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VYTAUTAS AKSTINAS

ASSESSMENT OF FLOODS OF LITHUANIAN RIVERS AND THEIR RISK IN THE CONTEXT OF CLIMATE CHANGE

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES, ENVIRONMENTAL ENGINEERING (T 004)

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KAUNAS UNIVERSITY OF TECHNOLOGY
VYTAUTAS MAGNUS UNIVERSITY
LITHUANIAN ENERGY INSTITUTE

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Doctoral dissertation has been prepared at the Lithuanian Energy Institute during 2014-2018 at Laboratory of Hydrology.

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INTRODUCTION

According to the geographical and climatic conditions of Lithuania, the floods are identified as extreme hydrological phenomena. In this work, there are analyzed the spring floods as well as flash floods of summer and autumn seasons. These types of floods differ from each other by different conditions of their formation. River floods are a natural phenomenon that occurs in nature every year. Snow melting is a major factor of formation for spring flood. Very sudden, if the thaw season coincides with the rain, large-scale floods are generated. The magnitude of the spring floods is caused by the soil frost, which is still not thawed after winter. Therefore, there is almost no infiltration and most of the surface runoff flows directly into the rivers.

In Lithuania, flash floods of summer-autumn seasons are caused by prolonged rain or heavy rainfall. Usually, in the warm season the main reason of the heavy rainfall is the cold air front after a summer heat and the convective cumulonimbus clouds, which often have their own local patterns. The most important condition for the formation of these clouds is high amount of solar radiation, which causes intensive evaporation from the sea, lakes, wetlands and evapotranspiration from soil and plants. The formed cumulonimbus clouds oneself accumulate large amounts of water. Deep cyclones together with abundant rainfall form flash floods in autumn season.

Now it is believed that climate change is like a side-effect product of anthropogenic activity. In future, climate change is projected in terms of CO_2 and other greenhouse gas emission scenarios, which depend on further economic activities, as well as social and economic development. One of the main objectives of environmental engineering is to reduce the consequences of anthropogenic activities. After identifying possible changes in floods regime in the future, it is possible to assess their impact on human environment in the conditions of climate change. Further ways of solving problems, suggestions and recommendations can be provided only after a detailed change analysis of the floods. In the conditions of climate change, the changed hydrological regime of Lithuanian rivers will have impact on the planning, construction and maintenance of hydrotechnical structures. Due to the unstable regime of rivers, the watery redistribution and difficult prediction of extreme hydrological phenomena, the selection and implementation of safety measures for reduce disaster risk in climate change conditions will become a real challenge of the 21st century. The possible changes in extreme hydrological phenomena related to climate change will affect the social and economic environments of human.

There are many ways to solve these problems, but first of all, an expedient methodology has to be created that will help to select the most appropriate ways of solution carefully. When it comes to floods, it is important to analyze the patterns changes of historical floods in detail in order to better understand how hydrological processes will change in the future. First and foremost, when global climate changes, it makes changes in the regional climate as well and as a result of such feedback the hydrological regime of the rivers changes. According to different climate scenarios, the projections of future floods are created. Having summarized research results, the recommendations can be made to prevent or minimize the impact of extreme hydrological phenomena in changing climate conditions. It is particularly important to assess the consequences of projected floods that may be related to damage of hydrotechnical structures, as well as construction and exploitation. The most severe damage for mentioned structures can be caused by the floods of rare probability. After assessing the probability and magnitude of these floods in conditions of climate change, suggestions and recommendations for newly constructed hydrotechnical structures can be presented.

Relevance of the research

EU Water Framework Directive (2000/60/EC) laying down the framework for Community action in the field of water policy and directive on the assessment and management of flood risks (2007/60/EC) require that country policy makers and decision-makers take into account the changes in water resources in relation to climate change when assessing the risks of future floods and invite them to regularly update their projections using the newest generation climate scenarios.

Object of the research

Floods of Lithuanian Rivers – spring floods and flash floods of summer and autumn seasons.

The aim of the Doctoral Dissertation

To evaluate the regularities of changes of floods in Lithuanian rivers according to observed data and to carry out the projection of floods according to the newest climate scenarios using hydrological modeling, and after evaluating the changes of floods, to create recommendations and proposals for the preparation of documents for the protection and management of resources of water bodies.

The tasks of the Doctoral Dissertation

1. To evaluate the patterns of flood change in the past and to determine the main conditions of the formation of these phenomena.
2. To create the methodology for projections of floods under climate change conditions.
3. To carry out the projections of floods and to evaluate their possible changes in the 21st century according to selected climate scenarios applying the created hydrological models.

4. To evaluate the uncertainties of projection of runoff and floods related to the selection of climate scenarios, global climate models and statistical downscaling methods.
5. To provide recommendations and proposals for the preparation of documents for the protection and management of resources of water bodies.

Hypotheses

- The decrease of maximum discharge of spring floods is projected in the future, but still extreme floods are expected in a particular year.
- The projected average maximum discharge of flash floods of the warm season increases as well as the increase in extreme discharges.
- Global climate models, climate scenarios and statistical downscaling methods are primary sources of uncertainty of projections and their selection has a significant impact on the final projections of extremes.

Scientific novelty and application of Doctoral Dissertation

The impact of climate change on floods has been underestimated so far in Lithuania. Only in the report of flood risk assessment and management plans of River Basin District (RBD) and Flood risk of RBD, the climate change has been evaluated according to scenarios of SRES (Special Report on Emissions Scenarios, 2000) group that became out-dated in 2013 after realisation of RCP (Representative Concentration Pathways) scenarios. The documents of the Technical Construction Regulation (STR 2.02.06:2004 and STR 2.05.19:2005) specify how to select the probabilities of extreme discharge according to the classes of consequences of hydrotechnical structures, but the probabilistic assessment itself is based on historical data series, without considering the trends of potential climate change. Therefore, the created methodology of projection (tested in Lithuanian conditions) based on RCP climate scenarios will allow to assess the potential impact of climate change on the water bodies and to provide recommendations and suggestions for mitigation of possible consequences.

A part of the obtained results was applied in the National Program Project "Impact Assessment of Climate Change and Other Abiotic Environmental Factors on Aquatic Ecosystems" (2015-2018) during the period of doctoral studies The projection of Lithuanian river runoff and floods as well as the evaluation of uncertainty of the projection itself will help to determine the possible range of changes of seasonal and extreme values in Lithuanian rivers according to the newest climate scenarios. Also it will allow to provide recommendations and suggestions for the preparation of documents for the protection and management of resources of water bodies (Management plans of RBD and Flood risk of RBD, Flood hazard and risk maps, Construction Technical Regulation). The applied methodology and obtained results are important for present and future scientific projects related to the assessment of the climate change impact on hydrological extremes.

Approval of the Doctoral Dissertation

The material of the doctoral dissertation has been published in two articles in journals referred in "Clarivate Analytics – Web of Science Core Collection" database and one paper was accepted in the journal of mentioned database. One paper was published in journal referred in SCOPUS databases. Eight presentations based on the material of the dissertation have been presented in international conferences, two of them took place abroad.

Scope and structure of the dissertation

The dissertation consists of introduction, 6 chapters (literature review, methodology, study area and hydrometeorological database, evaluation of floods according to historical observations, analysis of hydrometeorological indicators in the 21st century according to different climate scenarios, recommendations and proposals for the preparation of documents for the protection and management of resources of water bodies), conclusions, the list of references and the list of scientific publications based on dissertation. The dissertation is comprised of 121 pages, including 40 figures and 20 tables. The list of references has 170 sources.

1. STUDY AREA AND HYDROMETEOROLOGICAL DATABASE

In assessing the regularities of the changes of floods in the Lithuanian rivers and the conditions for their formation in the past as well as creating hydrological models of selected rivers, a large amount of hydrometeorological data was collected from hydrological yearbooks (Q, m^3/s), meteorological yearbooks (T, °C; P, mm; SWE, mm), meteorological month books and agrometeorological yearbooks (SWE, mm). Temperature and precipitation data of three global climate models (GFDL-CM3, HadGEM2-ES and NorESM1-M) generated by three climate scenarios (RCP2.6, RCP4.5 and RCP8.5) were used for the modelling of projections of floods in the near and far future.

The trend analysis was applied and 31 Water gauging station (WGS) from Western (LT-W), Central (LT-C) and Southeastern (LT-SE) hydrological regions of Lithuania were selected for evaluation of the regularities of spring floods and summer-autumn flash floods changes in the past (Fig. 1.1). The data of these WGS were collected from yearbooks of Lithuanian Hydrometeorological Service (LHMT) for the observation period (Table 1.1) of a particular river. From the data of daily discharge observations, the maximum values of the analysed extreme hydrological phenomena (spring floods and summer-autumn flash floods) were used in further study and their average values according to the WMO reference period (1961-1990) are also listed in Table 1.1.

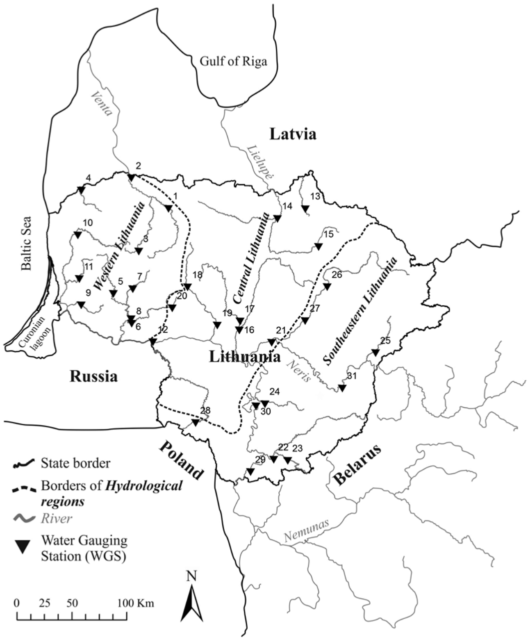

Fig. 1.1. Spatial distribution of analyzed WGS (numbering in Table 1.1.)

