ALDONA JURGELĖNAITĖ

WARM SEASON THERMAL REGIME OF LITHUANIAN RIVER WATER AND ITS FORECAST IN THE CONTEXT OF CLIMATE CHANGE

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES, ENVIRONMENTAL ENGINEERING (04T)

Kaunas
2015

KAUNAS UNIVERSITY OF TECHNOLOGY
LITHUANIAN ENERGY INSTITUTE

ALDONA JURGELĖNAITĖ

WARM SEASON THERMAL REGIME OF LITHUANIAN RIVER WATER AND ITS FORECAST IN THE CONTEXT OF CLIMATE CHANGE

Summary of Doctoral Dissertation

Technological Sciences, Environmental Engineering (04T)

2015, Kaunas

Doctoral dissertation has been prepared at the Lithuanian Energy Institute during 2009–2015 at Laboratory of Hydrology.

Scientific Supervisor:
Prof. Dr. Habil. Brunonas GAILIUŠIS (Lithuanian Energy Institute, Technological Sciences, Environmental Engineering – 04T).

Dissertation Defence Board of Environmental Engineering Science Field:
Prof. Dr. Habil. Jurgis Kazimieras STANIŠKIS (Kaunas University of Technology, Technological Sciences, Environmental Engineering – 04T) – **chairman**;
Prof. Dr. Arūnas BUKANTIS (Vilnius University, Physical Sciences, Physical Geography– 06P);
Assoc. Prof. Dr. Jolanta DVARIONIENĖ (Kaunas University of Technology, Technological Sciences, Environmental Engineering – 04T);
Prof. Dr. Violeta MAKAREVIČIENĖ (Aleksandras Stulginskis University, Technological Sciences, Environmental Engineering – 04T);
Prof. Dr. Žaneta STASIŠKIENĖ (Kaunas University of Technology, Technological Sciences, Environmental Engineering – 04T).

Official Opponents:
Prof. Dr. Inga DAILIDIENĖ (Klaipėda University, Physical Sciences, Physical Geography– 06P);
Prof. Dr. Arvydas POVILAITIS (Aleksandras Stulginskis University, Technological Sciences, Environmental Engineering – 04T).

The official defence of the dissertation will be held at public meeting of the Board of Environmental Engineering Science Field at 3 p.m. on 18th December, 2015 in the Session Hall at the Central Building of Lithuanian Energy Institute (Breslaujos str. 3, Room No. 202, Kaunas).

Address: Breslaujos str. 3-202, Kaunas, Lithuania.
Tel. (370) 37 300042, fax. (370) 37 324144, e-mail: doktorantura@ktu.lt

The summary of the Dissertation was sent on 18th November, 2015.

The dissertation is available at the libraries of Lithuanian Energy Institute (Breslaujos str. 3, Kaunas) and Kaunas University of Technology (K. Donelaičio str. 20, Kaunas).

KAUNO TECHNOLOGIJOS UNIVERSITETAS
LIETUVOS ENERGETIKOS INSTITUTAS

ALDONA JURGELĖNAITĖ

LIETUVOS UPIŲ VANDENS ŠILTOJO METŲ LAIKOTARPIO TERMINIS REŽIMAS IR JO PROGNOZĖ KLIMATO KAITOS SĄLYGOMIS

Disertacijos santrauka

Technologijos mokslai, aplinkos inžinerija (04T)

2015, Kaunas

Disertacija rengta 2009–2015 metais Lietuvos energetikos instituto Hidrologijos laboratorijoje.

Mokslinis vadovas:
Prof. habil. dr. Brunonas GAILIUŠIS (Lietuvos energetikos institutas, technologijos mokslai, aplinkos inžinerija – 04T).

Aplinkos inžinerijos mokslo krypties taryba:
Prof. habil. dr. Jurgis Kazimieras STANIŠKIS (Kauno technologijos universitetas, technologijos mokslai, aplinkos inžinerija – 04 T) – **pirmininkas**;
Prof. dr. Arūnas BUKANTIS (Vilniaus universitetas, fiziniai mokslai, fizinė geografija – 06P);
Doc. dr. Jolanta DVARIONIENĖ (Kauno technologijos universitetas, technologijos mokslai, aplinkos inžinerija – 04T);
Prof. dr. Violeta MAKAREVIČIENĖ (Aleksandro Stulginskio universitetas, technologijos mokslai, aplinkos inžinerija – 04T);
Prof. dr. Žaneta STASIŠKIENĖ (Kauno technologijos universitetas, technologijos mokslai, aplinkos inžinerija – 04 T).

Oficialieji oponentai:
Prof. dr. Inga DAILIDIENĖ (Klaipėdos universitetas, fiziniai mokslai, fizinė geografija – 06P);
Prof. dr. Arvydas POVILAITIS (Aleksandro Stulginskio universitetas, technologijos mokslai, aplinkos inžinerija – 04T).

Disertacija bus ginama viešame Aplinkos inžinerijos mokslo krypties tarybos posėdyje 2015 m. gruodžio 18 d. 15 val. Lietuvos energetikos instituto posėdžių salėje (Breslaujos g. 3, 202 kab., Kaunas).

Adresas: Breslaujos str. 3-202, Kaunas, Lietuva.
Tel. (370) 37 300042, Faks. (370) 37 324144, el.paštas: doktorantura@ktu.lt

Disertacijos santrauka išsiųsta 2015 m. lapkričio 18 d.

Su disertacija galima susipažinti Lietuvos energetikos instituto (Breslaujos g. 3, Kaunas) ir Kauno technologijos universiteto (Donelaičio g. 20, Kaunas) bibliotekose.

INTRODUCTION

Natural state of water in surface-water bodies at a given time is characterized by the complex of different characteristics: water level, flow rate, water temperature, turbidity, salinity, mineralization, biomass and others. Water temperature determines the thermal conditions of the water body. Temperature can be defined as a measure of the average thermal energy of a water body. Thermal energy is the expression of kinetic energy of molecules and atoms, so temperature in turn measures the average kinetic energy of these particles. This energy can be transferred as heat flow.

Water temperature is one of the main physical characteristics of surface water bodies, which has direct impact on water quality and the life of aquatic flora and fauna. The temperature of water affects physical and chemical characteristics of water: turbidity, colour, taste, odour, solid content, water: density, viscosity, specific weight, surface tension, conductivity, thermal capacity, acidity, alkalinity, salinity, suspended matter and others. Water temperature has direct impact on the chemical processes in the water body. The self-purification processes of water, chemical reaction rates and other chemical processes are dependent on the water temperature. Dissolved oxygen is especially dependent on water temperature (an inverse relation). Rising water temperature accelerates eutrophication of water body, which is one of the causes of the deterioration of water quality.

Water temperature has a significant impact on biological processes; so it is one of the most important parameters in the research of ecosystems. The life cycle of lotic biota is regulated by two key physical factors: water temperature and hydraulic conditions. Water temperature is a primary driver of the structure of aquatic ecosystems. Thermal conditions may affect growth rate, reproduction, migration, spawning, and even impact mortality of aquatic organisms. Different aquatic species, especially fish, live and thrive within certain optimal ranges of water temperature.

In hydrology, water temperature is not the main characteristic of river runoff; however, a component of water balance – evaporation – is determined by the water temperature of the water body and other factors. In hydro-ecological research and practice, especially where these relate to nutritional base of water bodies (including rivers), fish spawning, self-purification, hydro-ecological systems, and other issues, the hydrothermal regime of biotopes is one of the prevailing factors. In addition, the river ice phenomena and hydrological regime in the spring time are closely related to the water and air temperatures.

River water temperature can be influenced by a number of natural and anthropogenic factors. Air temperature is the main factor affecting the stream temperature. Other factors affecting river water temperature are hydrological regime of the river, river size, orographic conditions (altitude, catchment area, natural water bodies in the river basin) of river basin. Anthropogenic effects such as nuclear and thermal power plants, agricultural land, industrial waste waters, and thermal hydraulic equipment, changing the flow structure, may also influence this important physical parameter.

Thermal conditions of water body are important for supplying water for industrial, agricultural uses and public utilities. Over the last century, complex water supply systems for the collection, transmission, treatment, storage, and distribution of water were developed. In recent years, river water heat runoff has been increasingly used for heating of buildings and supplying domestic hot water using heat pumps.

Heat runoff or thermal energy amount in river water, as an important source of renewable energy, have still been insufficiently studied and evaluated. Summarized hydrothermal data would allow a more rational use of water resources of the rivers. Thermal regime data of the rivers Nemunas and Neris would be useful assessing the impact of cooling waters of the Baltic NPP on the lower reaches of the Nemunas River, and Astravas NPP on the Neris River. It is therefore appropriate to investigate the maximum heat flow and the formation of natural and anthropogenic factors and environmental impact, as well as heat flow and practical usability of reserves, and river sections that are influenced by anthropogenic activities.

Research Relevance

Water temperature is an important environmental factor in water ecosystems, which directly determines the quality of water, especially the oxygen regime and quantitative and qualitative changes in the biota. Species diversity and abundance of lotic biota are strongly associated with the thermal regime of the small and medium-sized rivers. The river thermal resource is a renewable energy source whose practical possibility of the exploitation must be analyzed and assessed.

Previous studies of thermal regime of Lithuanian rivers have been carried out episodically. Research of the thermal regime of the rivers is required for environmental impact assessments of the nuclear and thermal power plants, and industrial objects, and for evaluation of the impact of thermal pollution on the thermal balance and self-purification of the rivers. Information about the river water temperature is useful for fish farming, especially for constructing of fish ponds. Network of water gauging stations is denser than that of meteorological stations in Lithuania; therefore, water temperature could be used as an indicator of climate change.

Object of the Research

Thermal regime of Lithuanian rivers during the warm period (May-October) of the year.

The Aim of the Research

The aims of this research are to assess the changes of Lithuanian river water thermal regime; to identify its potential trends for the end of the 21st century (2071–2100) and evaluate heat runoff of Lithuanian rivers (amount of heat energy).

The Main Objectives of the Research

To achieve the aim of the research, the following objectives have been formulated:

1. To perform a detailed analysis of warm season (May-October) water temperature data of Lithuanian rivers for the period from 1945 to 2010 using a unified methodology.
2. To classify Lithuanian rivers into three groups (warm, cool and cold water) according to the warm season water temperature.
3. To compile a contour map of warm season (May-October) river water temperature, which allows the evaluation of water temperature for the unexplored Lithuanian rivers.
4. To identify climatic and local physical-geographical factors affecting the warm season (May-October) river water temperatures.
5. To evaluate warm season heat runoff (heat resources) of Lithuanian rivers.
6. To assess the impact of climate change on the water temperature of Lithuanian rivers, while performing prediction of the thermal regime for the end of the 21st century (2071–2100).

Hypotheses

1. Lithuanian river water temperature will rise due to the global warming, and river water availability changes will cause heat resources decrease in the future.
2. Lithuanian rivers can be divided into three groups: warm, cool and cold water. The main factor of the river water thermal state is the amount of groundwater inflow to the river.
3. Water in Lithuanian rivers holds a large amount of thermal energy (heat), which can be used as a renewable energy source in the future.

Scientific Novelty and Application of Doctoral Dissertation

For the first time ever, information on hydrothermal regime of Lithuanian rivers and its changes was presented; observations based on classification of rivers according to water temperature were made. Three groups of rivers were identified according to warm period (May to October) multi-annual mean water temperature of 1961-1990 year period. Also, a map of isolines of the warm season (May to October) river water temperature was drawn. Thermal energy resources of largest Lithuanian rivers were calculated in the work. Predictions of water temperature and heat runoff of Lithuanian rivers were made for the end of the 21st century (2071–2100).

The obtained information can be used for: assessing fish hatchery and fishery development opportunities, as well as the impact of thermal pollution on the water heat balance and self-purification capacity of the rivers (energy, sewerage, etc.); preparing Environmental Impact Assessments for power plants and industrial facilities (thermal effects are regulated by law); considering the possibilities for using water heat pumps.

Research scope and structure

The dissertation consists of the introduction, six main chapters that include literature review, methodology, results and conclusions. The scope of the dissertation is 46 pages, with annexes, including 15 figures and 9 tables.

