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Spatial and temporal variation in the water temperature of Lithuanian rivers

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Abstract Water temperature is one of the twelve physico–chemical elements of water quality, used for the assessment of the ecological status of surface waters according to the Water Framework Directive (WFD) 2000/60/EC. The thermal regime of Lithuanian rivers is not sufficiently studied. The presented article describes the temporal and spatial variation of water temperature in Lithuanian rivers. Since a huge amount of statistical data is available (time series from 141 water gauging stations), the average water temperatures of the warm season (May–October) have been selected to analyse because that is the time when the most intensive hydrological and hydro–biological processes in water bodies take place. Spatial distribution of river water temperature is mostly influenced by the type of river feeding, prevalence of sandy soils and lakes in a basin, river size, and orography of a river basin as well as anthropogenic activity. The temporal distribution of river water temperature is determined by climatic factors and local conditions. The averages of the warm season water temperature for 41 WGS are 15.1°C in 1945–2010, 14.9°C in 1961–1990, and 15.4°C in 1991–2010. The most significant changes in water temperature trends are identified in the period of 1991–2010. For this period, the rates of increase of water and air temperature are 0.04 and 0.06°C/warm season, respectively. Therefore, air temperature is one of the most significant factors affecting the water temperatures of Lithuanian rivers.

Keywords *Water temperature • Spatial distribution • Trends • Lithuanian rivers*

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INTRODUCTION

Water temperature is a basic physical characteristic describing properties of surface waters and having a direct impact on the flora and fauna of aquatic ecosystems. The temperature of a stream is determined by atmospheric (ambient) temperature. Other factors affecting river water temperature are the hydrological regime of a river and the orographical conditions of its basin (e.g. elevation, catchment area, number of natural reservoirs formed throughout a basin) (Pekarova *et al*. 2008). The anthropogenic impact, such as existing agricultural land uses (Borman, Larson 2003), industrial thermal discharges, or hydraulic installations that modify flow (Huguet *et al*. 2008), can also influence this important physical parameter.

Increased water temperature very often has a negative impact on water quality. Warm water intensifies eutrophication processes. As water gets warmer, it has a reduced ability to retain oxygen. In relation to freshwater fishes, a vast literature can be found that describes how water temperature influences tolerance and mortality; distribution, abundance and diversity; growth, feeding and bioenergetics; reproduction and embryonic development; swimming, movements and migrations; as well as disease, parasitism and predation (Webb, Walsh 2004). Warming of water can be problematic for other species that inhabit streams and rivers as well (Kaushal *et al*. 2010).

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 it relates to the nutritional base of water bodies (including rivers), fish spawning, self–purification, hydro–ecologic systems, and other issues, the hydrothermal regime of biotopes is one of the prevailing factors (Jablonskis 1986; Ecological sustainability 1999; Virbickas, Pliūraitė 2002; Galvonaitė, Valiukas 2005). In addition, the river / ice relation and hydrological regime in spring are closely related to water and air temperatures.

Recently water temperature studies have often been concentrated on climate change impact. In many cases, the relation between rising air temperatures and river water thermal regime changes is estimated. Stream water temperature data from the studied river catchment in Scotland were examined for systematic variation in the period of 1968–1997 (Langan et al. 2001). No change in mean annual temperature with time was identified, but at the seasonal scale of time some indications of increase in water temperatures during spring were detected. A strong relationship between air and stream temperatures (r2=0.96) implies that changes in streams are the result of changes in climate.

A study of the UK river temperature indicated that global warming would cause river temperatures to increase during the present century, but the magnitude of the rise would vary from modest to very significant depending on which climate scenario came to pass (Webb, Walsh 2004). An increasing trend in extremely high river temperatures for the next decades was detected in the studied case in France (Huguet *et al.* 2008). Water temperatures are increasing in many streams and rivers throughout the USA as well. The research showed that long–term increases in stream water temperatures were typically correlated with increases in air temperatures (Kaushal *et al.* 2010). A study of global river temperatures and sensitivity to atmospheric warming revealed increases in annual mean river temperatures of +1.3 °C, +2.6 °C, and +3.8 °C under air temperature increases of +2 °C, +4 °C, and +6 °C, respectively (Van Vliet *et al.* 2011).

The thermal regime of Lithuanian rivers has not yet been sufficiently investigated. Until now, more attention has been concentrated on the water temperature of the River Nemunas (Grižienė *et al.* 1983) and on the research of thermal regimes of river reaches below dams (Rimavičiūtė 2000; Meilutytė–Barauskienė *et al.* 2005). Vanagaitė and Valiuškevičius (2011) classified Lithuanian rivers according their water temperatures. They used the data of the period 2003–2007 and tried to assess the correspondence of Lithuanian river water temperature with the ecological requirements. River reaches were divided into three groups according two criterions: the relationship between the decade average and maximum temperatures, and the average temperature of May–September.

The aim of this paper is to clarify the thermal regime and its determinants as well as the character of temporal and spatial variations of water temperature in Lithuanian rivers. Since a huge amount of statistical data is available, the average water temperatures of the warm period (May–October) have been analysed because at that time, the most intensive hydrological and hydro–biological processes take place in water bodies.