Table 1.1. Characteristics of analysed rivers in three hydrological regions of Lithuania (LT-W, LT-C and LT-SE)

No.	River	Water gauging station (WGS)	Catchment area (km²)	Observation period	Average Q_{max} (m³/s) of 1961-1990	
					Spring floods	Summer and autumn flash floods
Western Lithuania (LT-W)						
1.	Venta	Papilė	1570	1948-2013	114	43
2.	Venta	Leckava	4060	1949-2014	231	128
3.	Rešketa	Gudeliai	84	1947-1996	9	7
4.	Bartuva	Skuodas	612	1957-2013	71	58
5.	Jūra	Pajūris	876	1946-1999	117	103
6.	Jūra	Tauragė	1690	1925-2013	210	148
7.	Akmena	Paakmenis	314	1955-2013	44	29
8.	Šešuvis	Skirgailai	1880	1941-2014	163	73
9.	Šyša	Jonaičiai	174	1960-1999	16	15
10.	Minija	Kartena	1230	1925-2013	117	111
11.	Veiviržas	Mikužiai	336	1954-1999	44	50
12.	Nemunas	Smalininkai	81200	1812-2013	1857	739
Central Lithuania (LT-C)						
13.	Agluona	Dirvonakiai	66	1946-1999	9	2,3
14.	Mūša	Ustukiai	2280	1958-2014	152	39
15.	Lėvuo	Kupiškis	307	1955-1999	25	9
16.	Nevėžis	Dasiūnai	5530	1961-2005	300	97
17.	Šušvė	Josvainiai	1100	1941-1999	76	36
18.	Dubysa	Lyduvėnai	1070	1941-2013	73	29
19.	Dubysa	Padubysys	1840	1930-1999	113	53
20.	Alsa	Paalsys	49	1957-1999	6	4
21.	Neris	Jonava	24600	1920-2013	660	272
Southeastern Lithuania (LT-SE)						
22.	Merkys	Puvočiai	4300	1946-2014	97	51
23.	Ūla	Zervynos	679	1960-2013	23	12
24.	Verknė	Verbyliškės	694	1952-2013	30	14
25.	Žeimena	Pabradė	2580	1954-2014	46	28
26.	Šventoji	Anykščiai	3600	1928-2013	119	46
27.	Šventoji	Ukmergė	5440	1925-2013	190	70
28.	Šešupė	Kalvarija	444	1954-2004	14	6
29.	Nemunas	Druskininkai	37100	1945-2013	718	305
30.	Nemunas	Nemajūnai	42800	1920-2013	828	366
31.	Neris	Vilnius	15200	1923-2013	365	161

The catchments of five rivers (Venta, Šešuvis, Mūša, Merkys and Žeimena) from the basins of three main rivers (Nemunas, Lielupė and Venta) were chosen to evaluate the conditions of the spring floods formation. Mentioned rivers selected for analysis represent each of hydrological regions of Lithuania and have the same continuous period of observations (1961-2014) of the daily discharge (Q, m^3/s). Data of daily precipitation amount (P, mm) for the period of 1961-2014 was collected from LHMT meteorological yearbooks and data of snow water equivalent (*SWE*, mm) in decades was from agrometeorological and meteorological yearbooks and meteorological month books. The weight of each meteorological station was determined using the Thiessen polygon method (Fiedler, 2003).

From the Nemunas River basin three river catchments (Minija, Nevežis and Šventoji) represented by water gauging stations of Minija-Kartena, Nevėžis-Dasiūnai and Šventoji-Ukmergė were selected for projections of future discharges and floods. Meteorological stations were also selected for hydrological modelling of mentioned rivers and the weight of each meteorological station in the selected river basins was determined using the Thiessen polygon method as well. Calibration and validation period was from 1986 to 2005 and the daily observations of the average air temperature (T, °C) and precipitation amount (P, mm) for that period were taken from the meteorological yearbooks.

The data of daily average air temperature and daily precipitation amount of three global climate models (GFDL-CM3, HadGEM2-ES and NorESM1-M) generated by three RCP climate scenarios (RCP2.6, RCP4.5 and RCP8.5) were used projecting runoff and floods of selected Lithuanian rivers in the 21st century. According to IPCC AR5 recommendations (IPCC, 2013) evaluating changes in future hydrometeorological parameters according to the RCP scenario, the projections of these parameters are usually created for two future periods – for the near future (2016-2035) and far future (2081-2100) and compared with the reference period, which is 1986-2005 in AR5 (IPCC Fifth Assessment Report).

2. METHODOLOGY

The data of historical observations of hydrological and meteorological parameters were used to evaluate the patterns of floods in the past and the conditions for their formation. The methods of trend analysis, probability distributions and multiple regression analysis were applied to highlight mentioned patterns. Meanwhile, in order to evaluate possible changes of analysed hydrological extreme phenomena in the future, according to observations and available geographic information, the hydrological models of selected rivers have been created. Output data of selected global climate models (GFDL-CM3, HadGEM2-ES and NorESM1-M) – temperature (*T*) and precipitation (*P*) according to RCP (2.6, 4.5, and 8.5) climate scenario were adjusted to Lithuanian conditions by applying statistical downscaling methods of BC, CF and QM. The following *T* and *P* data series were used to simulate projections of daily discharge in near (2016-2035 m) and far future (2081-2100) using the HBV software. The simulated annual and extreme values of runoff were compared with the values of the IPCC AR5 recommended reference period (1986-2005). Following the uncertainty analysis and the evaluation of floods in climate change conditions, the recommendations and suggestions for the preparation of documents for the protection and management of resources of water bodies were presented (Fig. 2.1).

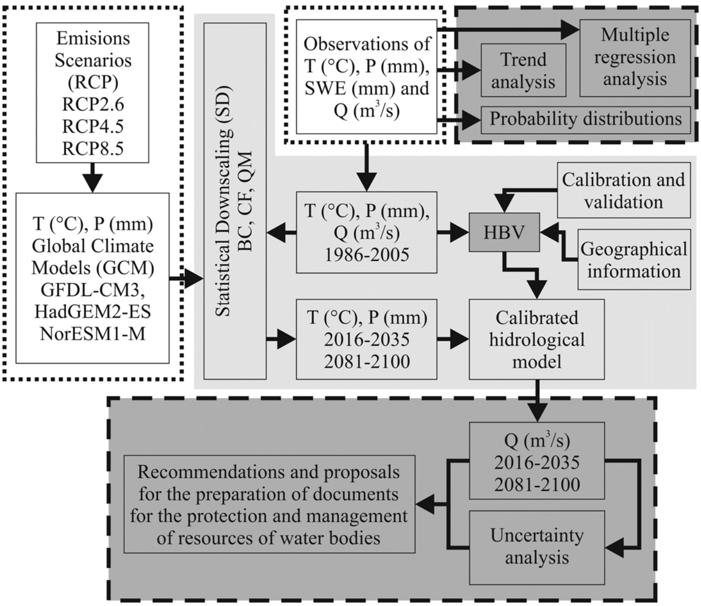

Fig. 2.1. Workflow of the projections of floods and their risk evaluation under climate change conditions

The trend analysis has been used to evaluate the tendencies of spring floods and flash floods of summer-autumn season in the past, as the trend is a purposeful change in the parameter under analysis in time. The trends of mentioned floods were analysed using a very widely applied nonparametric statistical analysis method – Mann-Kendall (MK) test. This test is applicable to both linear and non-linear trends. The MK test is recommended by the World Meteorological Organization (Maidment, 1993) and is used to evaluate trends in the variation of different meteorological or hydrological parameters. The Mann-Kendall test determines the positive or negative trends of the parameter under consideration, which corresponds to a 30% confidence level and a significant positive or negative trend to a 5% confidence level.

Using the Mann Kendall test, the basis of the method is the time series values of the parameter being analysed n ($X_1, X_2, X_3, ..., X_n$) and two data series (P_j and P_i), where i=1, 2, 3, ..., n-1, j=i+1, i+2, i+3, ..., n. In this way, indicators are evaluated as relative probabilistic values-grades ($P_1, P_2, P_3, ..., P_n$) and this statistical term is obtained by (Yue, Wang, 2004; Shadmani, Marofi, Roknian, 2012):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(P_j - P_i) \tag{2.1}$$

where

$$sign(P_j - P_i) = \begin{cases} 1, & if\ P_j > P_i \\ 0, & if\ P_j = P_i \\ -1, & if\ P_j < P_i \end{cases} \tag{2.2}$$

The value of each indicator is compared with all subsequent data values. If the value of the data from a subsequent period is greater than the value of the previous period, then S is increased by 1, otherwise the value is reduced by 1.

In the case of zero Hypothesis (H_0), when no significant trend is detected, the probability distribution becomes close to normal and has the following terms:

$$\mu = 0 \tag{2.3}$$

$$\sigma = \frac{n(n-1)(2n+5)}{18} \tag{2.4}$$

The positive S value indicates that the data series has gained a positive trend, a negative S value – a negative trend. The results of the trend analysis are presented by evaluating the significance of the positive or negative trends of each of the parameters tested at 5% and 30% confidence levels. The tendencies of extreme hydrological phenomena in Lithuanian rivers were evaluated over different historical periods using trend analysis.

The methods of **probability density distribution analysis** were used to evaluate spring floods. The purpose of analysis of probability density distribution is to relate the size of the analysed phenomena with their frequency, using probabilistic distributions. In this work, for evaluation of the values of maximum discharges of spring floods (Q_{max}) and maximum snow water equivalent (SWE_{max}) with probabilistic analysis, the probability distributions of Generalized Extreme Values (GEV), Generalized Logistic (GL) and Weibull (W) were selected. These distributions are flexible models of three-parameter. The GEV distribution is widely used to simulate extreme phenomena, such as extreme floods, heavy snowfall and so on. GL distribution is also important in modelling extreme phenomena. The distribution of Weibull is a continuous probabilistic distribution, which is often used in hydrology for extreme value studies related to analysis of maximum discharge. All these methods are widely described in scientific literature (Burr, 1942; Johnson et al., 1994; Forbes et al., 2011). The moments, L-moments and maximum likelihood methods were used to evaluate the parameters. The most suitable distributions were selected using Kolmogorov-Smirnov and Anderson-Darling tests. The study used the *EasyFit* (created by MathWave Technologies, www.mathwave.com) software.