1. RESEARCH OBJECT AND HYDROMETEOROLOGICAL DATABASE

The object of the research is the water temperature of Lithuanian rivers. Systematic observations of the thermal regime of the river water in the most water gauging stations of Lithuanian Hydrometeorological Service started in 1945. Until 2010, water temperatures in Lithuanian rivers were measured at 141 water gauging stations (WGS) that are located in 84 rivers of different size (Fig. 1.1). The longest series in the data set covers 66 years (1945–2010), the shortest one – 2 years. In the largest Lithuanian rivers, water temperature is measured in several WGS: in the Nemunas River (within the territory of Lithuania), at 15 WGS; in the rivers Šventoji, Nevėžis and Šešupė, at 5 WGS; in the rivers Merkys and Nemunėlis, at 4 WGS; and in the rivers Neris, Mūša, Lėvuo and Venta, at 3 WGS.

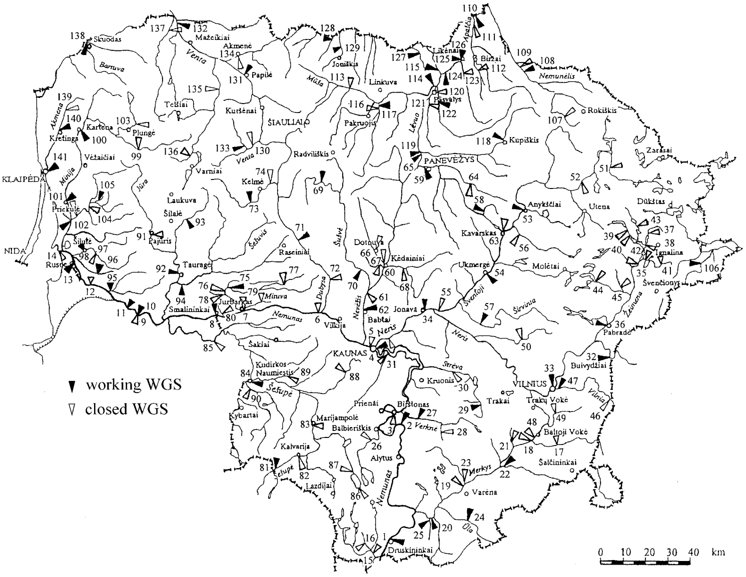


Fig. 1.1. River water temperature measuring sites (WGS)

Historical data series for the entire period of observations (a selected series from 141 WGS) and for the 30-year period (1961–1990), which is considered a standard (a series from 41 WGS), were used for the spatial and temporal analysis of the warm season water temperature. The World Meteorological Organization recommends computing averages of meteorological data at least every 30 years (1931–1960, 1961–1990, 1991–2020, etc.) as well as a decadal update, in part to incorporate newer weather stations. For this study, the period of 1961–1990 was chosen, because some WGS were closed in the last decade of the 20th century, and there was not enough data for the entire period of 1971–2000.

Data series of air temperature and precipitation of the warm season (May-October) from 17 meteorological stations were selected for the same time periods.

Six major Lithuanian rivers (9 VMS) with a long water discharge and temperature monitoring data sets were selected to assess the heat runoff: the Nemunas River – Druskininkai WGS (1945–2010), Nemajūnai WGS (1947–2010), Kaunas WGS (1947–2010) and Smalininkai WGS (1946–2010) VMS; the Merkys River – Puvočiai WGS (1945–2010); Neris – Jonava WGS (1946–2010); Jūra – Tauragė WGS; Mūša – Ustukiai WGS (1957–2010) and Venta – Leckava WGS (1946–2010). The basins of these rivers cover almost the entire territory of Lithuania and represent the rivers of various thermal groups; so according to them, one can consider the heat content/runoff of the rivers of the country. The continuity of data series was regarded important as well.

In order to assess the impact of anthropogenic activities on the heat runoff of warm season (May to October), the Nemunas River at Kaunas WGS, which is located at 208.6 km from the river mouth (basin area at WGS – 46300 km^2), has been selected. The water thermal regime of the Nemunas River at Kaunas WGS is evidently influenced by Kaunas Hydro Power Plant (HPP), which was built in 1960.

Three different size rivers, belonging to the different water temperature groups: the warm water river ($T = 16.0$°C) – Nemunas (Druskininkai WGS); the cool water river ($T = 14.2$°C) – Dubysa (Lyduvėnai WGS) and the cold water river ($T = 13.3$°C) – Merkys (Puvočiai WGS) were selected for the prediction of the thermal regime for the period 2071–2100 (Fig. 1.2). The data sets of water temperature and discharge and air temperature, which have the same period length, were used for the prediction.

Daily water discharge and monthly water temperature data of the rivers Nemunas – Druskininkai WGS, Merkys – Puvočiai WGS, and Dubysa – Lyduvėnai WGS as well as air temperature and precipitation data of Vilnius, Varėna, Lazdijai, Raseiniai, Šiauliai and Dotnuva meteorological stations (MS) of the standard normal period (1961–1990) were used for the prediction of water temperatures and heat runoff at the end of the 21st century (2071–2100).

2. METHODOLOGY

2.1. Methodology for monitoring data processing

Water temperature for the warm season of each year was calculated as an average temperature of six months (May-October). Average annual water temperature of warm period (May-October) and its statistical parameters were calculated for the entire period of observations and the standard normal period (1961–1990).

As the river water temperatures were measured over different time periods, statistical parameters (mean and standard error of the mean, standard deviation, variation and asymmetry coefficients) of different reliability were determined for each WGS separately.

The critical values of the Mann-Kendall S statistic (S_{max}) are used to identify strong and weak trends. (S_{max}) values are defined using p-values (two-sided) of 0.05 and 0.30, which indicate the magnitude of the trend that is likely to be in upper or lower 2.5 % and 15 %, respectively, of the statistical distribution. When the significance of the trend was poor, only 70 %, the trend was regarded as a weak trend (positive or negative), while only trends at the 95 % level were regarded as strong negative or strong positive. The magnitude of trends, expressed by slope of the Kendall-Theil Robust Line, enabled the evaluation of quantitative changes of parameters during the period.

For the analysis of annual thermal cycles, the mean monthly water temperature was calculated for the entire period of the observation (data of the water and air temperatures from 1945–2010 periods were used). Taking the long-term average values of mean monthly water temperature, the intra-annual water temperature curves were fitted for individual rivers. A comparison of long-term annual cycles of water temperature for the rivers of different size and water temperature (warm, cool and cold) was made to determine the differences in intra-annual thermal behaviour of rivers. Also, a comparison of long-term annual thermal cycles of different rivers and air temperature of geographically closest meteorological stations (MS) was made. The relationships between the long-term average monthly river water temperature and air temperature were explored, and coefficients of correlation were calculated.

For the analysis of the diurnal cycle of water temperatures, the hourly measurements have been carried out in the Šventoji River – Anykščiai WGS. Hourly water temperature was measured with a mercury thermometer on August 4, 2011 and July 27, 2012.

2.2. Research methodology of stream heat runoff

The amount of heat (heat runoff) transferred with the river water, where the water temperature in the stream is almost evenly distributed, is generally calculated according to the following formula:

$$\theta = c \cdot \rho \cdot Q \cdot T\, t, \tag{2.1}$$

where θ – the heat runoff (J); T – water temperature (°C); Q – water discharge (m^3/s); t – time interval (s); c – heat capacity of water (cal); ρ – water density (kg/m^3). Water density and heat capacity of water for calculation of heat runoff are taken as constant values (ρ = 1000 kg/m^3, c = 4.187 kJ/kg·K, when water temperature T = 14ºC).

According to average monthly river water discharge and water temperature data, the average monthly heat runoff for the warm season (May-October) was calculated, evaluating that month duration in seconds is different. The heat runoff for individual years was calculated as the average of monthly mean values during the warm season (May-October).

2.3. Methodology of prediction of thermal regime

The prognostic climate change indicators (according to output data of ECHAM5 and HadCM3 global climate models under A2 and B1 emissions scenarios) were used to predict river water temperature for the period of 2071–2100.

The obtained projection results were compared to the data of a 30-year (1961–1990) normal climate period. Correlation between the river water temperature and discharge or climatic parameters (air temperature and precipitation) was estimated for the period of 2071–2100. Water discharge of rivers for the end of the 21st century was simulated using the HBV model (developed at the Swedish Meteorological and Hydrological Institute), which is often used to simulate the effect of climate change on the river runoff.

Relations 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 (Fig. 2.1). Strong correlations between water and air temperatures were estimated: water temperature of the Nemunas River at Druskininkai well correlated with air temperature at Lazdijai MS (r = 0.98), water temperature of the Merkys River at Puvočiai – with air temperature at Varėna MS (r = 0.99), and water temperature of the Dubysa River at Lyduvėnai – with measured air temperature at Šiauliai MS (R = 0.98) (Fig. 2.1). Therefore, linear equations presented in this figure as well as 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.

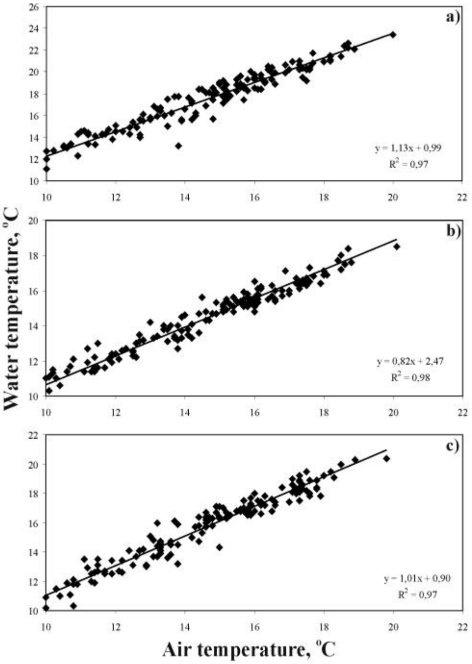


Fig. 2.1. Correlations between air temperatures in MS and the river water temperatures in WGS in 1961–1990: a) Lazdijai MS – Nemunas at Druskininkai; b) Varėna MS – Merkys at Puvočiai; c) Šiauliai MS – Dubysa at Lyduvėnai

HBV model was used for the simulation of water discharge of the rivers Nemunas – Druskininkai WGS, the Merkys – Puvočiai WGS, and the Dubysa – Lyduvėnai WGS for the period of 2071–2100. The observed meteorological elements and the regional climate model outputs (daily air temperature and precipitation), transferred to meteorological station sites, were used for the hydrological modelling.

The main equation of the HBV model:

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + V] \tag{2.2}$$

where P – precipitation; E – evapo-transpiration; Q – water discharge; SP – snow pack; UZ – upper groundwater zone; LZ – lower groundwater zone; V – lake or dam volume;

Heat runoff (*J*) of the Nemunas River at Druskininkai, the Merkys River at Puvočiai and the Dubysa River at Lyduvėnai was calculated according to equation (2.1), in Chapter 2.2.

Predicted water temperatures of the investigated rivers were assessed through the relation between the water temperature and air temperature of the closest meteorological stations (Fig. 2.1). Water discharges were predicted 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).

3. ANALYSIS OF SPATIAL DISTRIBUTION AND TEMPORAL VARIATION OF LITHUANIAN RIVER WATER TEMPERATURES

3.1. Variety of river water temperature

The analysis of the river water temperature indicates that the multi-annual mean of the warm season water temperatures in Lithuanian rivers, according to data from 141 WGS, varies by 9°C. The highest water temperature was found 16.7°C in the branch of the Nemunas River delta called Rusnė, at Panemunė WGS. The lowest water temperature was found 7.7°C in the Creek Smardonė at Likėnai WGS, which is a small stream that is significantly affected by groundwater.

The analysis of the rivers, using water temperature data sets from 41 WGS and covering a standard period of 1961–1990, indicates that an average warm season river water temperature varied from 12.3°C of the Vilnia River at Santakai to 16.1°C of the Šešupė River at Dolgoje) (Table 3.1). The range based on standard norms is 3.8°C. The water temperature of the standard period is approximately 0.17°C or 1.1% lower than the multi-annual average temperature.

3.2. River classification

The classification of Lithuanian rivers is based on the data of the warm season water temperature of 41 WGS (23 rivers) in the standard normal period (1961–1990). The water temperature averages $\overline{T}$ of the warm season (May-October) were calculated for 41 WGS (Table 3.1). The overall temperature average of the standard normal period ($\tilde{T}$ = 14.9°C) was calculated and accepted as the main point for classification of the rivers. The temperature step for this classification is $\Delta T = 0.5$°C, because it was ascertained that in the same river and between separate rivers, water temperature is statistically (α = 0.05) different, when $\Delta T \geq 0.5$°C. The rivers or river reaches, the water temperature data of which covers the period of 1961–1990, were divided into three groups: the warm water ($\overline{T} \geq 14.9$°C), the cool water (13.4°C<$\overline{T}$<14.9°C) and the cold water ($\overline{T} \leq 13.4$°) rivers or river reaches (Table 3.1, Fig. 3.1). Since the water temperature of the standard period differs slightly from the temperature of the whole observation period, all available data of 141 WGS of river temperature were reviewed.