DATA AND METHODS

The measurements of water temperature in Lithuania first began with those of the River Nemunas at Kaunas in 1928. Ice cover observations of the River Nemunas at Smalininkai have been performed since 1811. A systematic research of the thermal water regime based on most water gauging station data (WGS) of the Lithuanian Hydrometeorological Service (LHMS) was started in 1945. According to hydrological yearbooks, the water temperature of rivers in Lithuania has been measured at 141 WGS that were located in 84 rivers of different size (Fig. 1). The maximum duration of data collection for a dataset is 66 years (1945–2010), the shortest one – 2 years. In the River Nemunas (within the territory of Lithuania), the water temperature was measured 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.

Water temperature measurement at a WGS is performed in the hydrometric cross–section of a river flow twice a day, at 8 a.m. and 8 p.m., at a depth of 0.1 – 0.5 metres from the water surface. In the beginning only a morning water temperature was published in the yearbooks, but since 1957, an average of two measurements has been given. There are essential differences between these two temperatures, therefore the data published until 1957 were corrected using the archive sources (the 8 p.m. data were taken from the archived water measurement books of the LHMS). In such a way, the homogeneity of data sets was achieved. The water temperature for the warm season of each year was calculated as an average temperature of 6 months (May–October).

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 normal (a series from 41 WGS, Fig. 2), were used for the spatial and temporal analysis of the warm season water temperature. The World Meteorological Organization recommends computing the 30 year 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 (NOAA's National Climatic Data Center 2011). 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 whole period of 1971–2000. Data series of air temperature of the warm season from 17 meteorological stations were selected for the same time periods.

The classification of Lithuanian rivers is performed according to warm season water temperature data in the

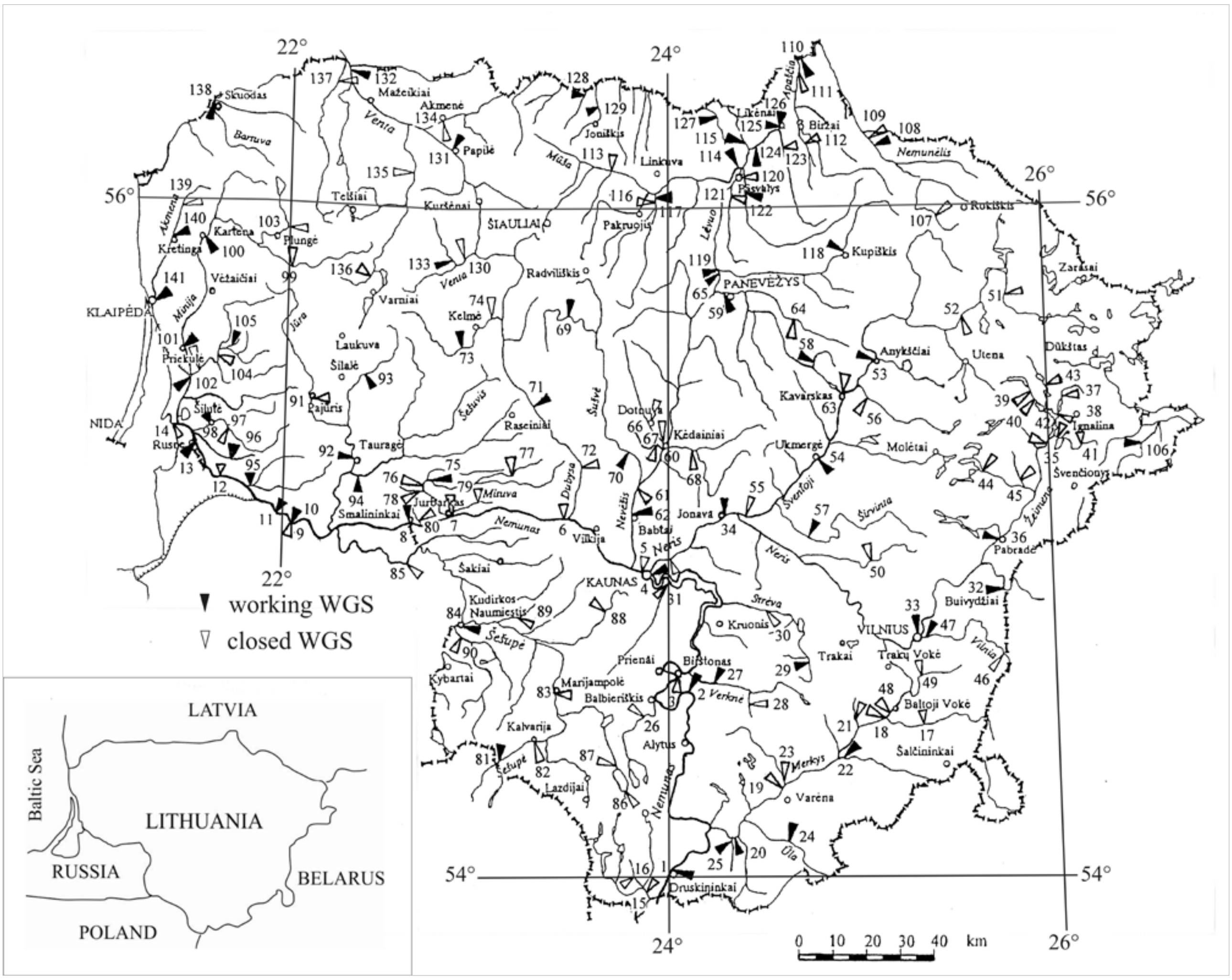

Fig. 1 Location of river water gauging stations. Compiled by A. Jurgelėnaitė.