Multiple regression analysis was used to create models used for prediction of the maximum spring discharge. The maximum spring discharge (Q_{max}) was selected as a dependent variable, whereas the maximum snow water equivalent before the flood (SWE_{max}) and the precipitation amount of 10 days before the flood (P_{10}) were selected as independent variables in the created multiple regression models. The meteorological factors (SWE_{max}, P_{10}) were extracted from the data series of meteorological stations in the selected river catchments by using the *Thiessen polygon* methods.
The determination of the dependent variable related to the independent variables is used to develop a model for simple predictions of a wide variety of outcomes (Higgins, 2005). In hydrology, the potential predictors are variables of climate, surface drainage, seasonality factors, etc. (Holder, 1985). In case of this research, the predictand Q_{max} and predictors SWE_{max} and P_{10} were used for the multiple regression analysis. Therefore,

$$Q_{\max} = a + b_1 SWE_{\max} + b_2 P_{10} \tag{2.5}$$

where Q_{max} – predicted value, which was a dependent variable, a – the "Q_{max} intercept", b_1 – the change in Q_{max} for each one increment change in SWE_{max}, b_2 – the change in Q_{max} for each one increment change in P_{10}. Variables b_1 and b_2 were described by

$$b_1 = \left(\frac{r_{Q_{\max},SWE_{\max}} - r_{Q_{\max},P_{10}} r_{SWE_{\max},P_{10}}}{1-\left(r_{SWE_{\max},P_{10}}\right)^2} \right) \left(\frac{SD_{Q_{\max}}}{SD_{SWE_{\max}}} \right) \quad (2.6)$$

$$b_2 = \left(\frac{r_{Q_{\max},P_{10}} - r_{Q_{\max},SWE_{\max}} r_{SWE_{\max},P_{10}}}{1-\left(r_{SWE_{\max},P_{10}}\right)^2} \right) \left(\frac{SD_{Q_{\max}}}{SD_{P_{10}}} \right) \quad (2.7)$$

$r_{Q_{\max},SWE_{\max}}$ – correlation between Q_{max} and SWE_{max}, $r_{Q_{\max},P_{10}}$ – correlation between Q_{max} and P_{10}, $r_{SWE_{\max},P_{10}}$ – correlation between SWE_{max} and P_{10}, $(r_{x1,x2})^2$ – the coefficient of determination (r squared) for SWE_{max} and P_{10}, $SD_{Q_{\max}}$ – standard deviation for Q_{max} (dependent variable), $SD_{SWE_{\max}}$ – standard deviation for SWE_{max} (first independent variable), $SD_{P_{10}}$ – standard deviation for P_{10} (second independent variable)

$$a = \overline{Q}_{\max} - b_1 \overline{SWE}_{\max} - b_2 \overline{P}_{10} \quad (2.8)$$

$\overline{Q_{\max}}$ – the mean of Q_{max}, $b_1 \overline{SWE}_{\max}$ – the value of b_1 multiplied by the mean of maximum snow water equivalent before the flood, $b_2 \overline{P}_{10}$ – the value of b_2 multiplied by the mean of rainfall amount of 10 days before the flood.

Projections of daily precipitation and temperature data in the periods of 2016-2035 (near future) and 2081-2100 (far future) were performed by three different **statistical downscaling methods** – Bias Correction with variable (BC), Change Factor with variable (CF) and Quantile Mapping (QM). The major purpose of these methods is to downscale the low resolution data to a fine spatial scale for purpose to reproduce local conditions. All methods were implemented according to reference period (1986-2005). BC method corrects the projected raw daily GCM outputs in mean and variance (Ho et al., 2012; Hawkins et al., 2013):

$$P_{\mathrm{BC}}(t) = \overline{O_{\mathrm{REF}}} + \frac{\sigma_{O,\mathrm{REF}}}{\sigma_{P,\mathrm{REF}}} (P_{\mathrm{RAW}}(t) - \overline{P_{\mathrm{REF}}}) \quad (2.9)$$

where P_{BC} is corrected meteorological parameter of GCM output, O_{REF} is observation in the historical reference period, P_{REF} is meteorological parameter of GCM output from the historical reference period, P_{RAW} is meteorological parameter of raw GCM output for the future period. The mean of meteorological parameter is denoted by the bar above a symbol. Equation (2.9) was used to represent the relationship between distribution of O_{REF} (observations in reference period) and distribution of P_{REF} (GCM simulations in reference period), therefore $\sigma_{O,\mathrm{REF}}$ and $\sigma_{P,\mathrm{REF}}$ are standard deviations of daily observations and meteorological parameter of GCM output in the reference period, respectively.

CF method corrects the observed variables according to the differences between projected variables of GCM output and simulated GCM output from the historical reference period. It is described by following equation (Ho et al., 2012; Hawkins et al., 2013):

$$P_{\mathrm{CF}}(t) = \overline{P_{\mathrm{RAW}}} + \frac{\sigma_{P,\mathrm{RAW}}}{\sigma_{P,\mathrm{REF}}}(O_{\mathrm{REF}}(t) - \overline{P_{\mathrm{REF}}}) \tag{2.10}$$

which was used to represent the relationship between distribution of P_{RAW} (GCM projection in the future) and distribution of P_{REF} (GCM simulations in reference period), therefore $\sigma_{P,\mathrm{RAW}}$ and $\sigma_{P,\mathrm{REF}}$ are standard deviation of GCM output of the future projections and deviation of GCM output in the reference period respectively. Meanwhile, QM method (Gudmundsson et al., 2012) is based on the concept of transformation h, such as:

$$P_{\mathrm{Obs}} = h(P_{\mathrm{GCM\ REF}}) = ECDF_{\mathrm{O}bs-1}(ECDF_{\mathrm{GCM\ REF}}(P_{\mathrm{GCM\ RAW}})) \tag{2.11}$$

where P_{Obs} is observed meteorological parameter, $P_{\mathrm{GCM\ REF}}$ is GCM output for reference period, $P_{\mathrm{GCM\ RAW}}$ is meteorological parameter, which is projected by GCM for the future period. $ECDF_{\mathrm{Obs-1}}$ is empirical cumulative distribution function for observed period and $ECDF_{\mathrm{GCM\ REF}}$ is empirical cumulative distribution function for GCM reference period. First, all the probabilities in $ECDF_{\mathrm{Obs-1}}$ and $ECDF_{\mathrm{GCM\ REF}}$ are calculated at a fixed interval of 0.01. Then, h in each interval is estimated as the relative difference between two different ECDFs. Interpolation between the fixed values is based on a monotonic tricubic spline interpolation. The correction of the number of wet days was estimated from the empirical probability of non-zero values in P_{Obs}. After that all RCM values below this threshold were set to zero (Sunyer et al., 2015). The method was implemented by *Python* software.

The HBV (Hydrologiska Byråns Vattenbalansavdelning) hydrological model was used for **hydrological modelling**. This model, created by SMHI (Swedish Meteorological and Hydrological Institute) is a rainfall-runoff model and describes hydrological processes as well as some meteorological processes in a river catchment scale. HBV is characterized by equation of particular water balance (Integrated Hydrological Modelling System 2005):

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + V] \tag{2.12}$$

where P – precipitation, E – evapotranspiration, Q – runoff, SP – snow pack, UZ – upper groundwater zone, LZ – lower groundwater zone, V – lake or dam volume.

The HBV model evaluates and calculates how the atmospheric precipitation in the river basin district is transformed into river runoff due to temperature, evaporation, infiltration, accumulation in natural water bodies and the influence of the basin relief (Fig. 2.2).

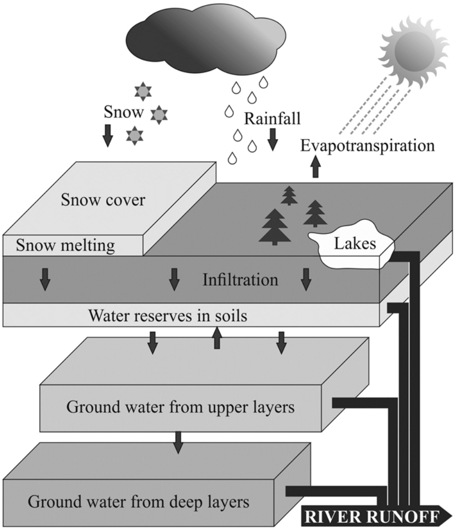

Fig. 2.2. Conceptual scheme and processes of HBV model (prepared according to the Integrated Hydrological Modelling System, 2005)

The reference period of 1986-2005 was selected for calibration and validation of hydrological models, i.e. 1986-1995 for calibration and 1996-2005 for validation. The hydrological model of each simulated river is calibrated in five stages using 16 basic calibration parameters, which depend on the local physico-geographical characteristics of the river basin. The models were evaluated how the measured discharge coincides with the simulated by changing values of the calibration parameters during the calibration steps. The calibration and validation values of the created hydrological models and the rates of average discharge (observed and simulated) are presented in Table 2.1.

Comparison of the discharges in Table 2.1 shows that the differences between observed and simulated values are low: they are the smallest in the

Minija river (up to 4%) and the largest in the Nevėžis river (up to 16%). These discrepancies are small because, according to various studies, the deviation of discharge measurement errors can reach 35% in individual cases (Winter, 1981; Sattary, 2002; Neff, Nicholas, 2005).