Table 3.1. Long-term average river water temperatures of the warm period

No.*	River – WGS	Basin area at WGS, km^2	Period	Water temperature $\overline{T}$, ºC		
				Whole period	1961–1990	1991–2010
Warm rivers ($\overline{T} \geq 14.9$ºC)						
1	Nemunas-Druskininkai	37400	1945-2010	16.24	16.04	16.76
2	Nemunas-Nemajūnai	42900	1947-2010	15.85	15.59	16.21
4	Nemunas-Kaunas	46300	1947-2010	16.28	15.95	16.66
5	Nemunas-Lampėdžiai	71400	1947-1999	15.89	15.82	-
6	Nemunas-Seredžius	79900	1947-1999	15.58	15.41	-
8	Nemunas-Smalininkai	81200	1946-2010	16.05	15.86	16.32
9	Nemunas-Sovetskas	91800	1946-1991	16.02	15.96	-
13	Nemunas-Rusnė	-	1950-2010	16.24	15.89	16.88
33	Neris-Vilnius	15200	1945-2010	15.35	15.14	15.59
34	Neris-Jonava	24500	1946-2010	15.55	15.41	15.89
35	Žeimena-Kaltanėnai	752	1961-2000	15.90	15.75	-
59	Nevėžis-Panevėžys	1130	1948-2010	15.66	15.47	15.96
61	Nevėžis-Dasiūnai	5530	1961-2005	15.89	15.94	-
70	Šušvė-Josvainiai	1100	1947-2010	15.84	15.70	15.94
72	Dubysa-Padubysys	1840	1947-1999	15.17	15.01	-
85	Šešupė-Dolgoje	5830	1956-1991	16.07	16.07	-
92	Jūra-Tauragė	1660	1946-2010	15.81	15.46	16.24
100	Minija-Kartena	1220	1948-2010	15.06	14.90	15.28
113	Mūša-Miciūnai	792	1945-1999	15.30	15.36	-
114	Mūša- Ustukiai	2280	1957-2010	15.62	15.36	16.01
120	Lėvuo-Pasvalys	1560	1945-2000	15.30	15.13	-
131	Venta-Papilė	1560	1947-2010	15.54	15.36	15.70
132	Venta-Leckava	4020	1945-2010	15.58	15.33	15.86
Cool rivers (13.4°C< $\overline{T}$ <14.9°C)						
27	Verknė-Verbyliškės	694	1947-2010	14.14	13.90	14.32
36	Žeimena-Pabradė	2600	1947-2010	14.64	14.46	14.87
53	Šventoji-Anykščiai	3600	1945-2010	15.02	14.85	15.17
54	Šventoji-Ukmergė	5440	1945-2010	14.92	14.65	15.12
69	Šušvė-Šiaulėnai	162	1951-2010	14.71	14.60	14.81
71	Dubysa-Lyduvėnai	1070	1945-2010	14.42	14.20	14.84
82	Šešupė-Kalvarija	444	1945-2004	14.48	14.24	-
91	Jūra-Pajūris	877	1946-1999	14.75	14.61	-
93	Akmena-Paakmenis	314	1950-2010	14.08	13.94	14.21
94	Šešuvis-Skirgailai	1880	1946-2010	15.08	14.70	15.71
104	Veiviržas-Mikužiai	336	1945-1999	13.77	13.69	-
118	Lėvuo-Kupiškis	302	1945-2010	14.46	14.39	14.41
138	Bartuva-Skuodas	617	1947-2010	14.49	14.13	14.66
139	Akmena-Danė-Tūbausiai	196	1958-1991	14.44	14.38	-
Cold rivers ($\overline{T} \leq 13.4$°C)						
20	Merkys-Puvočiai	4300	1945-2010	13.56	13.28	13.58
24	Ūla-Zervynos	679	1960-2010	12.88	12.87	12.91
46	Vilnia-Santakai	164	1947-1992	12.44	12.33	-
136	Rešketa-Gudeliai	84.1	1946-1999	13.40	13.17	-

*Numbers of WGS according to Fig. 1.1.

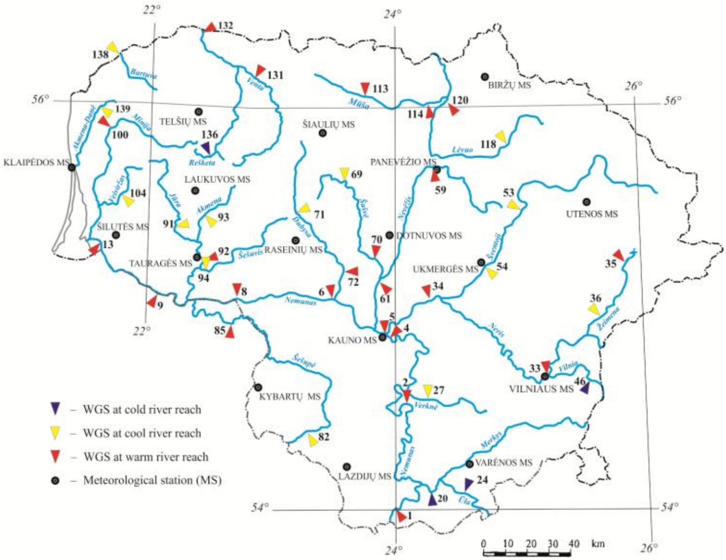


Fig. 3.1. The selected 41 WGS on 23 rivers depending on different water temperature groups (WGS No according to Fig. 1.1)

Warm water rivers. The rivers, water temperature of which is higher than the overall temperature average of the standard normal period ($\overline{T} \geq 14.9$ºC), are assigned to the group of warm water rivers. The data shown in table 3.1 indicate that almost all large rivers are warm: the Nemunas River, its major tributaries, i.e., the rivers Neris, Nevėžis, and Šešupė, the Mūša River, a tributary of the Lielupė River, the Venta River. Several small rivers of south-eastern Lithuania with the laky catchments: the rivers Lakaja, Srovė, Kretuona, and Dumblys are also the warm rivers of the country. Classification of river water temperature shows that the large rivers are warmer than the small ones (Fig. 3.1).

Cool water rivers. The rivers, water temperature of which is between 13.7ºC and 14.8ºC, are assigned to the cool rivers group. The cool rivers of the slopes of the Žemaičiai (Samogitian) Highland and Baltic Highlands are the rivers Veiviržas (13.8°C), Bartuva (14.5°C), Virinta (13.6°C) and Širvinta (14.5°C). These rivers are 40% or more fed by deep, cold groundwater. This group includes the upper reaches of medium-sized rivers (Šešuvis, Jūra, Dubysa, Šušvė, Lėvuo, etc.), too.

Cold water rivers. The smallest number of rivers belongs to this group**.** The Merkys River, its tributary the Ūla, the Rešketa, the upper reaches of the Vilnia River and additionally 10 investigated rivers, which have an average water temperature lower than 13.4°C ($\overline{T}$<13.4ºC) during the warm season, are attributed to the group of cold water rivers. The average water temperature of the rivers of this group during the observed period varies in a wide range: from 7.7°C (the Smardonė Creek at Likėnai) up to 13.4°C (the Aunuva River at Aunuvėnai). The largest river of southeastern Lithuania, the Merkys River ($\overline{T}$ =13.3°C) is the coldest river among the main rivers of the country. The lowest water temperature in this group is in the upper reaches of the Vilnia River at Santakai, $\overline{T}$ =12.3°C. The average water temperatures of the warm season those are lower than 13.4°C may be found in other 13 small rivers with sandy catchments.

3.3. Spatial distribution of river water temperature and its downstream changes

When the rivers were classified according to water temperature, it was noticed that cold water rivers are located in different regions. Therefore, the analysis of spatial water temperature distribution was carried out – the map of isotherms was drawn according to the warm season average water temperature (Fig. 3.2). The step of the temperature $\overline{T}_{30}$ isolines is $\Delta T = 0.5$°C, because it was ascertained that on the same river and between separate rivers, water temperature is statistically (at $\alpha = 0.05$) different, when $\Delta T \geq 0.5$°C. On the map, the 15°C isotherm is prevalent. It could be treated as the main or the central one. It reflects the territorial mean of all the researched rivers, which is $\tilde{T} = 14.9$°C and which has a standard deviation of $S = 0.92$°C. Thus, based on the 15°C isotherm, it is possible to consider the thermal capacity of the rivers that flow through the Lithuanian territory: when $\overline{T}$ >15.0°C – it is a warm water river, when $\overline{T}$ <15.0°C – cool water river. 15°C isotherm clearly surrounds Žemaičiai Highland, goes through Lithuanian Middle Lowland and encircles the laky part of Aukštaičiai Highlands. The 14°C isotherm is prevalent in Žemaičiai Highland and Southeast Lithuania. Thus, the warmest water (15°C – 16°C) is in Southwest and Middle Lithuania (in the watersheds of the Nemunas River and Mūša). The "islands" having low water temperature are highlighted on the map. One of them is a karst region between Biržai and Pasvalys towns, where streams Smardonė, Verdenė, Tatula, Įstras with water temperature of only 7.6°C – 13.2°C flow. Another region is the lower reaches of the Merkys River at Puvočiai and its tributaries Ūla and Skroblus, which have water temperature of 10.8°C and 13.3°C. Thus, the water temperature of the river, which has not been investigated, could be determined according to this map of isotherms, combining with the water temperatures of nearby rivers and air temperatures of closest meteorological stations.

In order to understand how river water temperature changes downstream, longitudinal water temperature profiles of the Nemunas River (8 WGS) for different time periods were made (Fig. 3.3). Graphs show similar variation of water temperature. The average water temperature of the warm season for the standard period in the Nemunas River at Druskininkai WGS is 16.0°C, and that at Rusnė WGS – 15.9°C.

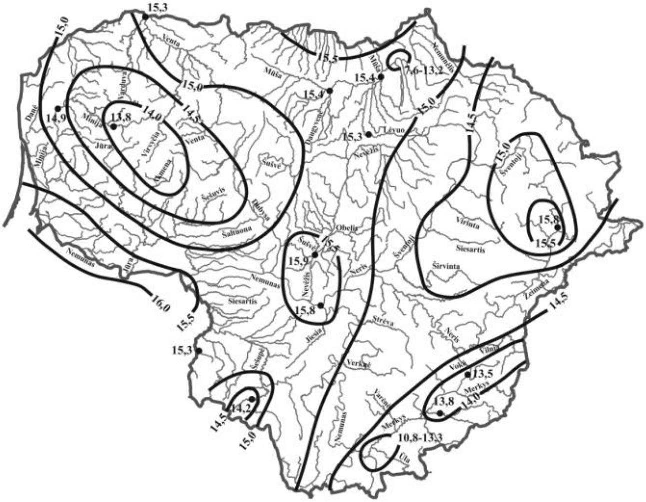


Fig. 3.2. Spatial distribution of warm season (May-October) averages of river water temperatures (map of isotherms)

The Nemunas River is slightly cooler at Seredžius WGS, 15.4°C, and in the middle course, at Nemajūnai WGS, 15.6°C. The Kaunas Reservoir (Kauno marios) raises the average water temperature of the warm season from 15.6°C at Nemajūnai WGS up to 16.0°C at Kaunas WGS, but the cooler waters of the Neris River ranging 15.4°C at Jonava WGS again decrease the water temperature down to 15.8°C (Lampėdžiai WGS).

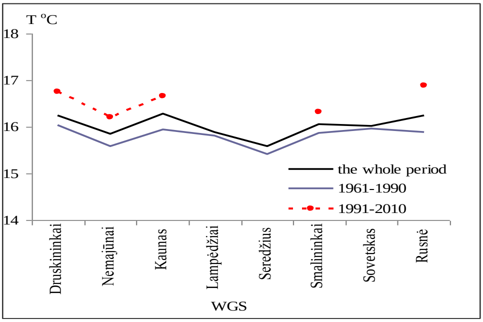


Fig. 3.3. Longitudinal water temperature profiles of the Nemunas River during the studied periods

3.4. Temporal variation of river water temperatures

The multi-year changes. Analysis of temporal variation of river water temperatures was applied to the data from 41 WGS (Fig. 3.1). The chronological variation of average warm season water temperature in three different rivers is presented in Figure 3.4; a cold river, the Merkys at Puvočiai WGS, a cool river, the Dubysa at Lyduvėnai WGS, and a warm river, the Venta at Leckava WGS. There are similar tendencies of synchronic variation of temperature in all these rivers. The lowest temperature was determined for all of them in 1976. For the Merkys, that was 12.0°C, for the Dubysa – 13.0°C, and for the Venta – 14.0°C. The highest temperature for the Dubysa was found 16.2°C and for the Venta – 17.3°C; both were found in 2006. The highest temperature for the Merkys was 14.9°C in 1948.