standard normal period (1961-1990). The water temperature averages of the warm season (May–October) were calculated for 41 WGS (Table 1). The overall temperature average of the standard normal period (t = 14.9°C) was accepted as the main point for the classification of the rivers. The temperature step for this classification is Δt = 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 Δt ≥ 0.5°C (Jablonskis, Jurgelėnaitė 2010). 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 (t ≥ 14.9°C), the cool water (13.4°C<t<14.9°C) and the cold water (t ≤ 13.4°) rivers or river reaches (Table 1, Fig. 2). 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.

The Mann–Kendall test (the details of its theoretical background are described by J. D. Salas [1993]) searches for trends in time series data of water temperature without specifying whether the trends are linear or non–linear. According to Wilson et al. (2010), the critical values of the Mann–Kendall S statistic (S_{max}) are used to identify strong and weak trends. The S_{max} values are defined using p–values (two–sided) of 0.05 and 0.3, which indicate the magnitude of the trend is likely to be in the 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 the slope of the Kendall–Theil Robust Line, enables the evaluation of quantitative changes of parameters during the period (Helsel, Hirch 2002).

The analysis of the integrated curves of air and water temperatures is used to describe the synchronicity of these parameters. The integrated curve ($\sum_{i=1}^{n}(k_i-1)$) is the sum of variations of modular coefficients from the average value. The modular coefficient is $K_i = T_i / \bar{T}$ where T_i – temperature in the warm period i, $\bar{T}$ – the mean temperature for the entire period of observation.

