers. Power Engineering, Vol. 56, No. 2, pp. 163–171. [In Lithuanian];

Lithuanian Hydrometeorological Service, 2013. Climate Atlas of Lithuania. P. 176. ISBN 9789955975854;

Liu B., Yang D. (2011) Siberian Lena River heat flow regime and change. Cold Region Hydrology in a Changing Climate. Symposium in Melbourne, Australia, pp. 71-76;

Mackey A.P., Berrie A.D. (1991), The prediction of water temperatures in chalk streams from air temperatures. Hydrobiology, Nol. 210, No. 3, pp. 183-189. DOI: 10.1007/BF00034676;

Odrova T.V. (1984), Conditions of formation of Siberian Rivers heat runoff. Dynamic and thermic of the rivers and reservoirs, 1984, pp. 239-246. [In Russian];

Rimkus, E., Kažys, J., Junevičiūtė, J., Stonevičius E. (2007), Climate change predictions for 21st century in Lithuania. Geographia, Vol. 43, no. 2, pp. 37–47. [In Lithuanian];

Smith, K. (1981) The prediction of river water temperatures. Hydrological Sciences Bulletin, Vol. 26, No. 1, pp. 19–32; http://dx.doi.org/10.1080/02626668109490859;

Thomas M.A., Timmreck C., Giorgetta M.A., Graf H.F., Stenchikov G. (2009), Simulation of the climate impact of Mt. Pinatubo eruption using ECHAM5 – Part 1: Sensitivity to the modes of atmospheric circulation and boundary conditions. Atmospheric Chemistry and Physics, Vol. 9, pp. 757–769. doi:10.5194/acp-9-757-2009;

Wagner I. (2008), Ecohydrology: Understanding the Present as a Perspective on the Future – Global Change. *In* Harper, D, Zalewski, M, Pacini, N. (eds.), Ecohydrology: Processes Models and Case Studies, pp. 303–317. ISBN 9781845930028;

Webb B., Acreman, Maksimovic C., Smithers H., And Kirby C. (eds.) (2004), Hydrology: Science and practice for the 21st century Volume II (Proceedings of the British Hydrological Society International Conference, Imperial College, London, July 2004), British Hydrological Society, pp. 177-191;

WMO. 2013. The Global Climate 2001–2010: A Decade of Climate Extremes. Report No. 1103. pp. 119. ISBN 9789263111036.

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Upių vandens temperatūros prognozė ir priklausomybė nuo hidrometeorologinių veiksnių

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(gauta 2014 m. balandžio mėn.; atiduota spaudai 2014 m. birželio mėn.)

Upės yra viena jautriausių ekosistemų klimato kaitai, nes jas veikia tie patys šiluminiai procesai, kaip ir atmosferą. Upės vandens temperatūra glaudžiai susijusi su oro temperatūra, o jų kaita yra panašaus pobūdžio. Tekančio vandens organizmų veiklą reguliuoja du pagrindiniai fiziniai veiksniai: vandens temperatūra ir hidraulinės sąlygos. Bet koks hidraulinis pokytis, kuris sukelia tekančio vandens ekosistemos nusistovėjusio terminio režimo pokytį, galiausiai sukelia dramatiškus šios ekosistemos organizmų sudėties ir išlikimo pokyčius. Siekiant įvertinti galimą klimato kaitos poveikį vandens telkinių terminiam režimui, svarbu žinoti įvairių klimatinių parametrų kaitos ilgalaikes prognozes. Šiuo tikslu buvo atliktas upių nuotėkio modeliavimas ir galimų pokyčių prognozavimas. Įvertinti kai kurių Lietuvos upių (Nemuno, Merkio ir Dubysos), turinčių skirtingą terminį režimą, šilto metų laikotarpio (gegužės–spalio mėn.) vandens temperatūros ir šiluminio nuotėkio pokyčiai XXI a. pabaigoje (2071–2100 m.), palyginti su klimato normos laikotarpiu (1961–1990 m.), naudojant du klimato kaitos modelius bei du emisijų scenarijus (ECHAM5 ir HadCM3, A2 ir B1) ir hidrologinį modeliavimą (HBV modelį).