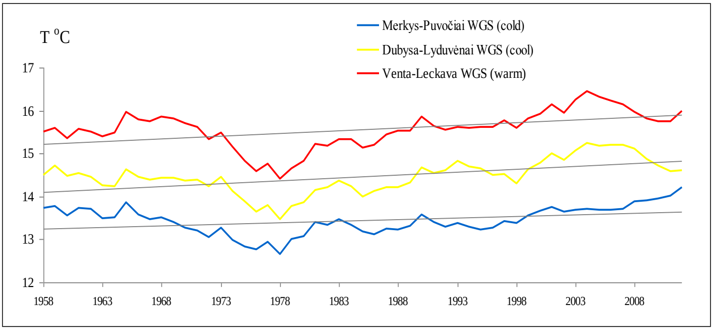


Fig. 3.4. 5-year moving averages of water temperature data sets and trends of the selected rivers from different groups during the entire studied periods

The variability of water temperature in different time periods has different tendencies. The following periods were selected for this study: a long-term period for all available data, a standard period of 1961–1990, and the most recent period, 1991–2010, when the warming effect of climate change in Lithuania has been defined in the literature. The results were assessed in two ways: by determining the significance of trends in the water temperature data series of the Lithuanian rivers (Table 3.2); and by compiling maps of temporal variability of the temperature trends for three periods (Fig. 3.5).

Insignificant trends of water temperature prevailed in the data of the period of 1945–2010 and 1961–1990 (73% and 88 % of the stations, respectively) (Table 3.2). Only some weak positive and weak negative trends were detected. The percentage of weak positive and strong positive trends increased to 19% and 54%, respectively, in the period of 1991–2010. There are no negative trends in this period. One of the reasons of such trend distribution in the most recent period can be a significant increase in air temperature.

Table 3.2. Summary of strong, weak and insignificant trends of river water temperature in three time periods (% of 41 WGS in 1945–2010 and 1961–1990, and % of 26 WGS in 1991–2010)

Period	Trend				
	Strong negative	Weak negative	Insignificant	Weak positive	Strong positive
1945–2010	7	0	73	5	15
1961–1990	5	5	88	0	2
1991–2010	0	0	27	19	54

Maps of the water temperature trends for three periods (Fig. 3.5) show that in the entire period (1945–2010), strong positive trends were found in the water temperature data of five rivers: the Nemunas – Druskininkai WGS (1st) and the Rusnė WGS (8th), the Neris – Jonava WGS (10th), the Mūša – Ustukiai WGS (21th), the Dubysa – Lyduvėnai WGS (29th), and the Šešuvis – Skirgailai WGS (17th) (Fig. 3.5a). These river reaches belong to groups of warm and cool water rivers. Strong negative trends were identified in the data of the cold rivers Merkys – Puvočiai WGS (38th) and Rešketa – Gudeliai WGS (41st) and cool Veiviržas River – Mikužiai WGS (34th). In the standard normal period of 1961–1990 (Fig. 3.5b), there were two weak negative trends, those of the Žeimena River – Pabradė WGS (25th) and the Ūla – Zervynos WGS (39th); two strong negative trends, those of the Verknė River – Verbyliškės WGS (24th) and the Rešketa – Gudeliai WGS (41st), and only one strong positive trend, that of the Vilnia River – Santakai WGS (40th). The most extensive changes in water temperature trends are assessed in the recent period of 1991–2010 (Fig. 3.5 c). Most of the trends became strong positive or weak positive for all the studied river groups.

Trend magnitudes were calculated in °C/warm season in the selected data sets and presented by box plots, which show the maximum, minimum, 25th and 75th percentiles as well as the mean water temperature data values (Fig. 3.6). The water temperature decreased slightly in the period of 1961–1991, -0.01°C/warm season, and did not change in the period of 1945–2010, 0.001°C/warm season. In the period of 1991–2010, water temperature rose significantly – by 0.04°C/warm season. Only the maximum and minimum values of the slope, the 25% and 75% percentiles, differ considerably. The possible reason for these changes could be climate change, i.e., the increasing air temperature. The slope analysis of air temperature confirms this assumption: the rates of air temperature increase are 0.01, 0.02 and 0.06°C/warm season in the periods of 1945–2010, 1961–1990, and 1991–2010, respectively.

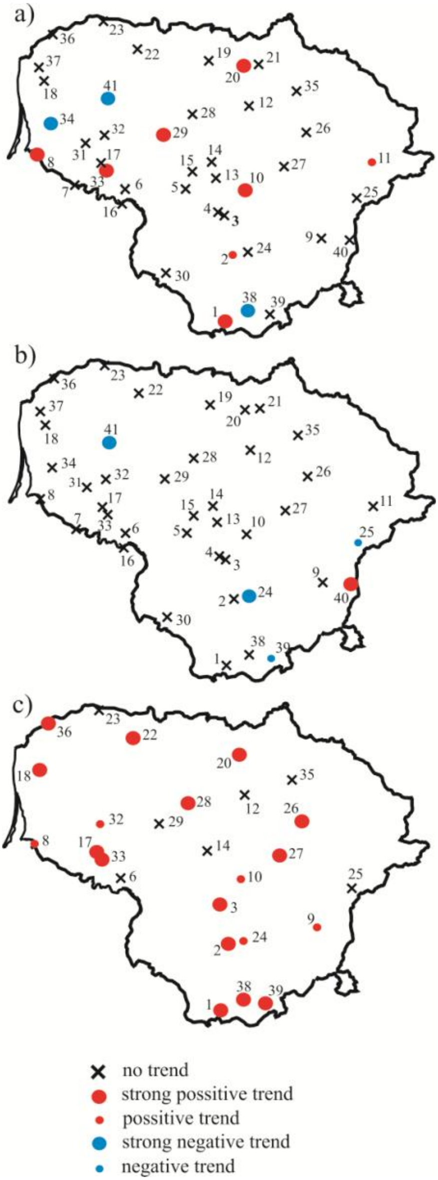


Fig. 3.5. Trends in river water temperature for the studied periods: a – the whole period, b – 1961–1990, c – 1991–2010

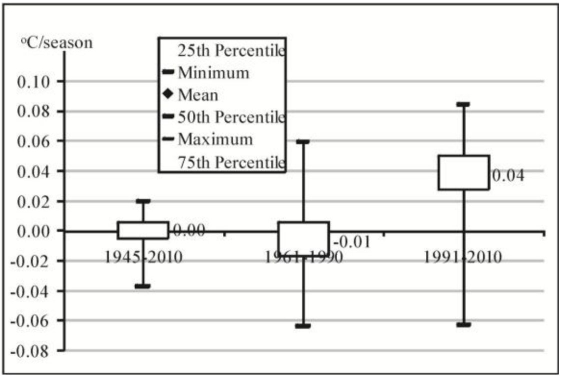


Fig. 3.6. Box plots of trend slopes for water temperature of the warm season for the periods 1945–2010, 1961–1990 and 1991–2010

Variation in the annual cycle of river water temperature. The annual thermal regime of rivers is not very complicated due to intense turbulent mixing and the absence of convection.

The studied rivers exhibit strong seasonal changes in water temperature. Analysis of annual cycle of water temperature of different rivers performed using long-term data revealed that the water temperature of Lithuanian rivers is generally close to freezing during the winter with a sinusoidal annual temperature cycle from spring to autumn (Fig. 3.7).

Figure 3.7a illustrates the annual cycles of warm water (Nemunas at Druskininkai), cool water (Žeimena at Pabradė) and cold water (Merkys at Puvočiai) large rivers. It is noticeable that the greatest thermal difference in rivers occurs at maximum summer water temperatures (in July).

The vast majority of large rivers are warm water rivers, and their annual water temperature cycles are very similar, although they run in different regions of the country (Fig. 3.7 b).

Almost all cold rivers are small, with the exception of the Merkys River. The annual thermal cycles of cold rivers differ more than those of the large rivers, and the smaller the river is, the colder is its water (Fig. 3.7 c). Also it can be concluded that contrasts in the annual temperature regime between the cold rivers are mainly a function of water temperature during the summer months.

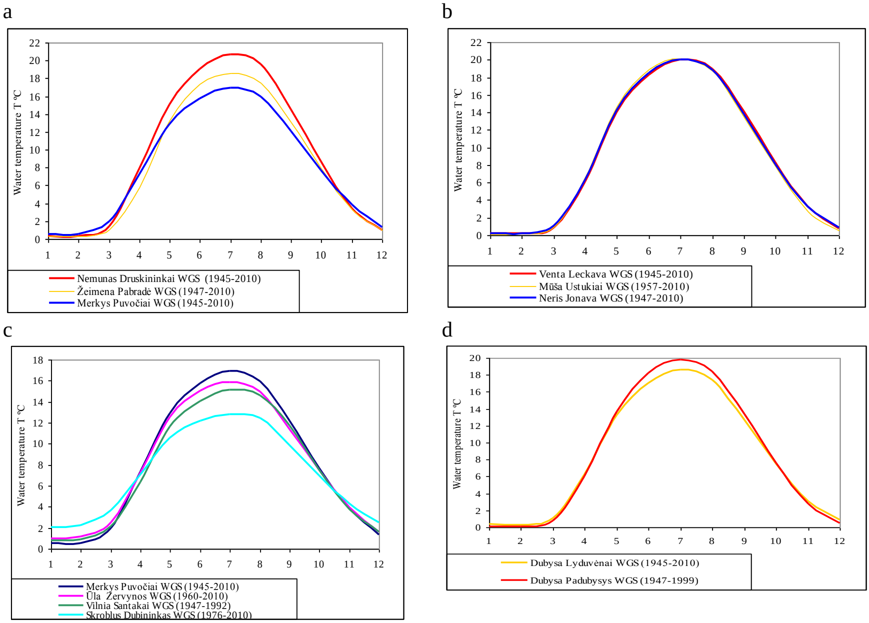


Fig. 3.7. Long-term annual component (annual cycle) in water temperatures in warm, cool and cold rivers

The comparison of annual cycles of river water temperature and air temperatures of geographically closest meteorological stations revealed that river annual thermal cycles follow atmospheric temperature (Fig. 3.8). However, the water and air temperatures vary with the lag in time.

A comparison of annual cycles highlights that water temperature of large warm rivers is higher than air temperature of neighbouring MS in all seasons of annual cycle (Fig. 3.8 a). The greatest thermal differences occur at summer temperatures (from July to August). In summer, the warm rivers are 3-4°C warmer than air temperature.

Water temperature of cold rivers is lower than atmospheric temperature in warm season, and higher – from late autumn to early spring (Fig. 3.8 b). The Merkys River is the exception. Warm season water temperature of this relatively large cold river and air temperature of geographically closest Varėna MS are similar (Fig. 3.8 c). Thus, it can be concluded that the warm season water temperature of small cold rivers is lower than the air temperature of closest MS, and the smaller and colder the river is, the greater is the difference (Fig. 3.8 b – 3.8 d). Small, cold rivers do not freeze in winter due to abundant groundwater feeding.