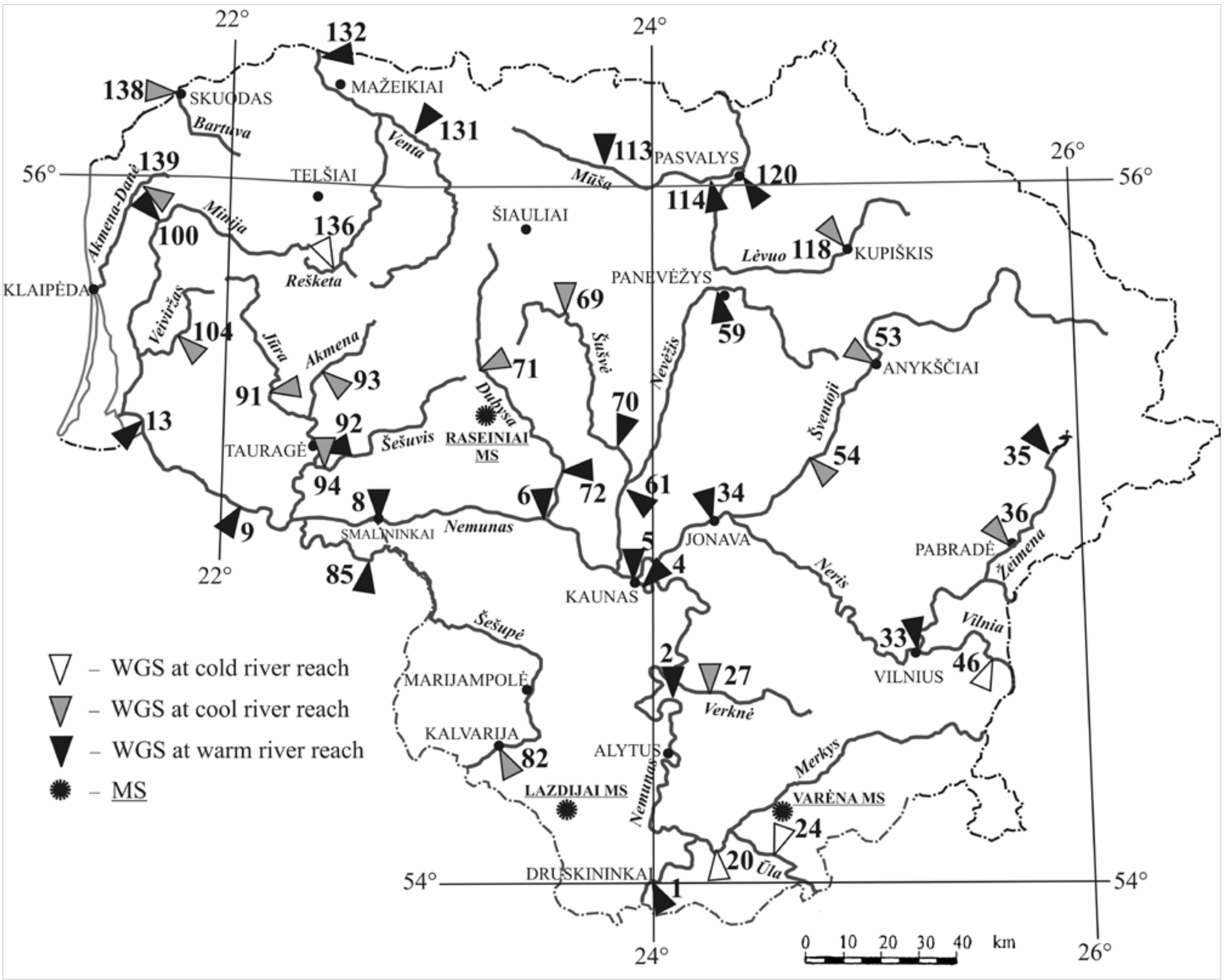

Fig. 2 The selected 41 WGS on 23 Lithuanian rivers. Compiled by D. Šarauskienė.

RESULTS

Spatial variation in water temperatures

The multi–annual mean of the warm season water temperatures in Lithuanian rivers, according to data from 141 WGS, varies 9.0°C. (The WGS number of the data collection site is shown in parentheses.) The lowest temperature was 7.7°C at the Smardonė River at Likėnai (125th WGS), which is a small stream that is significantly affected by groundwater. The highest temperature was 16.7°C at the branch of the River Nemunas delta called Rusnė, at Panemunė (13th WGS). 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 (the 46th WGS) to 16.1°C of the Šešupė River at Dolgoje (the 85th WGS) (see Table 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.

The spatial analysis of water temperature involves local physical – geographical factors for the classified river groups. The data shown in Table 1 indicate that almost all large rivers are warm: the River Nemunas (the 1st, 2nd, 4th, 5th, 6th, 8th, 9th and 13th WGS, Fig. 1), its major tributaries, i.e. the rivers Neris (the 33rd and 34th WGS), Nevėžis (the 59th and 61st WGS), and Šešupė (the 85th WGS), the River Mūša, a tributary of the River Lielupė (the 113th and 114th WGS), the River Venta (the 131st and 132nd WGS). Several small rivers of south-eastern Lithuania with the laky catchments: the rivers Lakaja (the 44th WGS), Srovė (the 39th WGS), Kretuona (the 42nd WGS), and Dumblys (the 40th WGS) are also the warm rivers of the country.

The cool rivers of the slopes of the Žemaičiai (Samogitian) Highland and Baltic Highlands are the rivers Veiviržas (the 104th WGS, 13.8°C), Bartuva (the 138th WGS, 14.5°C), Virinta (the 56th WGS, 13.6°C), and Širvinta (the 57th WGS, 14.5°C). These rivers are by 40% or more fed by deep, cool groundwater of over 5 m of depth with 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,

Table 1 Long–term average river water temperatures of the warm period.

No.	River – water gauging station	Catchment area, km^2	Period	Water temperature, °C		
				Whole period	1961–1990	1991–2010
Warm rivers (t ≥ 14.9°C)						
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<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 (t ≤ 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	–

and these waters later feed rivers. Sandy soils have a faster infiltration rate that allows more spring water to recharge the groundwater.

The rivers that flow out from lakes have warmer water. For example, the source of the River Žeimena is Lake Žeimenys. The water temperature of this river was measured in Kaltanėnai 1 km below the source (the 35th WGS) and is still measured at the Pabradė WGS, which is 17.5 km from the river mouth (the 36th WGS). Sandy soils cover about 44% and 76% of the total basin area at these WGS and the lakes cover 8.9% and 7.0%, respectively (Gailiušis *et al*. 2001). According to the chosen river grouping, the upper reaches of the River Žeimena (the 35th WGS) are assigned to the group of warm water rivers, and the lower reaches are attributed to the group of cool water rivers. That is a clear illustration of how the temperature of river water can be influenced by lakes and sandy areas of a river catchment.

The River Merkys (the 20th WGS, Fig. 1), its tributary the Ūla (the 24th WGS), the Rešketa (the 136th WGS), the upper reaches of the River Vilnia (the 46th WGS), and 10 additionally investigated rivers, which have an average water temperature lower than 13.4°C during the warm season, are attributed to the group of cold water rivers. One more exceptional determinate of water temperature can be detected; the rivers with more abundant groundwater feeding and with plenty of springs have lower water temperatures during the warm season of the year. For example, the largest river of south-eastern Lithuania, the River Merkys (the 20th WGS, Fig. 1) is the coldest, t=13.3°C, among the principal rivers of the country. Sandy soil covers about 70% of the River Merkys catchment area. Through this sandy layer, the river gets over 60% of its annual runoff. Water temperatures of the most tributaries of the River Merkys are even lower: in the Ūla (the 24th WGS) – 12.9°C, the Šalčia (the 22nd WGS) – 13.8°C, the Cirvija (the 21st WGS) – 10.1°C, and the Skroblus (the 25th WGS) – 10.8°C. The water temperature of the upper reaches of the River Vilnia at Santakai (the 46th WGS) is low as well – 12.4°C. The average water temperatures of the warm season that are lower than 13.4°C may be found in other rivers with sandy catchments: the Švogina (the 37th WGS) – 11.8°C, the Pilvė (the 88th WGS) – 13.0°C, the Upita (the 105th WGS) – 12.4°C, the Rešketa (the 136th WGS) – 13.2°C, and others. Sandy areas in the catchments of these rivers make up 30–95% of their total. Many of these basins are covered by forests (Gailiušis *et al*. 2001). Forest help maintain cool water temperature by providing shade and creating a cool and humid microclimate over the stream (Webb, Zhang 1997).