Table 2.1. The results of calibration and validation of created hydrological models

River-WGS	Calibration			Validation		
	R	Average Q (m^3/s)		R	Average Q (m^3/s)	
		Observed	Simulated		Observed	Simulated
Minija-Kartena	0.88	17.7	18.4	0.83	16.8	16.6
Nevėžis-Dasiūnai	0.86	38.9	34.6	0.77	29.0	33.7
Šventoji-Ukmergė	0.75	46.5	44.5	0.68	41.8	43.9

Taking into account the results of calibration and validation of the models and the long data series used for these procedures, the created models are well prepared for projections of river runoff according to different climate scenarios in the near and far future.

The **uncertainty analysis** is necessary for projections of runoff changes in the future, especially when uncertainties are associated with primary sources of origin. In this study, the uncertainties of runoff projections arise from the selection of climate scenarios (RCPs), global climate models (GCMs) and statistical downscaling (SDs) methods. In Lithuania, the uncertainties of runoff projections were evaluated using other sources of uncertainty (GCMs, SRES group climate scenarios and calibration parameters of HBV) (Kriaučiūnienė et al. 2013). Therefore, the uncertainty analysis of this research is based on similar methodology. All possible combinations of uncertainty sources were made for evaluating the three sources of uncertainty (A_{RCP}, B_{GCM} and C_{SD}), when each of them consists of three components ($A_{RCP2.6}$, $A_{RCP4.5}$, $A_{RCP8.5}$, B_{GFDL}, B_{Had}, B_{Nor}, C_{BC}, C_{CF} and C_{QM}) (Table 2.2). The variable A represents the analysed source of uncertainty, while B_{GCM} and C_{SD} are the remaining two sources of uncertainty. The combinations of analogous components (B_{GFDL}, B_{Had}, B_{Nor}, C_{BC}, C_{CF} and C_{QM}) help to identify the uncertainties of A_{RCP} components ($A_{RCP2.6}$, $A_{RCP4.5}$, $A_{RCP8.5}$). The uncertainties of source A_{RCP} were calculated by combining the analogous combinations of components B_{GCM} and C_{SD}. The maximum value minus minimum value was estimated from the horizontal selections of A_1, A_2 and A_3 and the arithmetic average of the above mentioned difference was calculated. The calculation of contribution of each source is based on the uncertainty caused by the three sources of uncertainty and calculates the percentage from other sources of uncertainty based on the average in difference.

Table 2.2. Combinations of runoff projections according to selected uncertainty sources (GCMs (A), RCPs (B) and SD methods (C))

	Combinations of runoff projections		
No.	$A_{RCP2.6}$	$A_{RCP4.5}$	$A_{RCP8.5}$
1.	$A_{RCP2.6}\,B_{GFDL}\,C_{BC}$	$A_{RCP4.5}\,B_{GFDL}\,C_{BC}$	$A_{RCP8.5}\,B_{GFDL}\,C_{BC}$
2.	$A_{RCP2.6}\,B_{GFDL}\,C_{CF}$	$A_{RCP4.5}\,B_{GFDL}\,C_{CF}$	$A_{RCP8.5}\,B_{GFDL}\,C_{CF}$
3.	$A_{RCP2.6}\,B_{GFDL}\,C_{QM}$	$A_{RCP4.5}\,B_{GFDL}\,C_{QM}$	$A_{RCP8.5}\,B_{GFDL}\,C_{QM}$
4.	$A_{RCP2.6}\,B_{Had}\,C_{BC}$	$A_{RCP4.5}\,B_{Had}\,C_{BC}$	$A_{RCP8.5}\,B_{Had}\,C_{BC}$
5.	$A_{RCP2.6}\,B_{Had}\,C_{CF}$	$A_{RCP4.5}\,B_{Had}\,C_{CF}$	$A_{RCP8.5}\,B_{Had}\,C_{CF}$
6.	$A_{RCP2.6}\,B_{Had}\,C_{QM}$	$A_{RCP4.5}\,B_{Had}\,C_{QM}$	$A_{RCP8.5}\,B_{Had}\,C_{QM}$
7.	$A_{RCP2.6}\,B_{Nor}\,C_{BC}$	$A_{RCP4.5}\,B_{Nor}\,C_{BC}$	$A_{RCP8.5}\,B_{Nor}\,C_{BC}$
8.	$A_{RCP2.6}\,B_{Nor}\,C_{CF}$	$A_{RCP4.5}\,B_{Nor}\,C_{CF}$	$A_{RCP8.5}\,B_{Nor}\,C_{CF}$
9.	$A_{RCP2.6}\,B_{Nor}\,C_{QM}$	$A_{RCP4.5}\,B_{Nor}\,C_{QM}$	$A_{RCP8.5}\,B_{Nor}\,C_{QM}$

3. RESULTS AND DISCUSSION

3.1. Changes of hydrological extremes according to historical observations

The spring and flash flood patterns vary depending on hydrological regions. One of the main reasons for this behaviour is different sources of river feeding (Fig. 3.1). A marine type of climate dominates in the Western region (LT-W) with the largest amount of precipitation, the highest winter temperature and the least number of days with snow cover (Kriaučiūnienė et al., 2012). Precipitation is the major source of river feeding in this region, exceeding 53%. The other sources include snowmelt (18%) and groundwater (29%). Rivers here often have "winter floods", due to frequent thaws in wintertime, some of which are greater than spring floods. The continental type of climate is characteristic for Southeastern Lithuania (LT-SE): the snow cover has the longest duration and the winters are the coldest here. Subsurface feeding dominates in the rivers of this region (45%). Permeable sandy soils, which are widespread, effectively absorb snowmelt and gradually release it later, supplying rivers in the low water period. The type of river feeding in Central Lithuania (LT-C) is mixed; the rivers get water mostly from two main sources: rainfall and snowmelt. A very irregular distribution of discharges during the year is the major feature of the rivers in this region.

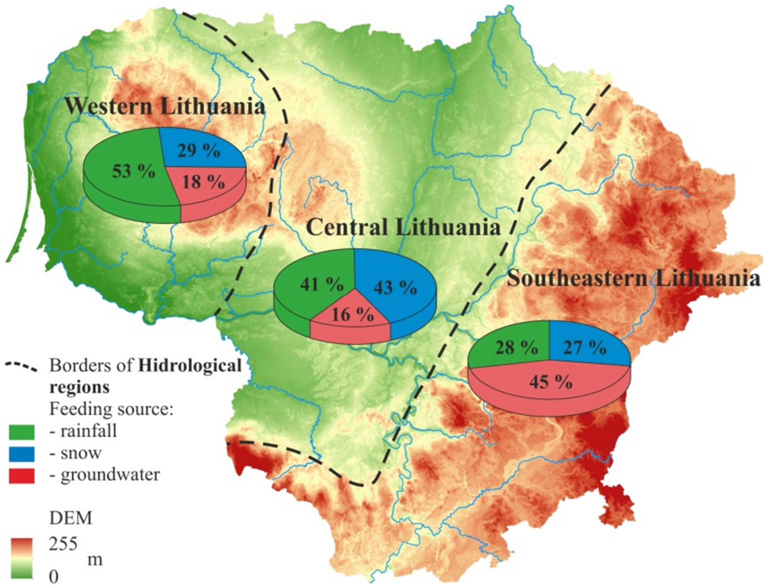

Fig. 3.1. Rivers feeding sources in different hydrological regions of Lithuania (prepared according to Gailiušis et al., 2001)

Using the Mann-Kendall test, the trends (30% confidence level) of data series of maximum discharges (Q_{max}) of spring floods and summer-autumn flash floods or significant trends that correspond to a 5% confidence level were determined. The trend analysis was carried out in four different periods (1922-2013, 1941-2013, 1961-2013 and 1991-2013) in order to evaluate the importance of the length of the available hydrological data series for the trend of extreme hydrological phenomena (spring floods and summer-autumn flash floods) (Fig. 3.2). Hydrological data of 31 WGSs were used for this analysis. In the longest period (1922-2013), the maximum discharge of spring floods in most of WGSs had a significant negative trend (Figure 3.2a). Only two WGSs (Minija-Kartena and Jūra-Tauragė) located in Western hydrological region of Lithuania had no trend in Q_{max} of spring flood. Meanwhile, significant negative trends in flash floods were determined in four WGSs (Fig. 3.2b). Two of them belonged to the LT-SE region and one to LT-W and LT-C.

During the period of 1941-2013, the Q_{max} of spring flood had a decreasing trend in all WGSs of the LT-C and LT-SE hydrological regions, where significant negative trends were estimated (Fig. 3.2c). A similar situation formed in LT-W, where negative trends were determined in three rivers, while in two of them there were significant negative ones. The Q_{max} of spring floods did not have any trend only in WGS of Jūra at Tauragė. The nature of flash floods of summer-autumn season differed from the spring floods in 1941-2013 because significant negative trends were recorded in only three WGSs (Šešuvis-Skirgailai, Neris-Jonava and Neris-Vilnius), i.e. one from each hydrological region (Fig. 3.2d).

The largest number of WGSs with historical observations were detected in the period of 1961-2013, but not in all stations the observations were collected until 2013. Some stations were closed in 1999 and 2005, but the study used all available data from 1961 until the end of the observations or 2013. During this period, the negative trends of spring flood were determined at the following water gauging stations of the Western region: Nemunas-Smalininkai, Venta-Leckava and Rešketa-Gudeliai, while the significant negative trends were established in the Bartuva-Skuodas and the Venta-Papile (Fig. 3.2e). Significant negative trends were dominant in even four WGSs of Central Lithuania. The negative trends also dominated in the Southeastern hydrological region and included 8 of the 10 analysed WGSs. The trends of flash floods remained hardly unchanged in 1961-2013, as only in WGSs of Šyša-Jonaičiai (LT-W) and Ūla-Zervynos (LT-SE) the significant negative trends were detected (Fig. 3.2f). During the shortest period of 1991-2013, a significant negative trend of Q_{max} of spring flood was determined only in the Bartuva at Skuodas, while the negative trend was established in the Minija at Kartena and the Verknė at Verbyliškės (Fig. 3.2g). The Q_{max} of flash floods of summer and autumn seasons did not have any trend in the last analysed period (Fig. 3.2h).