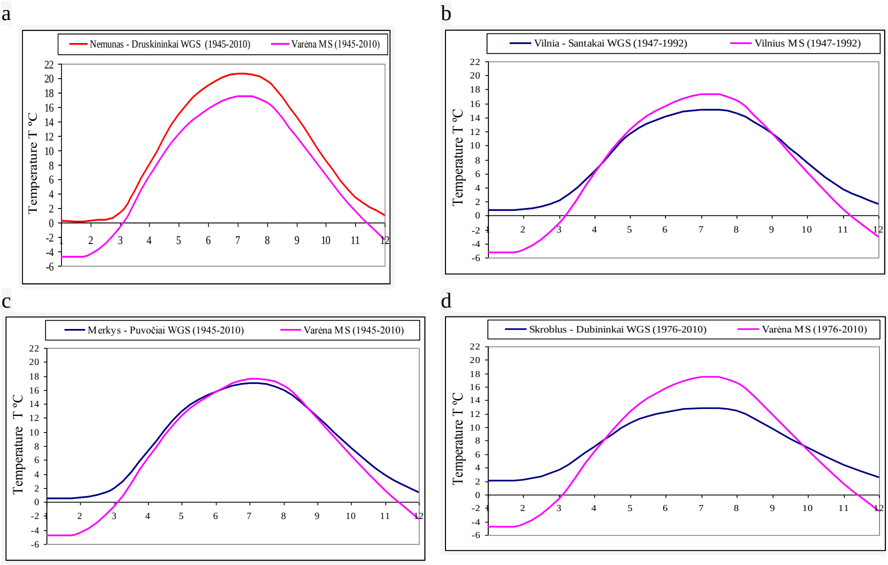


Fig. 3.8. Long-term annual cycles of river water temperature and air temperature

Diurnal fluctuations in stream temperature. River water temperatures exhibit diurnal fluctuations. The diurnal variation of river water temperature is characterized by amplitude and time of occurrence of the highest and lowest water temperatures.

For the analysis of the diurnal thermal cycle, the data of hourly water temperature measurements in the Šventoji River over a 24-hour period were used. The curves of diurnal water temperature variation were plotted (Fig. 3.9).

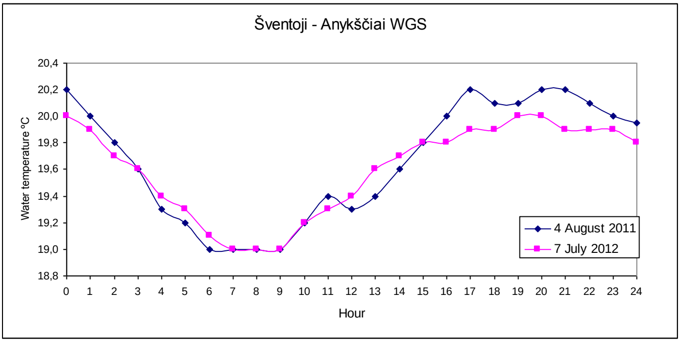


Fig 3.9. Diurnal fluctuations in water temperature in the Šventoji River – Anykščiai WGS on 4 August 2011 and 27 July 2012

The curve of diurnal water temperature variation shows that water temperature in a daily course varies from 19.0°C to 20.2°C, so daily amplitude of water temperature is 1.0°C – 1.2°C. Over a 24-hour period, water temperature was at a maximum in the evening (from 17:00 to 21:00) and at a minimum in the morning (from 06:00 to 09:00). The average water temperature of 24–hour period was 19.7°C (4 August 2011) and 19.6°C (27 July 2012).

Table 3.5. Indicators of diurnal water temperature measurements

Date of measurements	Mean daily water temperature, ºC	Maximum daily water temperature, °C	Minimum daily water temperature, °C	Amplitude of the diurnal fluctuations, °C
4 August 2011	19.7	20.2 (at 17 and 20 - 21 o'clock)	19.0 (at 6-9 o'clock)	1.2 (19.0 – 20.2)
27 July 2012	19.6	20.0 (at 19 and 20 o'clock)	19.0 (at 7-9 o'clock)	1.0 (19.0 – 20.0)

4. FACTORS INFLUENCING THERMAL REGIME OF LITHUANIAN RIVERS

Dependence of river water temperature on air temperature. Variety of water temperature is determined by local physical-geographical (azonal) factors influencing the general background temperature, which is formed by climatic conditions. Air temperature is the main factor affecting the river water temperature. The relations between the monthly warm season water temperature at WGS in different sized rivers flowing in different parts of the country and air temperature of closest meteorological stations were made (Table 4.1).

Table 4.1. Relations between the monthly warm season river water temperature and air temperature of closest MS

River – WGS	MS	WGS basin area (*A*) km²	Average water discharge (*Q*) m³/s	Period	Regression equation	Correlation coefficient *r*
Nemunas – Kaunas (Kauno HE)	Kaunas	46300	298	1947-1959	y = 1.1255+1.1563	0.98
		45700	254	1960-2010	y = 0.8555+4.5084	0.93
Nemunas – Smalininkai	Raseiniai	81200	535	1961-2010	y = 1.0396+2.4339	0.97
Merkys – Puvočiai	Varėna	4300	32.6	1961-2010	y = 0.7945+2.7275	0.99
Ūla – Zervynos	Varėna	679	4.92	1961-2010	y = 0.7408+2.9025	0.98
Neris – Vilnius	Vilnius	15200	106	1961-2010	y = 0.9997+1,9757	0.98
Bartuva – Skuodas	Telšiai	617	7.42	1961-2010	y = 0.8897+2.7474	0.97
Mūša – Ustukiai	Biržai	2280	10.4	1961-2010	y = 1.0751+1.3152	0.98
Smardonė – Likėnai	Biržai	7.90	0.26	1994-2010	y = 0.0615+6.8059	0.84

The analysis shows a fairly strong correlation between the average monthly river water temperatures and air temperatures – the correlation coefficient varies from 0.84 to 0.99. Correlations between monthly warm season water and air temperatures are very strong for the majority of the rivers – the correlation coefficients vary from 0.97 to 0.99. The relationship between the water temperature of the karst stream Smardonė – Likėnai WGS and air temperature of Biržai MS is the weakest (r = 0.84). The Smardonė is a very small stream, and its thermal regime is strongly influenced by cold groundwater; therefore, the stream temperature is slightly affected by the air temperature.

Water temperature dependency on altitude. Relation between the average river water temperature of the warm season (May to October) and WGS altitude was made/drawn N m (BS). The statistical relation between these two variables is quite weak (r = 0.56).

In most cases, the empirical relations of the hydrological characteristics and the factors affecting them are not very close, because their influence is diverse. Position of relation points in the correlation field indicates the general nature of the course of phenomenon – a trend that can be mathematically expressed and evaluated.

The influence of groundwater. Another factor that affects water temperature is river feeding. The water temperature of the rivers, which are abundantly fed by groundwater and have a lot of springs in their basins, is low. The largest river in Southeast Lithuania – the Merkys, almost 70% of the basin's area of which is covered by sands (more than 60% of the annual runoff flows to the river through its column) is the coolest major river of the country. The average warm season (May-October) water temperature of the River Merkys at Puvočiai WGS is 13.3°C, at Varėna WGS – 14.5°C. It is about 1.5°C lower than the water temperature of the River Nemunas. Other Southeast Lithuanian rivers, most of which are tributaries of the River Merkys are too abundantly groundwater fed: Ūla – Zervynos WGS (T = 12.9°C), Šalčia – Valkininkai WGS (T = 13.8°C), Cirvija – Inkleriškės WGS (T = 10.1°C), Skroblus – Dubininkas WGS (T = 10.8°C). The water temperature of the upper reaches of the Vilnia River – Santakai WGS, which flows in this part of the country and is abundantly groundwater fed, is low too – 12.3°C, despite the fact that in 1971, when the pond Margiai was constructed, it slightly increased.

North Lithuanian karst region rivers: small streams the Smardonė – 7.6°C and the Verdenė – 7.8°C; larger rivers the Tatula (Trečionys WGS) – 13.3°C, and the Įstras (Talačkoniai WGS) – 13.8°C, water thermal regime of which is affected by the groundwater of karst origin, have lowest water temperature. Water temperature of the rivers Smardonė and Verdenė is significantly lower (by about 7°C) than the standard normal of all investigated rivers ($\tilde{T}$ = 14.9°C). The Smardonė water temperature does not drop below +5°C during year, because its thermal regime is strongly affected by groundwater.

Rivers flowing in Samogitian (Žemaičiai) Highlands and its slopes, abundantly fed by groundwater, are cool as well: the rivers Rešketa (13.2°C), Kražantė – Pluskiai WGS (13.4°C), Veiviržas (13.7°C), Bartuva (14.1°C), Širvinta (14.4°C). These rivers are 40% or more fed by deep, cold groundwater laying at the depth of more than 5 m with the runoff exceeding 1.5 l/(s·km^2). This may be explained by the fact that groundwater of sandy catchments is filled up with spring snowmelt, and these waters later feed the rivers. Sandy soils have a faster infiltration rate that allows more spring water to recharge the groundwater. This group includes the upper reaches of medium-sized rivers (Šešuvis, Jūra, Dubysa, Šušvė, Lėvuo, etc.) too. Groundwater also has impact on thermal regime of western Lithuanian rivers: Minija – Vainaičiai WGS (13.8°C) and Akmena – Tūbausiai WGS (14.4°C).

Influence of lakes and ponds on river water temperature. Rivers flowing out of lakes have warmer water. The Žeimena River starts at the Žeimenys Lake. Water temperature of this river used to be measured in Kaltanėnai WGS (1 km downstream the source) and is still measured at Pabradė WGS, which is at the distance of 17.5 km from the river mouth. Lakes cover 8.9% and 7.0% of the total basin area at these WGS, respectively. Water temperature of this river at its lower reaches is lower than the temperature at the upper reaches, which are fed by warmer water of lakes. According to the submitted river grouping, the Kaltanėnai WGS was assigned to the group of the warm water rivers and the Pabradė WGS was attributed to the cool water river group (Fig. 3.1). Figure 4.1 shows water temperature change in the Žeimena River at Kaltanėnai and Pabradė WGS. It clearly illustrates how river water temperature can be influenced by lakes of the river catchments.

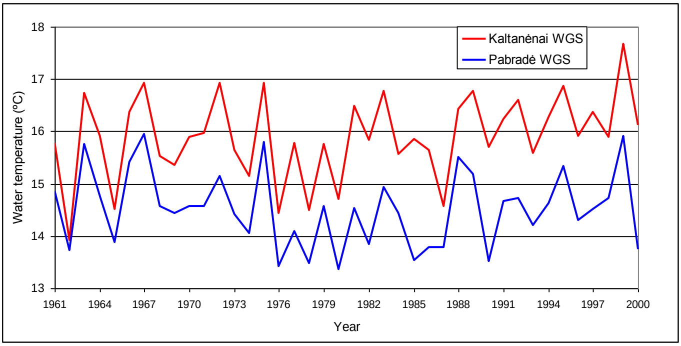


Fig. 4.1. Water temperature change in the River Žeimena at Kaltanėnai and Pabradė WGS

Some small rivers with laky basins of Southeastern Lithuania (Lakaja, Srovė, Kretuona, Dumblys) are warm water rivers, too.

The reservoirs constructed on the rivers affect their thermal regimes as well. After the installation of a pond, river water temperature of warm season increased. Results of analysis of the water temperature of the Baltoji Ančia River indicate that temperature difference between the periods of 1946–1955 (before the pond installation) and 1956–1965 (after the installation) was +1.74°C (ΔT = 1.7°C). Similar situation occurred in the Vilnia River, where water temperature in Santakai WGS increased (ΔT = 0.7°C) after the construction of a reservoir (1972).

5. HEAT RUNOFF OF LITHUANIAN RIVERS

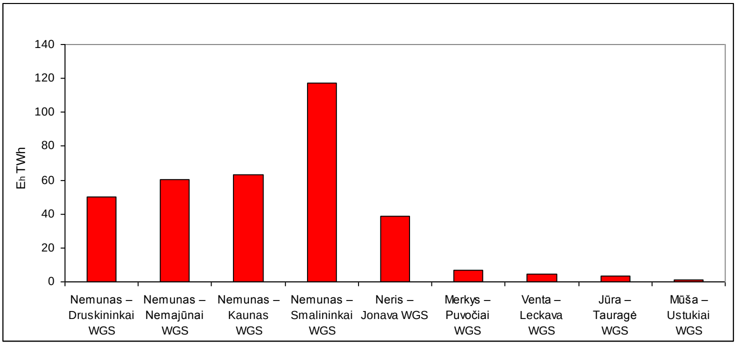
River heat runoff is a renewable source of energy and a thermal energy reserve. The heat runoff or the thermal/heat energy amount of the largest Lithuanian rivers Nemunas, Neris, Jūra, Merkys, Mūša and Venta was calculated for the evaluation of heating power carried by the discharge of the rivers in the country (Table 5.1). As the heat runoff is the synthetic measure of water discharge and water temperature, table 5.1 shows the water discharge Q (m^3/s), water temperature T (ºC), heat runoff θ (J/s, W), and heat (thermal) energy E_h (Wh) of different periods**.** It has been estimated that the largest Lithuanian river water transports a relatively large amount of heat.