The classification of river water temperatures shows that the majority of large rivers are warmer than the small ones (see Table 1). In many cases, water temperature changes downstream from the river: it is higher in the lower reaches than in the upper ones. This phenomenon can be observed in all investigated rivers which have two or more WGS. Rivers transporting water downstream are increasingly acquiring heat energy due to friction as well as recieving water from their tributaries (Hammond, Pryce 2007; Odrova 1979). The increase of water temperature is characteristic of all investigated major rivers: the Venta, Šešupė, Nevėžis, Dubysa and its tributary the Kražantė, Jūra, Minija, Mūša and its tributary the Lėvuo, Akmena and its tributary the Danė, and Vilnia. A quite opposite phenomenon has been observed only in the River Žeimena. As mentioned before, this river gets warmer as it flows out from the lake.

The downstream thermal regime of the River Nemunas varies for several reasons: the change of geographical direction of the river flow, the water volume, differences in groundwater feeding, the distribution of northern and southern tributaries, the influence of the hydropower plant (HPP) reservoir in Kaunas, and the other reasons (Grižienė *et al*. 1983). An average water temperature of the warm season for the standard period in the River Nemunas at Druskininkai (the 1st WGS) is 16.0°C and in the Nemunas at Rusnė (the 13th WGS) – 15.9°C. The Nemunas is slightly cooler at Seredžius, 15.4°C (the 6th WGS), and in the middle course, 15.6°C at Nemajūnai (the 2nd WGS). The Kaunas Reservoir (Kauno marios) raises the average water temperature of the warm season from 15.6°C (the 2nd WGS) up to 16.0°C (the 4th WGS), but the cooler water of the River Neris, ranging from 15.1°C (the 33rd WGS) to 15.4°C (the 34th WGS), lowers the temperature down again to 15.8°C (the 5th WGS). The same tendencies in changes of water temperature downstream from the River Nemunas are observed for the whole period and the last 20 year period (1991–2010) of observations (Fig. 3).

Reservoirs formed on rivers impact the thermal regime of a river. Water temperatures of the River Baltoji Ančia in 1946–1963 were measured 1.5 km

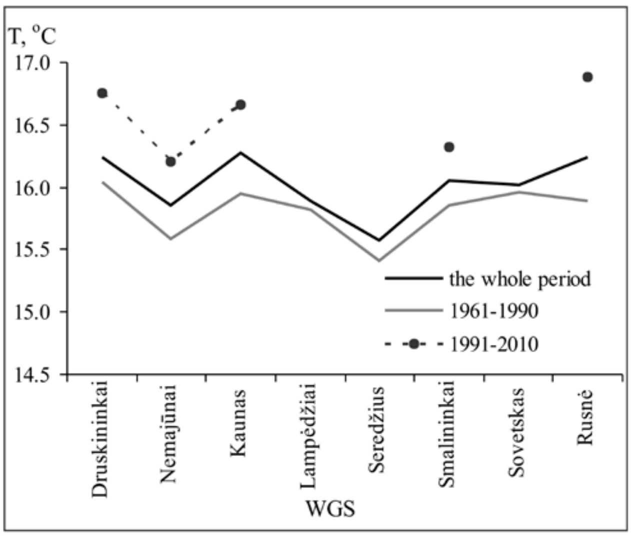

Fig. 3 Water temperature averages of the warm season in the different River Nemunas WGS during the studied periods. Compiled by A. Jurgelėnaitė.

above Guronys (the 15th WGS). The Student's t-test was applied to test whether the water temperature below the dam (constructed in 1955) changed with time. The results indicated that the difference of temperature (Δt=15.61°C–13.87°C=1.74°C) was statistically significant between the periods of 1946–1955 and 1956–1963. In another similar case, a reservoir with the water surface area of 55.5 hectares was formed in 1972 at the upper reaches of the River Vilnia, 5 km above Santakai (the 46th WGS). Comparing the periods prior to the reservoir forming and after the essential difference of water temperatures (Δt=12.84–12.10=0.74°C) was determined have a significant level of α=0.05. Over 1.2 thousand reservoirs with water surface areas of at least 0.5 ha have been constructed on rivers of Lithuania. The influence of reservoirs on river water temperatures is significant.

In conclusion, the spatial variability of water temperatures of Lithuanian rivers during the warm season can be explained by local physical–geographical and anthropogenic factors. The most important factors are landscape, groundwater flow, the prevalence of sandy soils and lakes in the catchments, river size, reservoirs, and others.