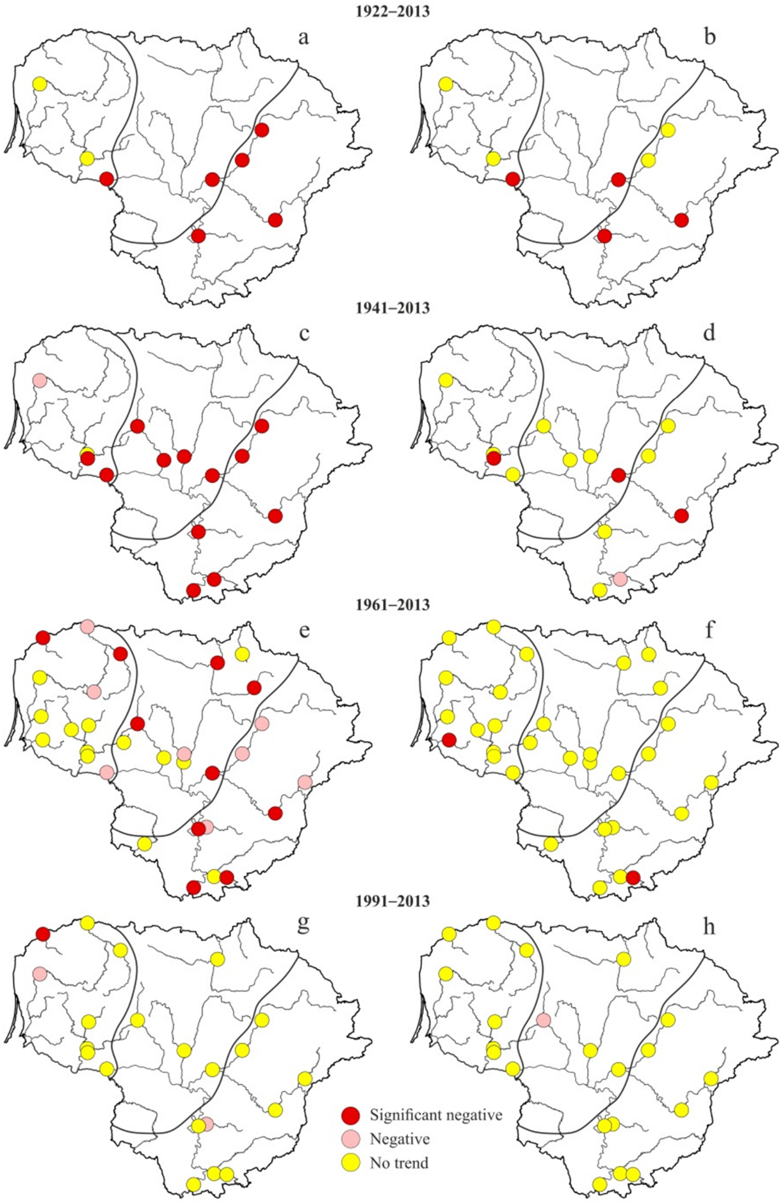

Fig. 3.2. Trends of maximum discharges of spring floods (a, c, e, g) and flash floods of summer-autumn season (b, d, f, h) in different periods

In the next trend analysis, the Z values of Mann-Kendall test were used to indicate the trend direction and strength (Fig. 3.3). The spring floods decreased in most of WGSs in 1961-2013. This is confirmed by Figure 3.3a column chart. From the 21 water gauging stations, even in the 15 of them the negative trends were identified, among which nine had significant (1.96) negative. Looking at the flash floods of summer-autumn season in the same period, there is a tendency for a downward trend. However, only the trend of data series of Ūla-Zervynos WGS (Fig. 3.3b) was significant negative. In the second period (1991-2013), only two WGSs with negative trends of Q_{max} of spring floods were determined and one (Bartuva-Skuodas) with a significant negative trend (Fig. 3.3c). Meanwhile, the Q_{max} of flash floods had both direction tendencies, but no trends were observed in different WGSs in the period of 1991-2013(Fig. 3.3d).

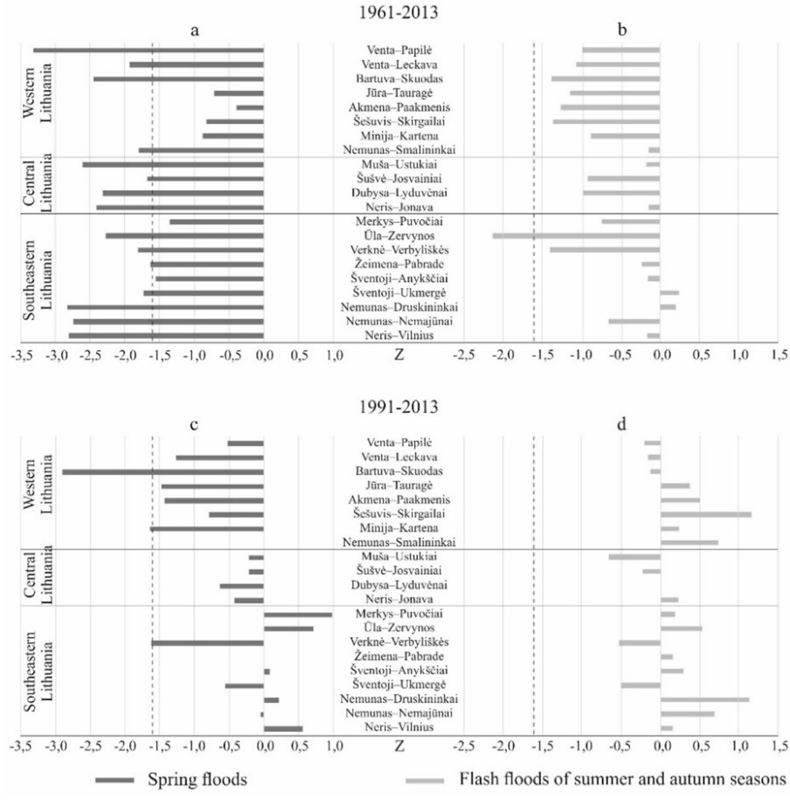

Fig. 3.3. The results of Z values of Mann-Kendall test of spring floods (a, c) and flash floods of summer-autumn seasons (b, d) in the periods of 1961-2013 and 1991-2013 (dashed line – the boundary of negative trend)

Regional fluctuations in spring floods and flash floods of summer-autumn season and deviations of mentioned extreme hydrological phenomena from WMO reference period are illustrated in Figure 3.4. In the Western hydrological region, the biggest spring floods occurred in 1961-1970 (24.6% larger), while at the same time in the hydrological regions of Central and Southeastern Lithuania the largest spring floods (respectively – 59.2 and 80.8%, comparing with the reference period) were determined in the period of 1951-1960 (Fig. 3.4). The smallest spring floods were determined in the last analysed decade (2001-2010). The maximum discharge of spring floods and summer-autumn flash floods declined during the last two decades (Fig. 3.4a, b) and their deviations were negative (from -25.3 to -45.2%) in comparison with the conditions of previous decades in the hydrological regions of Western and Central Lithuania.

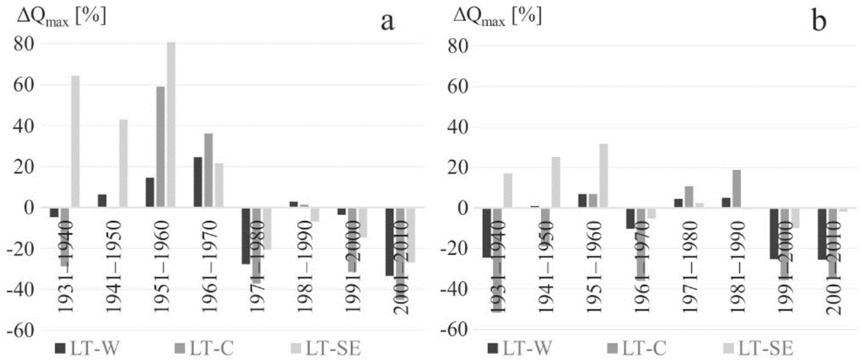

Fig. 3.4. The deviations (%) of maximum discharge of spring floods (a) and flash floods of summer-autumn season (b) from WMO reference period (1961-1990) in different hydrological regions of Lithuania

3.2. Conditions of spring floods formation

In order to evaluate the conditions of the formation of spring floods, the maximum snow water equivalent before the spring flood (SWE_{max}, mm) and the precipitation amount of 10 days during the spring flood Q_{max} day (P_{10}, mm) were selected. Under the conditions of snow and rainfall in Lithuania, the maximum discharge of spring flood (Q_{max}, m^3/s) was evaluated.

The analysis of meteorological factors (snow and rain) showed their significance on the formation of a maximum discharge of spring flood in order to determine the decisive factor of a particular year. For this purpose, the matrix with four meteorological situations over five selected river catchments was formed (Fig. 3.5). According to the evaluated periods of 1961-1987 and 1988-2014, it was determined that for most of the analysed spring floods the both meteorological factors interacted with each other; only in particular year the floods were caused by a single meteorological factor. In the period of 1961-1987 the year of 1972 stands out, while in the period of 1988-2014 – 1990, when the spring flood was caused exclusively by a rainfall. A similar situation occurred in 1969, 2008 and 2014, when in four of the five rivers the spring floods were caused only by a rainfall. Only snow-driven floods fragmentarily occurred in concrete rivers and in particular years, but in all the analysed rivers in 1996, floods were caused by snow melting. The snow cover had greater impact on spring flood formation in the period of 1961-1987 (57% of all cases) and rainfall was a dominant factor (64% of all cases) in the second analyzed period (1988-2014). This analysis showed major changes in spring flood formation, i.e. snow driven flood events decreased as well as increased of flood events caused by rainfall.