Thermal energy transferred by the Nemunas River at Smalininkai during the year accounts for 117.8 TWh (Table 5.1., Fig. 5.1.). This is more than twice the amount of the heat that the Nemunas River carries through the border with Belarus.

According to the average data of decades (Table 5.1.), river water discharges of 1951–1960, 1971–1980 and 1981–1990 periods were higher than the multi annual mean of almost all the rivers, while in 1961–1970, 1991–2000 and 2000–2010 periods – lesser. Water temperature and flow rate fluctuated asynchronously during these decades (Fig. 5.2.). This was indicated by the river water temperature, which was lower when the river was more waterabundant, although the river water temperature usually increased downstream due to hydraulic friction.

Table 5.1. Warm period (May-October) water discharge Q (m^3/s), water temperature T (ºC), heat runoff θ (J/s, W) and heat (thermal) energy E_h (Wh) of the rivers

River – WGS	Basin area A (km^2)	Charac-teristics	Year							
			1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	1961-1990	1951-2010
Nemunas – Druskininkai	37100	Q (m^3/s)	157.4	157.9	179.4	174.4	157.4	159.1	170.6	166.5
		T (ºC)	16.1	16.3	15.7	16.1	16.3	17.2	16.0	16.3
		θ (GJ/s, W)	10.6	10.8	11.8	11.8	10.8	11.5	11.5	11.4
		E_h (TWh)	46.9	47.6	52.3	52.1	47.6	50.7	50.7	50.2
Nemunas – Smalininkai	81200	Q (m^3/s)	422.9	367.5	403.4	431.1	372.6	376.0	400.7	395.6
		T (ºC)	16.0	16.1	15.6	15.9	16.2	16.3	15.9	16.0
		θ (GJ/s, W)	28.4	24.8	26.4	28.8	25.3	25.7	26.7	26.6
		E_h (TWh)	125.7	109.5	116.7	127.3	111.9	113.6	117.8	117.5
Merkys – Puvočiai	4300	Q (m^3/s)	28.13	25.62	26.92	29.82	26.87	30.26	27.45	27.94
		T (ºC)	13.9	13.5	13.0	13.4	13.4	13.8	13.3	13.5
		θ (GJ/s, W)	1.64	1.45	1.46	1.67	1.51	1.75	1.53	1.58
		E_h (TWh)	7.23	6.41	6.47	7.37	6.65	7.72	6.75	6.98
Neris – Jonava	24600	Q (m^3/s)	148.8	131.0	120.3	144.4	122.9	132.8	131.9	133.4
		T (ºC)	15.4	15.5	15.2	15.5	15.6	16.2	15.4	15.6
		θ (GJ/s, W)	9.63	8.53	7.65	9.39	8.05	8.99	8.52	8.71
		E_h (TWh)	42.6	37.7	33.8	41.5	35.6	39.7	37.6	38.5
Jūra – Tauragė	1690	Q (m^3/s)	11.34	8.67	12.75	13.13	8.69	11.20	11.52	10.95
		T (ºC)	15.8	15.7	15.3	15.4	15.9	16.4	15.5	15.8
		θ (GJ/s, W)	0.752	0.571	0.816	0.848	0.579	0.768	0.746	0.723
		E_h (TWh)	3.32	2.52	3.61	3.75	2.56	3.40	3.30	3.20
Mūša – Ustukiai	2280	Q (m^3/s)	–	3.25	5.77	5.52	4.19	3.89	4.85	4.52***
		T (ºC)	–	15.4	15.1	15.6	15.7	16.3	15.4	15.6***
		θ (GJ/s, W)	–	0.210	0.366	0.360	0.276	0.266	0.312	0.296
		E_h (TWh)	–	0.927	1.62	1.59	1.22	1.18	1.38	1.31
Venta – Leckava	1690	Q (m^3/s)	11.3	8.67	12.8	13.1	8.69	11.2	11.5	11.0
		T (ºC)	15.8	15.7	15.3	15.4	15.9	16.4	15.5	15.8
		θ (GJ/s, W)	1.02	0.735	1.15	1.29	0.816	0.838	1.06	0.975
		E_h (TWh)	4.52	3.25	5.09	5.71	3.61	3.70	4.69	4.33



5.1 Fig. Resources of thermal/heat energy E_h (TWh) in major Lithuanian rivers

The data of thermal energy of major Lithuanian rivers can be compared to the available annual resources of wind and river water power as well as energy consumption in the country. According to the available data, the maximum theoretical resources of wind power in Lithuania are 1000 MW (2.63 TWh), and the total potential energy of Lithuanian rivers – 5.13 TWh. Lithuanian primary energy consumption amounts to 7388.4 ktoe (tonnes of oil equivalent), or 85.9 TWh in 2012.

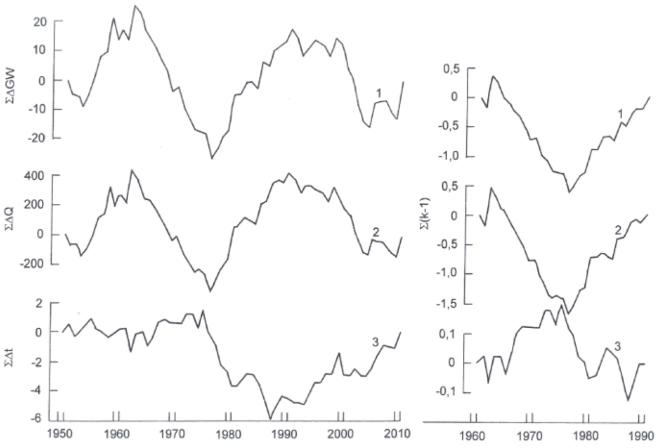


Fig. 5.2 Integral curves of heat runoff, Θ (W) – (1); water discharge, Q (m³/s) – (2); water temperature T (°C) – (3) of warm period (May-October) of the Nemunas River–Smalininkai WGS

The figure shows that water discharge and heat runoff vary cyclically and synchronically, and water temperature varies cyclically asynchronously with water discharge and heat runoff.

6. PREDICTION OF LITHUANIAN RIVER THERMAL REGIME UNDER CLIMATE CHANGE SCENARIOS

Correlation between water and air temperature. Currently, climate change impacts on physical-geographical factors are a widely discussed issue; therefore, it is important to know how climate change will affect river water temperature. One of the main factors affecting river water temperature is air temperature, which in turn is one of the most important climatic factors. Rapid increase of average annual air temperature has been observed in Lithuania for the last 30 years. Average annual air temperature in Lithuania in the period of 1981–2010 was 6.9ºC, while that of baseline period of 1961–1990 was 6.2ºC. Air temperatures are expected to continue to increase.

Relations 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 (Fig. 2.3). Strong correlations between water and air temperatures were estimated, correlation coefficients being 0.98 – 0.99 (Table 6.1).

Table 6.1. Regression equations and correlation coefficients between river water temperatures (y) and air temperatures (x) of closest MS.

	River – WGS	MS	Regression equations	Correlation coefficients *r*
1	Nemunas – Druskininkai	Lazdijai	y = 1.13x + 0.99	0.98
2	Merkys – Puvočiai	Varėna	y = 0.82x + 2.47	0.99
3	Dubysa – Lyduvėnai	Šiauliai	y = 1.01x + 0.90	0.98

6.2. River water temperature analysis according to climate change scenarios

Prognostic air temperature data from global climate models (ECHAM5 and HadCM3) and emission scenarios (A2 and B1) as well as relations between the water and air temperatures during the climate normal period (1961–1990) were used for river water temperature prediction.

Regression equations (Table 6.1) were used to calculate the average water temperature of warm season of the rivers Nemunas, Merkys and Dubysa for the period of 2071–2100. Results are presented in Table 6.2. The data of the predicted river water temperatures were compared with the data of the baseline period.

The warm season water temperature in the studied rivers is expected to increase in 2071–2100 (compared to the baseline period) under all analyzed climate models and emission scenarios. The biggest water temperature increase is predicted under HadCM3 A2 (Table 6.2). Average water temperature of the Nemunas River at Druskininkai is expected to rise to 20.9°C in 2071–2100; this is by 4.9°C (31%) higher than the water temperature of the baseline period.

Water temperature of the Dubysa River should increase the most – by 4.6°C (32%), while that of the Merkys River at Puvočiai is likely to be minimum – 3.1°C (23%). The lowest water temperature of the warm season was predicted under ECHAM5 B1 climate scenario (Table 6.2). Comparing with the water temperature of the baseline period, water temperature of 2071–2100 should be higher by 1.9°C (12%) in the Nemunas River, 1.7°C (12%) in the Dubysa River and 1.3°C (10%) in the Merkys River.

Table 6.2. Warm-season temperature changes comparing the predicted data of the 2071–2100 year period and baseline period data

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 changes of water temperature for individual months were found (Fig. 6.1). The highest water temperature in the Nemunas River and Merkys will be under the A2 scenario in July, while in August, it will be under the B1 scenario (Fig. 6.1 a and b). Different regularities were identified while analyzing water temperatures of the Dubysa River. Under the ECHAM5 model, regardless of the emission scenarios, the water will warm up most in July (Fig. 6.1c). Meanwhile, the water in the Dubysa River will be the warmest in July under the HadCM3 model A2 scenario; under B1 scenario – in August. The results suggest that summer water temperature in three Lithuanian rivers could increase by 10-12% by the low emission scenario (ECHAM5 B1) and by 23-32% by the high emission scenario (HadCM3 A2) by the 2071–2100. While comparing the predicted water temperatures in studied rivers, more significant differences were found between A2 and B1 emission scenarios of the HadCM3 and smaller differences between the same scenarios of the ECHAM5 model.

Analysis of the results showed the biggest 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 Merkys River (2.1°C higher than the temperature of the baseline period) in 2071–2100.

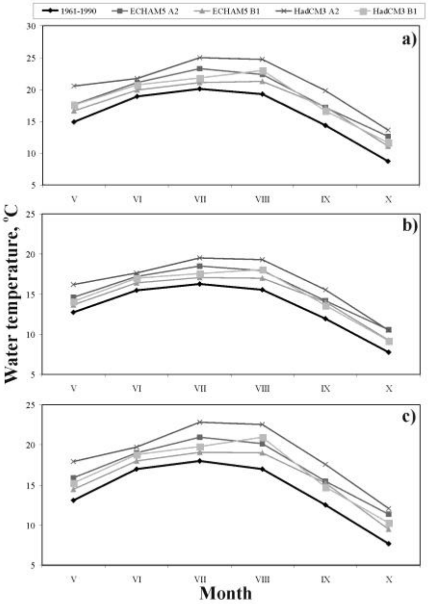


Fig. 6.1. Multi-annual monthly average for the baseline period and predicted (according to 4 climate models) for the period of 2071–2100 water temperatures: a) the Nemunas at Druskininkai, b) the Merkys at Puvočiai, and c) the Dubysa at Lyduvėnai

Results of water discharge simulation (Table 6.3) indicate that in 2071–2100 the warm season water discharge of the Nemunas River and the Merkys River will decrease under both models and emission scenarios, compared with the climate normal period discharge. During the same period, the warm season water discharge in the Dubysa River will slightly increase (1% –11%), except for the projected one under the HadCM3 A2 scenario (water discharge will decrease by 13%).

Table 6.3. Changes of the warm season water discharge in the period of 2071–2100 comparing with the baseline period

River	WGS	Average discharge, m^3/s in 1961–1990	Average discharge, m^3/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%

6.3. Heat runoff changes according to climate scenarios

River heat runoff is influenced by two major hydro-meteorological factors, which determine the thermal state of water: water discharge and air temperature. Using the created hydrological models, decreases of discharge of 18.0% in the Nemunas River and 22.4% in the Merkys River, and an increase of discharges of 1.7% in the Dubysa River were identified for the last 30-year period of the 21st century compared to the baseline period (Table 6.3). Based on the output data of the global climate scenarios (ECHAM5, HadCM3 under the A2 and B1 emission scenarios), the average water temperature is projected to rise in 2071–2100 compared with the baseline period: in the Nemunas River – by 3.1°C, in the Dubysa River – 2.9°C and Merkys – 2.1°C. These water discharge and water temperature changes will result in the change of river heat runoff compared to the climate normal period: in the Nemunas River and the Merkys River it will decrease (except for HadCM3 B1 climate scenario), and in the Dubysa River it will increase at the end of 21st century (Table 6.4).

Table 6.4. Heat runoff changes (in %) in 2071–2100 compared with the baseline period

River – WGS	Heat runoff change compared with 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 of 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 6.4) and less increased water temperature (Table 6.3) of warm season in these rivers, i.e., the increase of air temperature is unlikely to be compensated by water discharge decrease. In the future, increase of heat runoff of the Dubysa River 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 6.3), i.e., the increase of water discharge and temperature at the same time will cause higher heat runoff.