Temporal variation in water temperatures

The temporal analysis of long–term data series of water temperatures was applied to the data from 41 WGS (Fig. 2). The chronological variation of water temperature in three different rivers is presented; a cold river, the Merkys at Puvočiai (the 20th WGS); a cool river, the Dubysa at Lyduvėnai (the 71st WGS); and a warm river, the Venta at Leckava (the 132nd WGS) (Fig. 4). 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 16.2°C and for the Venta, 17.3°; both were recorded in 2006. The highest temperature for the Merkys was 14.9°C in 1948.

The variability of water temperature in different time periods has different tendencies. The following time periods were selected for this study: a long–term period for all available data, a standard normal 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 (Galvonaitė, Valiukas 2005). Trends with different significance levels (strong positive, weak positive, weak negative, strong negative) were used for the analysis. The results were assessed in two ways: by determining the significance of trends in the water temperature data series of the Lithuanian rivers (Table 2) and by compiling maps of temporal variability of the temperature trends for three periods (Fig. 5).

Insignificant trends of temperature prevailed in the data of the period of 1945–2010 and 1961–1990 (73% and 88 % of the stations, respectively) (Table 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.

In the longest period, 1945–2010, strong positive trends were found in the water temperature data of the rivers Nemunas (the 1st and 13th WGS, Fig. 5a),

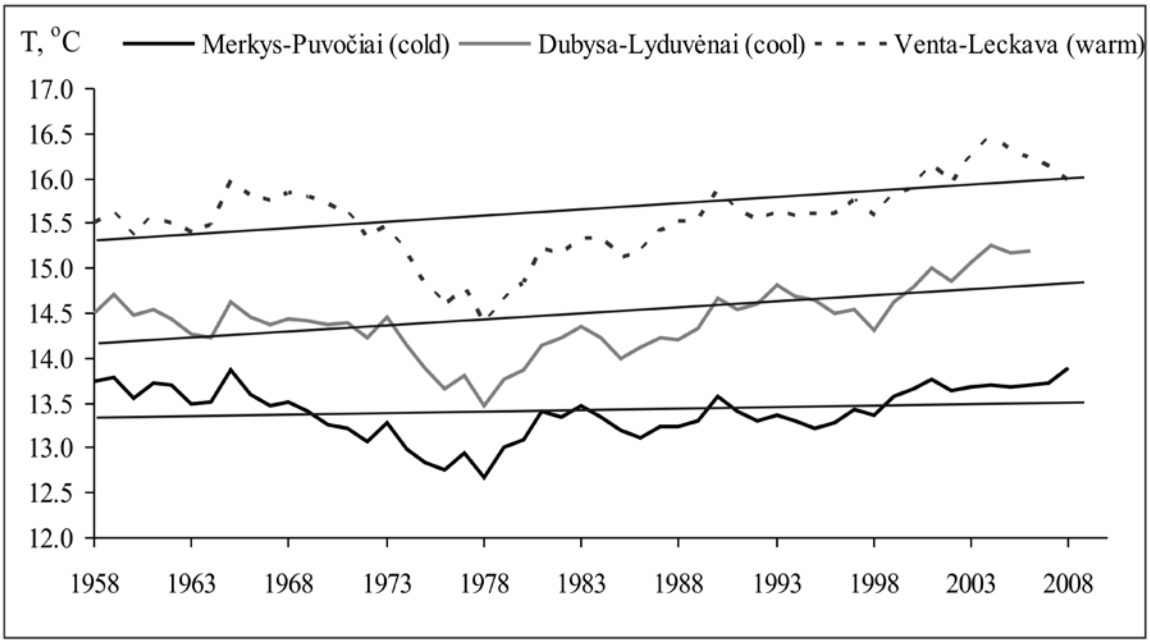

Fig. 4 5-year moving averages of water temperature data sets and trends of the selected rivers from different groups during the whole studied periods. Compiled by A. Jurgelėnaitė.

Table 2 Summary of strong, weak and insignificant trends of river water temperatures in three time periods (% of 41 WGS in 1945–2010 and 1961–1990, and % of 26 WGS in 1991–2010).

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

Neris (the 34th WGS), Mūša (the 114th WGS), Dubysa (the 71st WGS), and Šešuvis (94th WGS). These river reaches belong to a group of warm and cool rivers. Strong negative trends were identified in the data of the cold rivers Merkys and Rešketa (the 20th and 136th WGS). In the standard normal period of 1961–1990 (Fig. 5b), there were two weak negative trends, those of the Žeimena (the 36th WGS) and the Ūla (the 24th WGS); two strong negative trends, those of the Verknė (the 27th WGS) and the Rešketa (the 136th WGS); and only one strong positive trend, that of the Vilnia (the 46th WGS). The most extensive changes in water temperature trends are assessed in the recent period of 1991–2010 (Fig. 5c). Most of the trends became weak positive or strong positive for all the studied river groups.

Trend magnitudes are 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 temperature data values (Fig. 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.