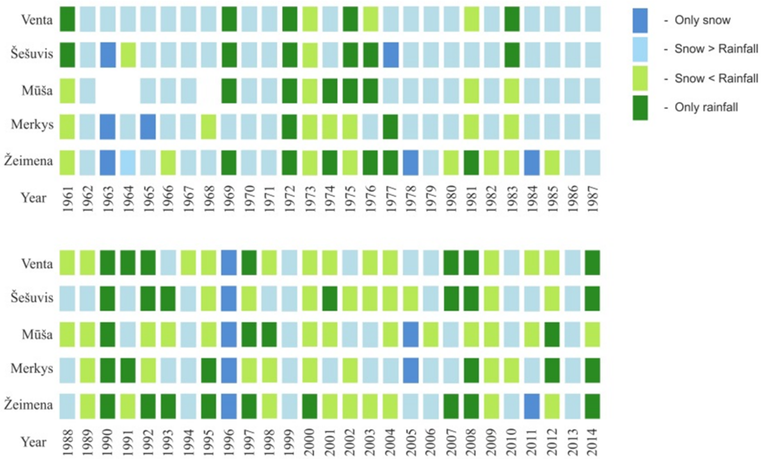

Fig. 3.5. Conditions of spring flood formation according to meteorological factors: only snow – P_{10} do not exceed 5% of SWE_{max}; snow > rainfall – $SWE_{max} > P_{10}$; snow < rainfall – $P_{10} > SWE_{max}$ and only rainfall – SWE_{max} do not exceed 5% of P_{10}

3.3. Probability distributions of maximum discharge of spring floods and maximum snow water equivalent

The Kolmogorov-Smirnov (K-S) and Anderson-Darling (A-D) statistics indicating the goodness-of-fit of three (GEV, GL and W) probability distributions were used for testing datasets of five river catchments (Venta, Šešuvis, Mūša, Žeimena and Merkys) in two analysed periods. The Weibull distribution showed the worst results in both K-S and D-S tests for maximum discharge of spring flood (Q_{max}) and maximum snow water equivalent before the flood (SWE_{max}) in the periods of 1961-1987 and 1988-2014. The GEV distribution had the best result for Q_{max} and SWE_{max} in the first analysed period (1961-1987), while results of both GEV and GL distributions were similar to datasets of SWE_{max} and Q_{max} in the period of 1988-2014.

Further research was carried out to quantify the influence of using different distributions and to estimate the changes of extreme floods in two different periods. Figure 3.6 illustrates the best distributions of SWE_{max} and Q_{max} for five river catchments in the periods of 1961-1987 and 1988-2014. The maximum discharge of the most probable value did not change in both analysed rivers of LT-W in the comparison of two periods, but SWE_{max} of the most probable value decreased in 1988-2014. In the Southeastern and Central hydrological regions, Q_{max} and SWE_{max} of the most probable value decreased in the period of 1988-2014.

The analysis of SWE_{max} and Q_{max} according to the data of two periods based on the best-fit distributions confirmed that floods were mostly formed by snowmelt in LT-C (Fig. 3.6). The formation of floods depended not only on SWE_{max}, but also on other feeding sources (rainfall and groundwater) in LT-SE. The detected changes of SWE_{max} did not have a significant influence on the formation of spring floods, since Q_{max} of the most probable value changed only slightly in LT-W.

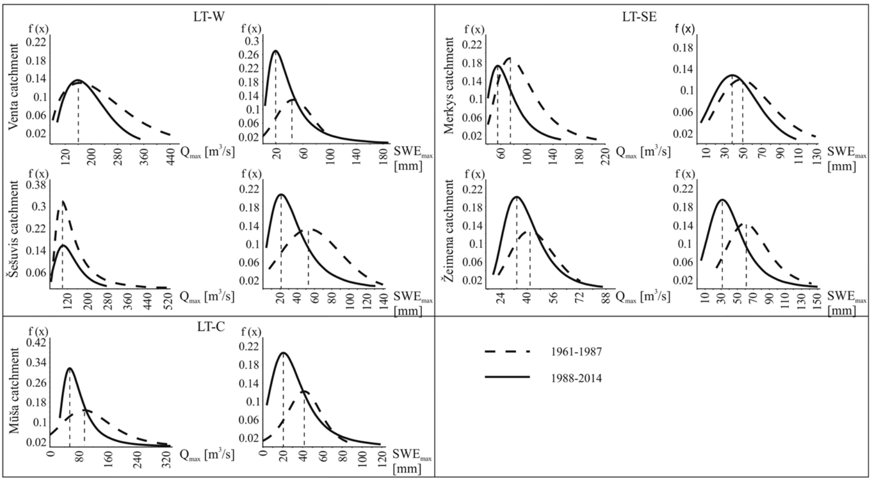

Fig. 3.6. Probability distributions of Q_{max} and SWE_{max} in the rivers of Venta, Šešuvis, Mūša, Merkys and Žeimena according to best fit distributions in the periods of 1961-1987 and 1988-2014

3.4. Multiple regression analysis

Multiple regression analysis was used in this research as a tool to create simple prediction models when the amount of variables is limited. Correlation coefficient (R) between the observed Q_{max} and predicted Q_{max} according to regression models fluctuated from 0.63 to 0.86 in two periods and five river catchments. The highest correlation (R = 0.86) between the observed Q_{max} and predicted Q_{max} was found for the Žeimena River in the period of 1961-1987. The same R was calculated for the Mūša River in 1988-2014.

Meanwhile, the Merkys River had the lowest correlation coefficients in both periods (0.63 and 0.67, respectively). This river has strong groundwater feeding. Consequently, Q_{max} of the Merkys River did not react directly to the surface processes (SWE_{max} and P_{10}) as fast as the other rivers.

The prediction of Q_{max} was carried out according to unstandardized coefficients (B) of each independent variable (SWE_{max} and P_{10}) for two periods (1961-1987 and 1988-2014). The relation between the observed Q_{max} and predicted Q_{max} fluctuated in various ranges (Table 3.1). The closest relations were found for the rivers of Žeimena and Muša in different periods. In the Merkys River, the relations of Q_{max} indicated the worst correlation (0.63 and 0.67, respectively); hence the differences between the predicted Q_{max} and observed Q_{max} had a large dispersion. The analysis of extreme values showed that the regression models predicted lower values of Q_{max} than the observed Q_{max} in the first period in the rivers of Šešuvis and Mūša.

Table 3.1. The results of multiple regression analysis of five selected rivers catchments in the periods 1961-1987 and 1988-2014

Region		**Western**				**Central**		**Southeastern**			
Catchment		**Venta**		**Šešuvis**		**Mūša**		**Merkys**		**Žeimena**	
Period		1961-1987	1988-2014	1961-1987	1988-2014	1961-1987	1988-2014	1961-1987	1988-2014	1961-1987	1988-2014
R		0.85	0.82	0.70	0.84	0.77	0.86	0.63	0.67	0.86	0.77
B	Constant of Q_{max}	70.72	63.98	16.67	26.45	8.64	13.94	34.58	31.42	27.15	25.79
	SWE_{max}	3.87	1.79	3.34	2.06	3.07	2.44	1.01	0.87	0.44	0.40
	P_{10}	1.83	1.95	2.02	2.41	2.14	1.36	1.34	0.73	0.21	0.23
Lower boundary	Constant of Q_{max}	14.92	18.03	-73.29	-8.91	-56.48	-23.06	-5.75	2.30	20.76	17.19
	SWE_{max}	2.82	1.25	1.89	1.47	1.91	1.81	0.47	0.47	0.33	0.26
	P_{10}	0.54	1.12	-0.61	1.51	0.30	0.02	0.12	-0.09	0.03	-0.02
Upper boundary	Constant of Q_{max}	126.52	109.95	106.63	61.80	73.75	50.95	74.91	60.55	33.54	34.38
	SWE_{max}	4.92	2.34	4.79	2.66	4.23	3.06	1.55	1.27	0.55	0.54
	P_{10}	3.12	2.781	4.66	3.32	3.99	2.70	2.57	1.55	0.40	0.48
Standard deviation	Constant of Q_{max}	27.04	22.27	43.59	17.13	31.31	17.93	19.54	14.11	3.10	4.16
	SWE_{max}	0.51	0.26	0.70	0.29	0.56	0.30	0.26	0.20	0.05	0.07
	P_{10}	0.62	0.40	1.28	0.44	0.89	0.65	0.59	0.40	0.09	0.12

3.5. Projections of air temperature and precipitation amount according to the various climate scenarios

The data series of meteorological parameters (air temperature and precipitation) from the grids of selected global climate models (GCM) were adjusted by statistical downscaling (SD) methods to the location of the meteorological stations (MS). Figure 3.7 shows the influence of SD methods on corrections of air temperature from GCMs output in the near future (2016-2035). Application of SD methods for MS provided decrease in range of projected air temperature because large positive deviations of the projections of near future were reduced and negative deviations were improved into positive side. Therefore, it is important to use SD for corrections of GCMs output, which sometimes does not properly reflect local meteorological conditions.