According to the heat runoff projection of three rivers (Nemunas and Merkys – decrease, Dubysa – increase trends), it is difficult to judge the dynamics of heat resources in all Lithuanian rivers. Therefore, water heat resources prediction for all larger Lithuanian rivers should be carried out in order to accurately assess the thermal runoff of Lithuanian rivers in the future.

CONCLUSIONS

1. Classification of Lithuanian rivers according to the average river water temperature during the warm season (May to October) of the standard normal period (1961–1990) has been presented. Groups of warm ($\overline{T} \geq 14.9$ ºC), cool (13.4ºC< $\overline{T}$ <14.9 ºC) and cold ($\overline{T} \leq 13.4$ ºC) water rivers have been distinguished. It has been statistically identified that river water temperature significantly varies if the difference of the temperature is bigger than 0.5 ºC. The classification of rivers according to water temperature has revealed that most of the large Lithuanian rivers are warmer than the small ones.
2. It was found that Lithuanian river water temperature depends on a variety of physical geographical factors that affect water temperature formed by climatic conditions. River water temperature variation over the time is as well caused by climatic factors and anthropogenic activities. Studied river water temperature and closest meteorological stations air temperature variations are statistically equal and change synchronically during multi-annual period. Correlation graphs between the warm season (May to October) average annual river water temperatures and the nearest meteorological stations air temperatures display direct linear relations. Large and warm river water temperature correlation with the air temperature is higher (*r* = 0.97–0.99) than that of the cold rivers (*r* = 0.84–0.98). The analysis of river water temperature dependence on local physical-geographical factors showed that water of rivers flowing out of lakes is warmer (1.4–4 ºC), and abundant underground feeding is the main source of cold water in Lithuanian rivers.
3. Constructed map of spatial distribution of water temperature shows that river feeding type, river size, basin orography and lakes in basin are the factors that have the biggest impact on river water temperature. Different river water temperature is also determined by other factors, the most significant of which are groundwater feeding, sandy soils in the basin, and anthropogenic activities. Unexplored river water temperature can be determined according to the isotherm map. Depending on the river size (length) and altitude, statistical relations of water temperature distribution have been made, according to which it is proposed to assess water temperature of unexplored rivers and ponds formed in their valleys.
4. Variation of Lithuanian river water temperature has been examined. It was found that over the past two decades, the Lithuanian river water temperature increased by 0.04°C per each warm season in all of the investigated rivers, regardless of river temperature groups. The multi-annual average warm period water temperature of all of the rivers (41

WGS) for the 1961–1990 year period was 14.9°C, while that of 1991–2010 year period was 15.4°C. Strong correlations (*r* = 0.95–0.98) found between air and river water temperatures show that river water temperature can be used as an important indicator of climate change.

5. Prediction of river water temperature indicates that climate change will cause the rise of river water temperature in the 21st century. Average warm-season river water temperature is projected to increase in 2071–2100 year period compared with the baseline period (1961–1990) by: Nemunas-Druskininkai WGS – 1.9°C (19.5%), Merkys-Puvočiai WGS – 1.3°C (15.2%), and Dubysa-Lyduvėnai WGS – 1.7°C (20.2%). Climate change will have the least impact on rivers with relatively low warm-season water temperature due to groundwater feeding.
6. Prediction of changes of Lithuanian river water temperature shows that in order to sustain good water quality and optimal conditions for aquatic ecosystems in rivers, specific environmental protection measures and research-based normative documents regulating economic activities will be required. Industrial and power (thermal and nuclear) plants cooling systems as well as domestic waste water will determine river water thermal state changes, which will affect the oxygen regime and self-purification capacity of rivers.
7. The results of a calculation of Lithuanian river (Nemunas, Neris, Jūra, Merkys, Mūša and Venta) thermal energy amount (from 1.3 TWh, Mūša at Ustukiai to 117.5 TWh, Nemunas at Smalininkai) show that possibilities of their use are related to the application of heat pumps for hot water supply and space heating. Considering the fact that energy costs in Lithuania were about 81.2 TWh (in 2013), river water thermal energy utilization possibilities and perspectives are obvious.

LIST OF SCIENTIFIC PUBLICATIONS ON THE SUBJECT OF THE DISSERTATION

Articles in the Thomson Reuters database Web of Science Core Collection refereed journals:

1. JURGELĖNAITĖ A., KRIAUČIŪNIENĖ J., ŠARAUSKIENĖ D. Spatial and temporal variation in the water temperature of Lithuanian rivers. *Baltica.* 2012, 25 (1), 65-76. ISSN 0067-3064. [Impact factor 0.607]

Articles in scientific journals registered in international science information databases:

1. JABLONSKIS J., JURGELĖNAITĖ A. Vandens temperatūros įvairovės savitumai Lietuvos upėse. *Energetika*. 2010, 56 (2), 163-171. ISSN 0235-7208. [INSPEC, IndexCopernicus]
2. JABLONSKIS J., JURGELĖNAITĖ A., TOMKEVIČIENĖ A. Lietuvos upių šilumos ištekliai ir jų daugiametė kaita. *Energetika.* 2013, 59 (4), 203-210. ISSN 0235-7208. [INSPEC, IndexCopernicus, SCOPUS].
3. JURGELĖNAITĖ A., JAKIMAVIČIUS D. Prediction of river water temperature and its dependence on hydro meteorological factors. *Environmental research, engineering and management*. 2014, 2(68), 15-24. ISSN 1392-1649. [INSPEC, CAB Abstract]

Papers at international conferences:

1. JURGELĖNAITĖ A., JABLONSKIS J. Variation in Lithuanian river water temperatures. In *Environmental engineering: 8th international conference*. May 19-20, 2011, Vilnius, Lithuania. Vilnius: VGTU Press "Technika", 2011, pp. 144-149. ISBN 978-9955-28-826-8.
2. JURGELĖNAITĖ A. Intra-annual thermal variability of Lithuanian rivers. In *9th annual conference of young scientists on energy issues CYSENI 2012: international conference.* May 24-25, 2012, Kaunas, Lithuania. Kaunas: LEI, 2012, pp. 624-633. ISSN 1822-7554.
3. JURGELĖNAITĖ A. Long-term variations of the heat runoff transferred by the rivers Nemunas and Merkys. In *10th annual international conference of young scientists on energy issues (10 CYSENI anniversary).* May 29-31, 2013, Kaunas, Lithuania. Kaunas: LEI, 2013, pp. 610-617. ISSN 1822-7554.
4. JURGELĖNAITĖ A., KRIAUČIŪNIENĖ J., MEILUTYTĖ D. Climate change impacts on Lithuanian river water temperatures. In *XXVIII Nordic Hydrological Conference "The Nordic Hydrology Model" – Linking science and practice.* August 11-13, 2014, Stockholm, Sweden. KTH Royal Institute of technology, 2014, p. 43. ISSN 1650-8610.

INFORMATION ABOUT AUTHOR

Name, surname:	Aldona Jurgelėnaitė (Mrs.)
Date of birth:	27 June, 1956
Place of birth:	Magadan, Russia
Academic background:	1976-1981 studies at Vilnius University, Faculty of Natural Sciences, Master of Geography (Hydrology); 2009-2014, Doctoral studies at Lithuanian Energy Institute, Laboratory of Hydrology;
Research interest:	sustainable energy and resource consumption, environmental impact assessment
For contacts:	email: aldona.jurgelenaite@lei.lt.

ACKNOWLEDGMENT

Author thanks for all scientific colleagues who helped to prepare this dissertation. Also author thanks all organizations that gave a lot of useful information for this scientific work.

Special thanks author want to say to her supervisor Prof. Dr. Habil. Brunonas Gailiušis for cooperation and understanding, Dr. Habil. Jonas Jablonskis for his help, suggestions and ideas. In addition, author wants to thank Dr. Jūratė Kriaučiūnienė (head of Laboratory of Hydrology in Lithuanian Energy Institute) for support, fellowship and management.

REZIUMĖ

Paviršinių vandens telkinių būklę konkrečiu laiko momentu apibūdina įvairių jo charakteristikų visuma: vandens lygis, debitas, vandens temperatūra, drumstumas, druskingumas, mineralizacija ir kt. Šių charakteristikų pokyčiai lemia vandens telkinio hidrologinį režimą. Vienas svarbiausių paviršinių vandens telkinių vandens būklės ir jo režimo parametrų yra vandens temperatūra, kuri lemia jo terminę būklę.

Vandens temperatūra yra fizinės vandens savybės išraiška, rodanti kiek yra karštas arba šaltas vanduo. Karštas ir šaltas – abu terminai yra sutartiniai. Temperatūrą galima apibūdinti kaip medžiagos vidutinės šiluminės energijos matą. Ji yra kūno atomų ir molekulių šiluminio judėjimo terpėje rezultatas, jų vidutinės kinetinės energijos matas.

Šiluminė energija yra kinetinės atomų ir molekulių energijos išraiška, todėl temperatūra yra matuojama atomų ir molekulių vidutinė kinetinė energija. Ši energija gali būti perduodama tarp medžiagų kaip šilumos srautas. Šilumos perdavimas vandens telkiniui iš oro, saulės ar kito vandens telkinio arba terminė tarša gali keisti vandens temperatūrą.

Vandens temperatūra yra viena pagrindinių paviršinių vandenų fizikinių savybių, daranti tiesioginį poveikį vandens florai ir faunai bei vandens kokybei. Temperatūra turi įtakos kitoms fizikinėms vandens savybėms: tankiui, klampumui, skoniui, kvapui, vandens paviršiaus įtempimui. Vandens temperatūra gali turėti tiesioginės įtakos cheminiams procesams vandens telkinyje. Nuo jos priklauso vandenyje ištirpusio deguonies koncentracija (prisotinimas deguonimi), savaiminio vandens apsivalymo greitis bei kiti cheminiai procesai. Todėl atliekant vandens cheminius tyrimus, būtina įvertinti ir jo fizines savybes – temperatūrą, spalvą, kvapą, skaidrumą ir kt. Vandens temperatūra turi didelės įtakos įvairių medžiagų skaidymuisi ir apykaitos greičiui. Padidėjusi vandens temperatūra dažnai daro neigiamą poveikį vandens kokybei, nes šiltas vanduo sustiprina eutrofikacijos procesus. Kai vanduo įšyla, sumažėja ir jo gebėjimas išlaikyti deguonį (Chislock et al., 2013; Moss et al., 2011).

Vandens temperatūra yra vienas svarbiausių ekosistemų tyrimų parametrų. Manoma, kad biotos gyvavimo ciklą reglamentuoja du pagrindiniai fiziniai veiksniai – temperatūra ir hidraulinės sąlygos (Gore et al., 2008). Vandens temperatūra veikia vandens organizmų gyvybinę veiklą: augimą, dauginimąsi, migraciją, net mirtingumą. Vandens gyvūnija, ypač žuvys, gyvena ir klesti esant konkrečiai vandens temperatūrai. Tačiau kai kurie primityvūs organizmai, pavyzdžiui, žaliai žydrieji dumbliai ir bakterijos, gali toleruoti temperatūros ekstremumus.

Hidrologijoje vandens temperatūra ne pagrindinė upių nuotėkio charakteristika, nors vandens balanso dedamoji – garavimas yra sąlygotas

vandens telkinio temperatūros ir vėjo greičio virš jo vandens paviršiaus bei kitų aplinkos veiksnių. Tačiau hidroekologiniuose tyrimuose ir praktinėje veikloje, ypač ten, kur susiduriama su vandens telkinių, tarpe jų ir upių, vandens maistine baze, žuvų nerštu, savivala, hidroekologinėmis sistemomis, biotopų hidroterminis režimas yra vienas vyraujančių veiksnių. Be to, ledo reiškiniai upėse ir hidrologinis režimas (ypač pavasarį) yra glaudžiai susiję su vandens ir oro temperatūromis.

Upių vandens temperatūra priklauso nuo daugelio natūralių ir antropogeninių veiksnių. Didžiausią poveikį vandens temperatūrai daro atmosferos (aplinkos oro) temperatūra. Kiti veiksniai, sąlygojantys upių vandens temperatūrą, yra upės hidrologinis režimas ir jos baseino orografinės sąlygos (aukštis virš jūros lygio, baseino plotas, natūralių vandens telkinių upės baseine skaičius). Antropogeninis poveikis (atominės ir šiluminės elektrinės, žemės ūkio paskirties žemės naudmenos, pramonės terminės nuotekos arba hidrauliniai įrenginiai, keičiantys tėkmės struktūrą) taip pat gali veikti šį svarbų vandens fizinį parametrą.