DISCUSSION

Spatial distribution of river water temperatures depend on local physical–geographic factors. The most significant factors are river groundwater feeding, lakes and reservoirs, catchment geology, river size, etc. The influence of other factors (e.g. the altitude of the WGS) on water temperature is presented in the study of Jablonskis and Jurgelėnaitė (2010). Lithuanian rivers were classified into three groups: the cold water, $t \leq 13.4°C$, the cool water, $13.4°C < t < 14.9°C$, and the warm water, $t \geq 14.9°C$, rivers. Other countries have different classifications, for instance, another system of classification exists in Slovakia (Martincova *et al.* 2011). The altitude of measurement sites is evaluated in the methodology of classification of water temperature for surface waters in Slovakia because the elevation of site reaches up to 1000 m. This characteristic is not very important in Lithuania where the highest altitude is only 293.84 m.

Temporal distribution of river water temperature is determined by climatic factors expressed by air temperature. In the period of 1961–1990, the mean water temperature is 14.9°C according to 41 WGS, and the mean air temperature is 13.2°C according to 17 meteorological stations. In order to find out the influence of air temperature on river water temperature, a correlation analysis was performed for the data from the period 1961–1990. The water temperature of every river reach was compared to the air temperature observed in the nearest meteorological station (MS). All correlation coefficients of these pairs are statistically significant, 0.78 – 0.93. The integral curves of river water temperature of three rivers – the Merkys at Puvočiai, the Dubysa at Lyduvėnai, and the Nemunas at Druskininkai – which were assigned to the cold, cool, and warm groups of rivers, as well as the curves of air temperature in Varėna, Raseiniai and Lazdijai meteorological stations are presented (Fig. 7). The correlation coefficients between the temperature of the Merkys and Varėna MS, of the Dubysa and Raseiniai MS, and of the Nemunas and Lazdijai MS are 0.78, 0.84 and 0.90 respectively. The curves (Fig. 7) demonstrate that the water temperature (except the water temperature of the Merkys) during the period of 1945–2010 changed in a relatively synchronic way. In addition, it coincides with the multi–annual variation of air temperature in all three meteorological stations quite well. The wave–shaped integral curves show that multi–annual trends of air and river water temperature were variable and synchronic during the study period of 66 years. The increasing parts of the integral curves highlight the periods when the temperature of air or water was increasing. All curves indicate increases from the period of 1990–1992. The air temperature of the warm season increased by 0.7°C in the period of 1991–2010 in comparison with the previous 30 year period. This air temperature rise has an obvious influence on the increasing water temperature in the Lithuanian rivers from 1991.

Other studies reveal the same strong linear relationship between water and air temperature internationally. A study of 157 river temperature stations around the globe using historical series of daily river temperature for the period of 1980–1999 showed obvious increases in annual mean river temperatures influenced by air temperature increases (Van Vliet *et*