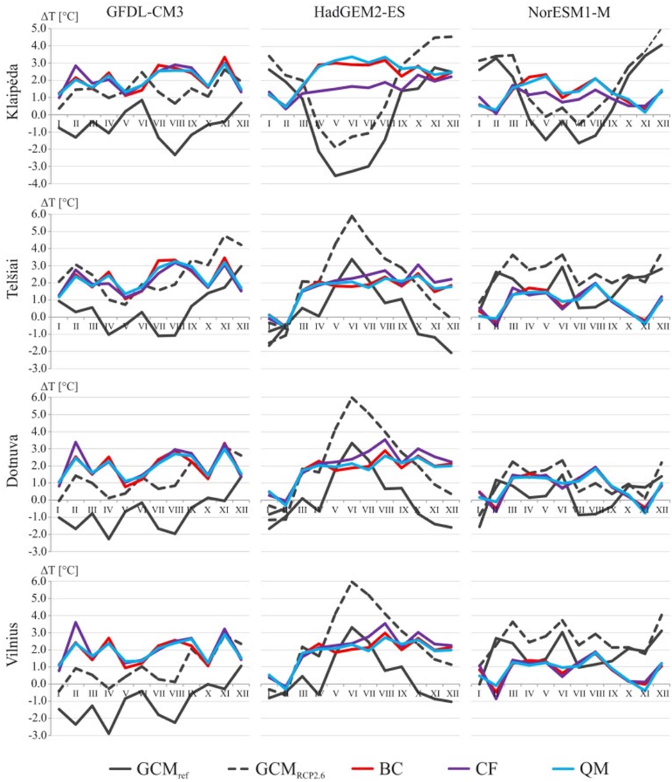

Fig. 3.7. Deviations of temperature simulation in reference period (GCM_{ref}) and projections in near future according to RCP2.6 scenario, three GCMs ($GCM_{RCP2.6}$) and three statistical downscaling methods (BC, CF, QM) comparing with observations of the reference period in four selected meteorological stations

The influence of SD methods on corrections of precipitation amount of GCM in the near future (2016-2035) is illustrated in Figure 3.8. The projections of near future precipitation amount showed large dispersion between different GCMs. Consequently, the raw data of GCM projections should be improved by statistical downscaling. The application of BC method (case of Dotnuva MS) is inappropriate to use when differences between GCM simulations in reference period and historical observations are very large (twice bigger than observations). Mostly, the BC provided the lowest projections of precipitation, meanwhile QM method generated the highest values with extreme events of precipitation.

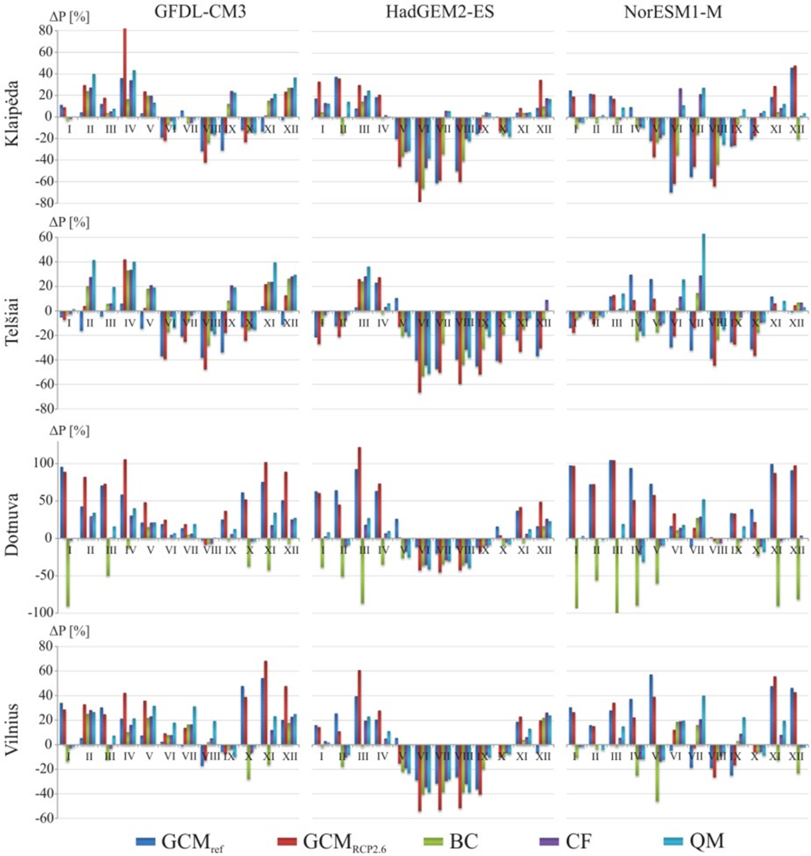

Fig. 3.8. Deviations of precipitation simulations in reference period (GCM_{ref}) and projections in near future according to RCP2.6 scenario, three GCMs ($GCM_{RCP2.6}$) and three statistical downscaling methods (BC, CF, QM) comparing with the observations of reference period in four selected meteorological stations

3.6. Runoff projections of selected Lithuanian rivers in XXI century

All deviations of runoff projections were calculated from simulations in the reference period according to an analogous combination of GCM and used SD methods. Depending on different global climate models and statistical downscaling methods, the projections of RCP scenarios fluctuated in a wide range. The deviations of annual runoff projections of the rivers of Minija, Nevėžis and Šventoji in the near and far future are shown in Figure 3.9. The projected annual runoff according to selected RCPs decreased on average from 13.3% in the near future to 33.9% in the far future, compared to the reference period. The lowest changes in rivers runoff were projected by RCP4.5 scenario in the near future, while the largest deviations and their variations were obtained according to RCP2.6 scenario. Meanwhile, the differences between RCPs increased in the far future because on average the RCP2.6 scenario projected the smallest decrease of river runoff, but the highest amplitude of possible projections. The most dramatic changes (up to a 47.2% decrease) of river runoff were projected by RCP8.5 in the far future.

The projections of river runoff determined by different GCMs showed similar patterns of deviations between the selected rivers and periods. The largest decrease of annual runoff was obtained applying the output of the Had climate model in both analysed periods, while the projections of Nor model were the closest to the reference period. The projections with the highest range of deviations were obtained according to the GFDL model, especially in the far future.

The effect of SD methods on the projections of annual runoff was significant in the near and far future as well. The projections based on the BC and CF methods showed similar deviations in runoff projections. According to the mentioned methods, the average decrease of runoff consisted of 11.3% and 9.7% in the near future, and 18.5% and 18.7% in the far future, respectively. The smallest average deviation of runoff projections from the reference period was obtained using the QM method in all analysed rivers. The alteration of deviations was -4.4% in the near future and -5.5% in the far future. However, the QM method provided the highest amplitude of projected changes in the rivers of Minija and Šventoji.

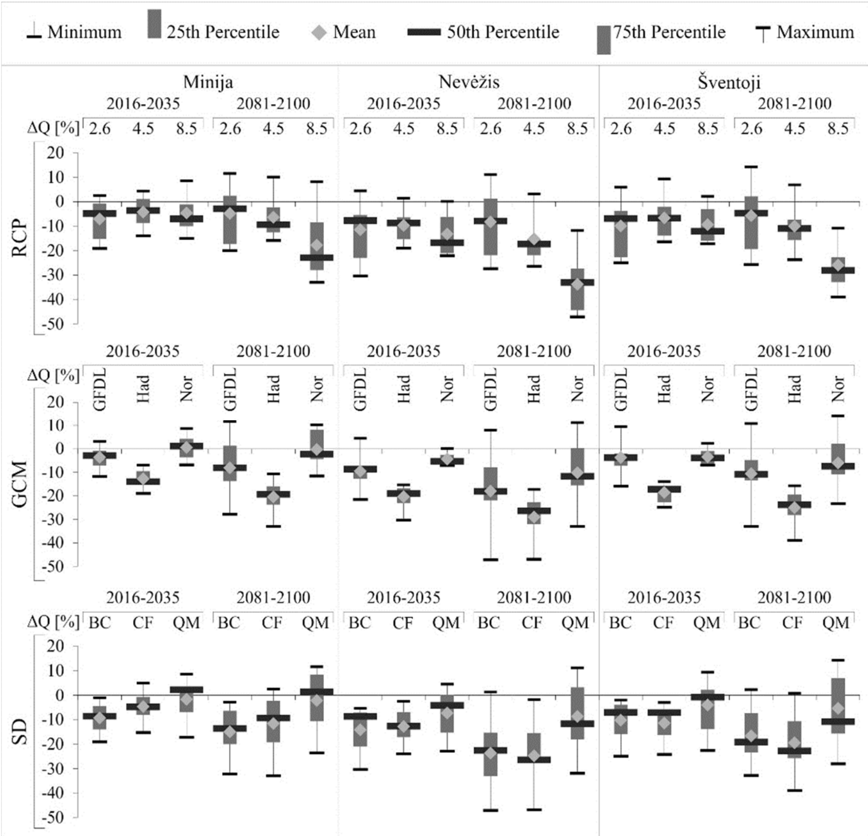

Fig. 3.9. Deviations (%) of annual runoff projections from the simulations of reference period in selected rivers according to RCP, GCM and SD in the near and far future

3.7. Projections of maximum discharge of spring floods and flash floods of summer-autumn season in Lithuanian rivers in XXI century

The projected data of air temperature and precipitation were used to project the maximum discharges of spring floods and flash floods of summer-autumn season in the selected river catchments. The projection of maximum discharges were created according to the output of all three GCMs for each RCP scenario adjusted by three SD methods in near and far future and analysed comparing to data of observations. The greatest changes of maximum discharge of spring floods are going to happen at the end of the century in all analysed rivers. According to the newest climate scenarios the decrease of spring floods was estimated and their seasonal redistribution, when part of the spring floods will occur in the winter, was indicated. Figure 3.10 illustrates the hydrological response of spring floods of Nevėžis River to expected climate changes. Comparison of maximum discharges in the reference period and in two future periods according to three GCMs, three RCPs and three SDs showed significant changes. These graphs clearly indicate the absence of spring flood peak in the projections adjusted by statistical downscaling method of BC, which indicate dramatic decrease of maximum discharges of spring floods. Such patterns were determined in the projections of all GCMs because on average they were projecting the decrease of maximum discharge of spring floods. This makes them the most sensitive to the expected climate changes. The main reason for such a response is projected higher temperatures in winter: snow cover is likely to melt or would not form at all and, as a consequence, no spring flood will occur. Instead, small, less expressed flash floods are going to emerge because of increased precipitation. Meanwhile, the differences between projections of RCP scenarios were not as large as influence of SDs. According to particular combinations of GCM, RCP and SD the very extreme values were projected and in separate years mentioned values beyond historical observations. This confirms the probability of happening of spring floods of rare return period. These tendencies were established in other analysed rivers as well. The flash floods of analysed rivers are going to increase in their average maximum discharge, which were projected by most of projection sources (case of Nevėžis River showed in Figure 3.11). Only using statistical downscaling method of BC, the projected maximum discharges of flash floods drastically decline. Also, some scenarios adjusted by methods of CF and QM projected very extreme values, especially together with global climate models of GFDL and Nor.