Upių terminis režimas – tai dėsningai pasikartojantys vandens šiluminės būsenos pokyčiai. Vandens temperatūra svarbi aprūpinant vandeniu pramonę, komunalinį ir žemės ūkį. Per pastarąjį šimtmetį sukurtos sudėtingos vandens atsargų surinkimo, perdavimo ir tiekimo sistemos energetikai, pramonei, žemės ūkiui, komunaliniam ūkiui bei kitoms reikmėms. Pastaraisiais metais upių vandens šiluminis nuotėkis vis dažniau yra naudojamas pastatams šildyti ir karštam vandeniui tiekti šilumos siurblių pagalba.

Upių vandens šilumos srautai ir šilumos energijos atsargos jose – svarbus atsinaujinantis energijos šaltinis, dalyvaujantis įvairiuose biofiziniuose procesuose, bet nepakankamai ištirtas ir kompleksiškai įvertintas naudojant upių vandens išteklius. Apibendrinus upių hidroterminius duomenis būtų galima racionaliau naudoti upių vandens išteklius. Duomenys apie Nemuno ir Neries šiluminį režimą praverstų vertinant statomų Baltijos ir Astravo AE aušinimo vandens poveikį Nemuno žemupiui ir Neriai. Todėl tikslinga tirti maksimalius šilumos srautus ir jų formavimosi gamtines bei antropogenines aplinkybes bei poveikį aplinkai, taip pat šilumos srautų ir atsargų praktinio panaudojimo galimybes ir upių ruožus, kuriems turi įtakos antropogeninė veikla.

Darbo aktualumas

Vandens temperatūra yra svarbus aplinkos veiksnys, tiesiogiai lemiantis vandens kokybę, ypač deguonies režimą bei kiekybinius ir kokybinius biotos pokyčius. Ypač stipriai su terminiu režimu susijusi mažų ir vidutinių upių biotos įvairovė ir gausumas. Praktiniu požiūriu upių vandens šilumos ištekliai yra atsinaujinančios energijos šaltinis, kurio panaudojimo galimybės turi būti nagrinėjamos ir įvertintos.

Upių terminio režimo tyrimai Lietuvoje iki šiol buvo atliekami epizodiškai. Vandens temperatūra matuojama daugelyje stočių, tačiau nėra išsamesnės jos kaitos analizės. Šie tyrimai reikalingi vertinant energetikos ir pramonės objektų poveikį aplinkai, terminės taršos šaltinių įtaką upių šiluminiam balansui bei savivalai. Žinios apie upių vandens temperatūrą svarbios žuvivaisai, ypač įrengiant žuvininkystės tvenkinius. Kadangi upių vandens temperatūros matavimo stočių (VMS) tinklas yra tankesnis nei oro temperatūros matavimo stočių (MS), tai ji gali būti indikatoriumi vertinant klimato kaitą.

Darbo objektas

Lietuvos upių vandens terminis režimas šiltuoju metų sezonu (gegužė–spalis).

Darbo tikslas

Įvertinti Lietuvos upių vandens šiltojo metų laikotarpio terminio režimo pokyčius, nustatant galimas jo kaitos tendencijas XXI a. ir įvertinti Lietuvos upių šiluminį nuotėkį (šilumos atsargas).

Darbo uždaviniai

1. Atlikti išsamią Lietuvos upių šiltojo metų laikotarpio vandens temperatūros matavimų nuo 1945 iki 2010 m. duomenų analizę pagal vieningą metodiką.
2. Atlikti Lietuvos upių klasifikaciją pagal šiltojo metų sezono (gegužė–spalis) vandens temperatūrą, išskiriant 3 upių grupes: šilto, vėsaus ir šalto vandens.
3. Sudaryti šiltojo metų sezono (gegužė–spalis) upių vandens temperatūros izolinijų žemėlapį, leidžiantį įvertinti neištirtų Lietuvos upių vandens temperatūrą.
4. Nustatyti klimato ir vietos fizinių-geografinių veiksnių įtaką upių vandens temperatūrai šiltuoju metų sezonu (gegužė–spalis).
5. Įvertinti Lietuvos upių šiltojo metų sezono (gegužė–spalis) šiluminį nuotėkį (šilumos atsargas).
6. Įvertinti klimato pokyčių įtaką upių vandens terminiam režimui, atliekant upių šiltojo metų sezono (gegužė–spalis) terminio režimo XXI a. prognozę.

Ginami disertacijos teiginiai

- Vykstant globaliam klimato atšilimui Lietuvos upių vandens temperatūra kils, o šilumos ištekliai ateityje mažės dėl upių vandeningumo pokyčių.

- Lietuvos upes galima suskirstyti į 3 grupes: šilto, vėsaus ir šalto vandens. Pagrindinis upės šiluminės būklės veiksnys – upės požeminės prietakos dydis.
- Lietuvos upės turi didelius šilumos išteklius, kuriuos įvertinant gamtosaugos reikalavimus galima panaudoti ateityje, kaip atsinaujinančios energijos šaltinį.

Darbo mokslinis naujumas ir jo taikymas

Darbe pirmą kartą pateiktos žinios apie Lietuvos upių hidroterminį režimą ir jo pokyčius, atlikta matavimais pagrįsta upių klasifikacija pagal vandens temperatūrą. Išskirtos 3 upių grupės pagal šiltojo laikotarpio (gegužė–spalis) vidutinę daugiametę (1961–1990) vandens temperatūrą. Taip pat sudarytas šiltojo laikotarpio (gegužė–spalis) upių vandens temperatūros izolinijų žemėlapis. Atlikta Lietuvos upių vandens temperatūros ir šiluminio nuotėkio prognozė XXI a. pabaigai. Darbe apskaičiuoti Lietuvos upių šiluminės energijos ištekliai.

Gautos naujos žinios gali būti panaudotos vertinant žuvivaisos ir žuvininkystės plėtros galimybes, taip pat terminės taršos šaltinių įtaką upių šiluminiam balansui ir savivalai (energetika, kanalizacija ir kt.), rengiant pramonės objektų poveikio aplinkai vertinimą (terminis poveikis normuojamas įstatymais) bei numatant atviro vandens šilumos siurblių panaudojimo galimybes.

Publikacijos

Disertacijos tema paskelbta 1 publikacija „Web of Science Core Collection (Thomson Reuters)“ duomenų bazėje bei 3 publikacijos kituose mokslo leidiniuose. Pristatyti 4 pranešimai tarptautinėse konferencijose.

Darbo struktūra ir apimtis

Disertaciją sudaro šios dalys: įvadas, šeši skyriai (mokslinės literatūros disertacijos tema apžvalga, duomenų bazė ir tyrimų metodika, rezultatai), išvados, literatūros sąrašas, mokslinių publikacijų disertacijos tema sąrašas ir priedas. Darbo apimtis – 101 puslapis, tarp jų 22 lentelės ir 24 paveikslai. Literatūros sąraše pateikti 148 literatūros šaltiniai.

IŠVADOS

1. Pateikta Lietuvos upių klasifikacija pagal standartinės normos laikotarpio (1961–1990) šiltojo metų sezono (gegužė–spalis) vidutinę upių vandens temperatūrą. Išskirtos šilto ($\overline{T} \geq 14{,}9$ ºC), vėsaus (13,4 ºC $< \overline{T} < 14{,}9$ ºC) ir šalto ($\overline{T} \leq 13{,}4$ ºC) vandens upių grupės. Nustatyta, kad vandens temperatūra upėse statistiškai reikšmingai skiriasi, kai temperatūrų skirtumas didesnis kaip 0,5 ºC.
2. Nustatyta, kad Lietuvos upių vandens temperatūros įvairovė priklauso nuo fizinių–geografinių veiksnių, kurie sąlygoja klimato fono suformuotą vandens temperatūrą. Tyrinėtų upių vandens temperatūrų ir artimiausių meteorologijos stočių oro temperatūrų variacijos statistiškai vienodos ir daugiamečiu periodu teritorijoje kinta sinchroniškai. Ryšio grafikai tarp šiltojo metų sezono (gegužė–spalis) vidutinių upių vandens temperatūrų ir artimiausių meteorologijos stočių oro temperatūrų rodo, kad tarp jų yra tiesioginė linijinė priklausomybė. Didelių ir šiltų upių vandens temperatūros koreliacija su oro temperatūra aukštesnė (r = 0,97–0,99) nei šaltų upių (r = 0,84–0,98). Analizuojant upių vandens temperatūros priklausomybę nuo vietinių fizinių–geografinių veiksnių nustatyta, kad iš ežerų ištekančių upių vanduo yra šiltesnis (nuo 1,4 iki 3,8 ºC), o gausus požeminis maitinimas yra pagrindinė Lietuvos upių šalto vandens priežastis.
3. Sudarytas šalies vandens temperatūros teritorinio (erdvinio) pasiskirstymo izotermų žemėlapis rodo, kad labiausiai upių vandens temperatūrą veikia maitinimo tipas, upių dydis, baseino orografija, ežerų paplitimas upių baseinuose. Įvairių upių skirtingą vandens paviršiaus įšilimą lemia dar ir kiti vietiniai fiziniai–geografiniai veiksniai, kurių reikšmingiausi yra upės požeminis maitinimas, smėlingi dirvožemiai ir antropogeninė veikla. Atsižvelgus į upių dydį (ilgį) ir vietovės aukštį, sudarytos Lietuvos upių vandens temperatūros pasiskirstymo statistinės priklausomybės, pagal kurias siūloma nustatyti neištirtų upių bei jų slėnyje įrengtų tvenkinių vandens temperatūrą.
4. Ištirta Lietuvos upių vandens temperatūros kaita. Nustatyta, kad per pastaruosius du dešimtmečius (1991–2010) visose tirtose Lietuvos upėse vandens temperatūra reikšmingai kilo (vidutiniškai 0,04 °C per šiltąjį metų sezoną). Nuo 1961–1990 m. laikotarpio iki 1991–2010 m. laikotarpio vidutinė šiltojo metų sezono vandens temperatūra pakilo 0,5 °C (nuo 14,9 °C iki 15,4 °C). Nustatytas glaudus ryšys (r = 0,95–0,98) tarp oro ir upių vandens temperatūrų rodo, kad vandens temperatūra gali būti naudojama kaip svarbus klimato kaitos indikatorius.
5. Dėl klimato kaitos XXI a. upių vandens temperatūra Nemune – Druskininkų VMS kils 1,9 °C (19,5 %), Merkyje – Puvočių VMS – 1,3

°C (15,2 %), Dubysoje – Lyduvėnų VMS – 1,7 °C (20,2 %). Mažiausią įtaką klimato kaita turės toms upėms, kurių šiltojo sezono vandens temperatūra yra žema dėl gruntinio maitinimo.

6. Lietuvos upių vandens temperatūros pokyčių prognozė rodo, kad siekiant upių vandens kokybės ir vandens ekosistemų geros būklės, būtinos gamtosaugos priemonės ir tyrimais pagrįsti normatyviniai dokumentai, reglamentuojantys ūkinę veiklą skirtingo terminio režimo upėse. Pramonės ir energetikos įmonių aušinimo sistemos bei miesto nuotekos lems ir upių terminės būklės antropogeninius pokyčius, kurie paveiks upių vandens deguonies režimą ir savivalos galimybes.
7. Apskaičiavus Lietuvos upių Nemuno, Neries, Jūros, Merkio, Mūšos ir Ventos šiluminės energijos atsargas (nuo 1,3 TWh, Mūša ties Ustukiais iki 117,5 TWh, Nemunas ties Smalininkais) nustatyta, kad jų panaudojimo galimybės sietinos su šilumos siurblių taikymu namams šildyti ir karštam vandeniui tiekti. Įvertinus tai, jog Lietuvoje 2013 m. energijos sąnaudos buvo apie 81,2 TWh, upių vandens šiluminės energijos panaudojimo galimybės ir perspektyvos akivaizdžios.

UDK 556.5

SL344. 2015-11-05, 3 leidyb. apsk. l. Tiražas 60 egz. Užsakymas 396.
Išleido Kauno technologijos universitetas, K. Donelaičio g. 73, 44249 Kaunas
Spausdino leidyklos „Technologija“ spaustuvė, Studentų g. 54, 51424 Kaunas