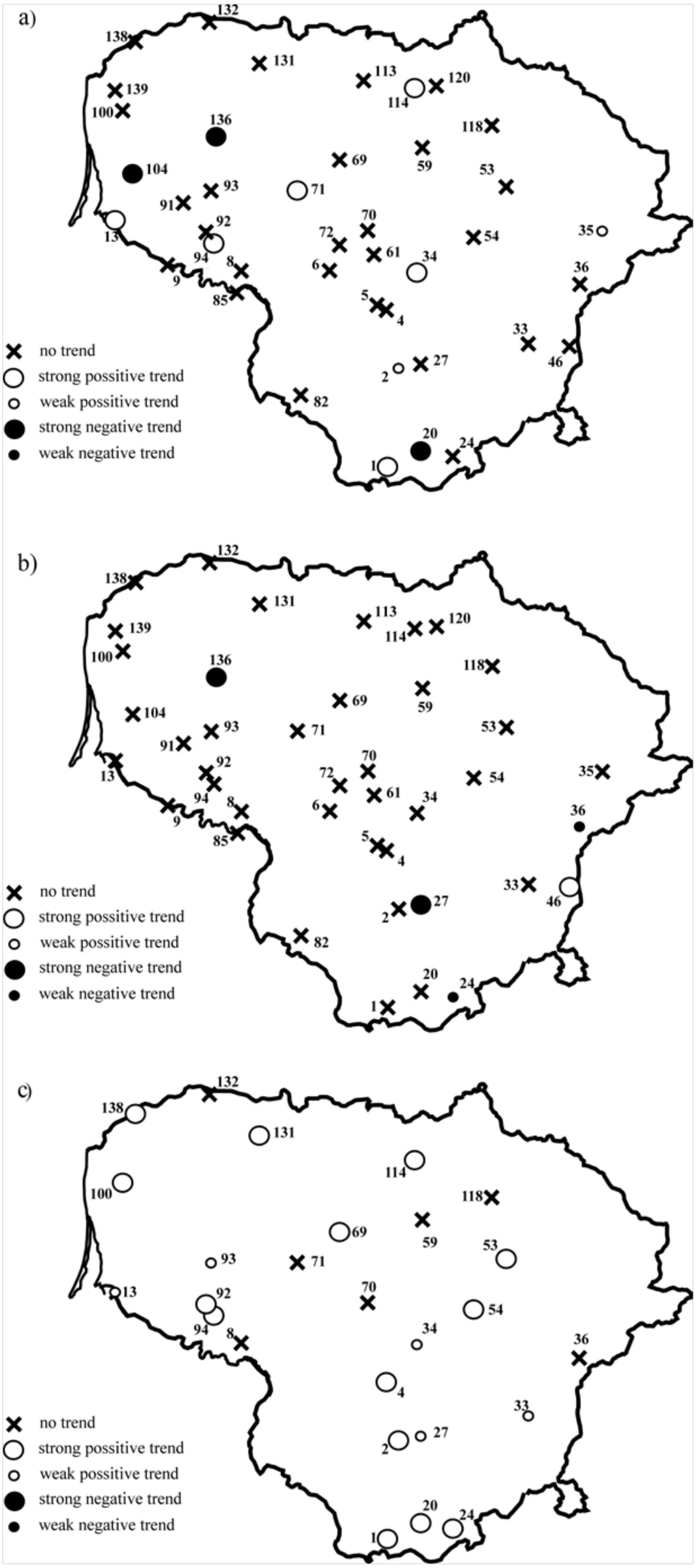

Fig. 5 Trends in river water temperature for the studied periods: a – the whole period, b – 1960-1991, c – 1991-2010. Compiled by D. Šarauskienė.

Fig. 6 Changes of slope of water temperatures for three studied periods. Compiled by J. Kriaučiūnienė.

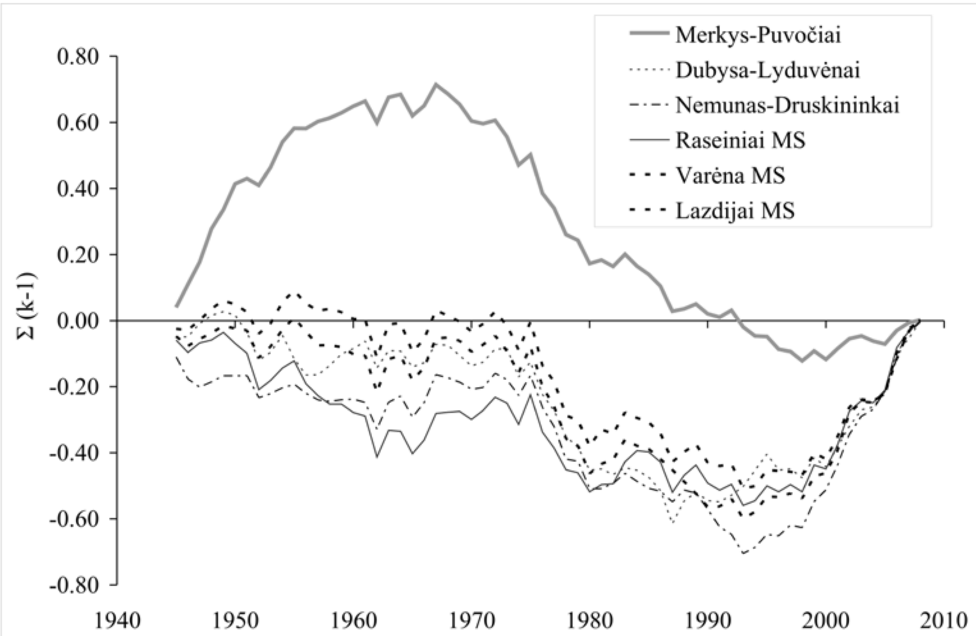

Fig. 7 The integral curves of variation of air and river water temperature of the warm season (May-October) in 1945-2010. Compiled by J. Kriaučiūnienė.

al. 2011). Weather conditions are identified as having the dominant influence on river temperature in other scientific works as well (Borman, Larson 2003; Pekarova *et al.* 2008; Kaushal *et al.* 2010).

CONCLUSIONS

The thermal regime of Lithuanian rivers was assessed by analysing the water temperature of 84 rivers at 141 WGS. A wide variety of average water temperatures of the warm season of the year (May–October) was determined in the studied rivers: from 16.7 °C in the River Nemunas at Panemunė up to 7.7 °C in the River Smardonė at Likėnai, which is a small stream significantly affected by groundwater.

The spatial distribution of river water temperatures is mostly influenced by the type of river feeding from groundwater, prevalence of sandy soils and lakes in the basin, river size, orography of the river basin as well as anthropogenic activity. The temporal distribution of river water temperatures is determined by climatic factors and local conditions. Variation in water temperature of the studied rivers and air temperatures measurements from meteorological stations were statistically identical and had multi–annual synchronical fluctuation. The greatest changes in water temperature trends were detected in the recent period of 1991–2010. The averages of the warm season water temperature for 41 WGS were 15.1°C in 1945–2010, 14.9°C in 1961–1990, and 15.4°C in 1991–2010. The rates of increase of water and air temperature were 0.04 and 0.06°C/warm season, respectively in the period of 1991-2010. Therefore, air temperature is one of the most significant factors affecting water temperatures of Lithuanian rivers.

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