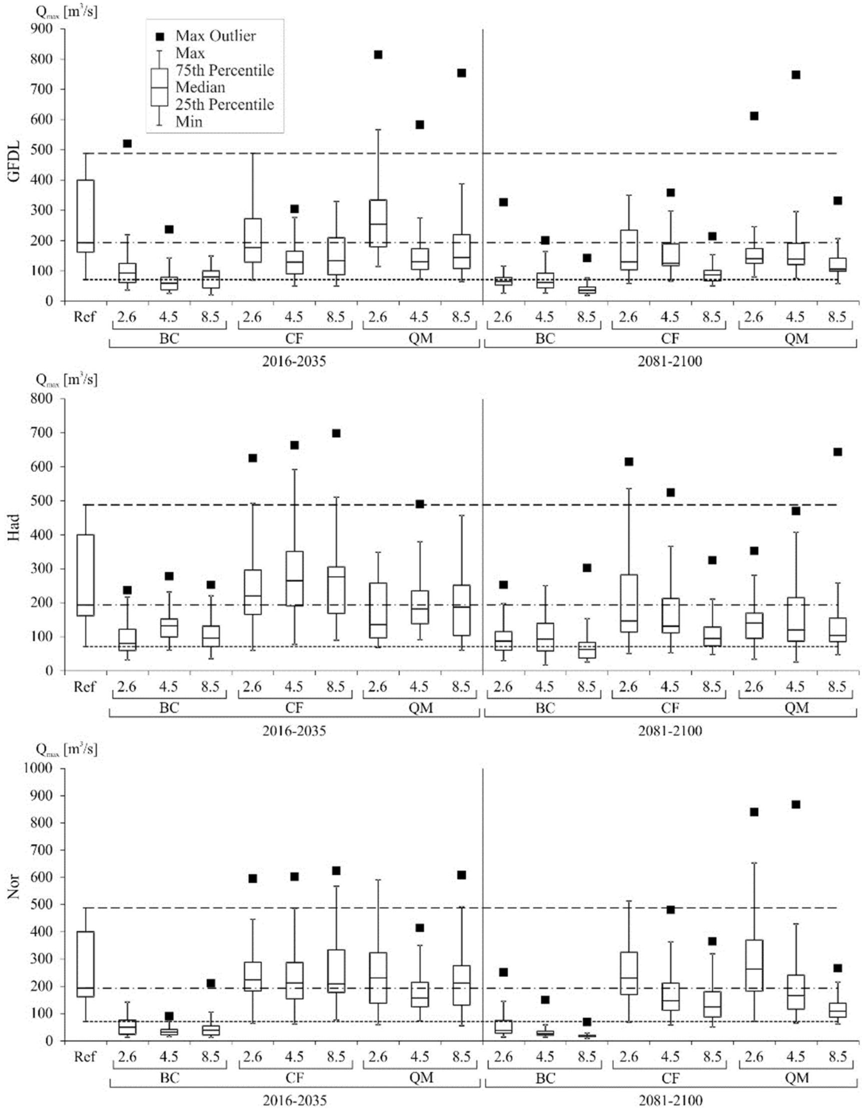

Fig. 3.10. The projections of maximum discharge (Q_{max}, m^3/s) of spring floods according to global climate models of GFDL-CM3 (GFDL), HadGEM-2ES (Had) and NorESM1-M (Nor), three RCP climate scenarios (2.6, 4.5, 8.5) and three statistical downscaling methods (BC, CF, QM) in Nevėžis-Dasiūnai WGS in the periods of 2016-2035 and 2081-2100

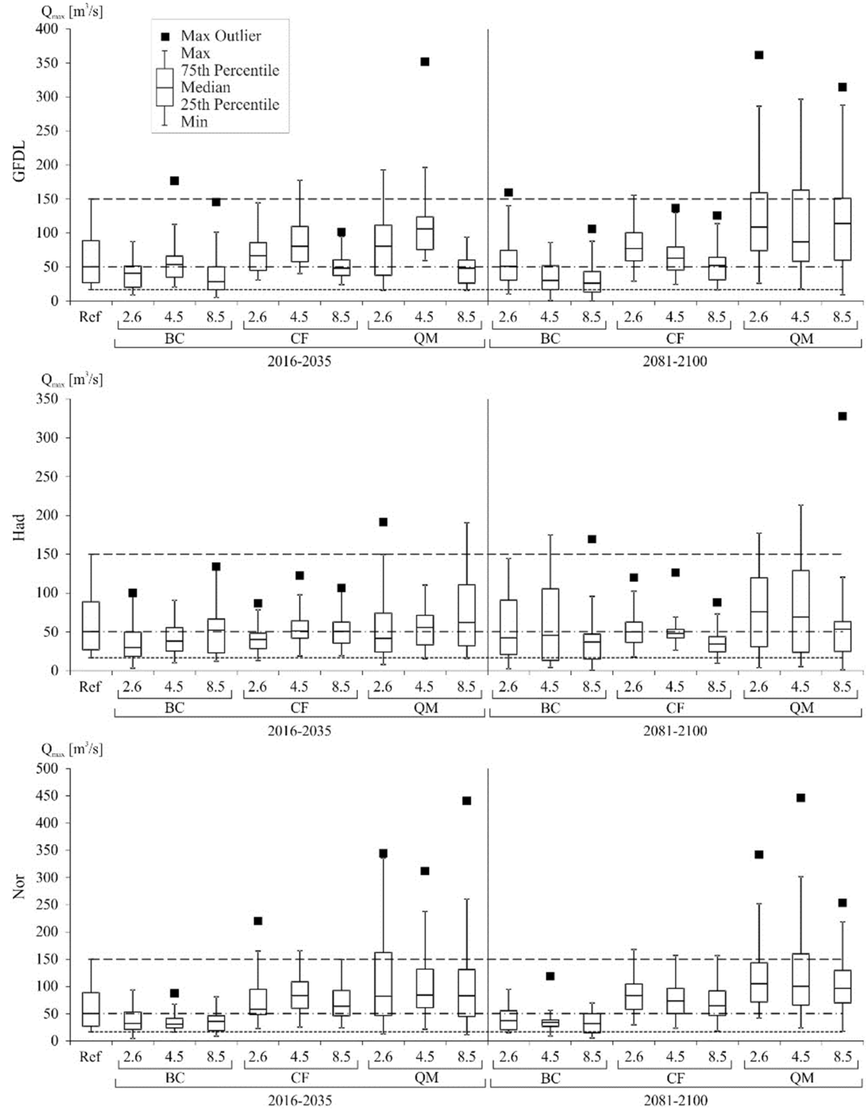

Fig. 3.11. The projections of maximum discharge (Q_{max}, m^3/s) of flash floods of summer-autumn season according to global climate models of GFDL-CM3 (GFDL), HadGEM-2ES (Had) and NorESM1-M (Nor), three RCP climate scenarios (2.6, 4.5, 8.5) and three statistical downscaling methods (BC, CF, QM) in Nevėžis-Dasiūnai WGS in the periods of 2016-2035 and 2081-2100

3.8. Analysis of uncertainties of projections of annual runoff and maximum discharge of spring floods and flash floods of summer-autumn season

The uncertainties of projections of the annual runoff and maximum discharge of spring floods and flash floods of summer-autumn season were estimated according to the uncertainty sources: climate scenarios (RCPs), global climate models (GCMs) and statistical downscaling methods (SD). The calculations of the percentage of uncertainty sources revealed which source had the greatest impact on the wide scattering of projected values in the rivers of Minija, Nevėžis and Šventoji (Table 3.2). The largest uncertainties of annual runoff projections of the Minija River (Kartena WGS) were caused by the GCMs in near and far future. Due to selected GCMs, 44.5% and 41% of uncertainties were raised up in near and far future respectively. A significant influence of SD methods was also estimated, causing uncertainties of 38.8% and 34.7% in near and far future respectively. Meanwhile, the uncertainties of projections of maximum discharge of spring floods and flash floods of summer-autumn season in this river were strongly related to SD methods (42.5-51.0%)

The uncertainties of projections of annual runoff of the Nevėžis River (Dasiūnai WGS) were as high as 60.9% using SD methods in the near future, while the influence of RCP scenarios was only 11.2% (Table 3.2). The uncertainties caused by SD methods decreased up to 51.3% and uncertainties of RCP increased up to 24.4% in the far future. The same was obtained in projections of maximum discharge of spring floods when SD methods caused the largest uncertainties in near (56.2%) and far future (46.3%). The projections of maximum discharge of flash floods of summer-autumn season highly depended from the SD methods as well. There was only one feature, that the uncertainties caused by SD methods raised from 43.9% in the near future up to 56.5% in the far future, while uncertainties related to RCP scenarios, decreased by 6.1 percentage points. In any case, the uncertainties of projections of annual and extreme values of Nevėžis River were mostly related to SD methods and accounted to 43.9-60.9%.

The largest scattering of projections of annual runoff of the Šventoji River was determined for the SD method as well, because uncertainties related to the SD methods consisted of 46.2% in near future. The rest of uncertainty sources provided uncertainties of 38.1% (GCMs) and 15.7% (RCPs) (Table 3.2). The influence of RCP scenarios increased and the uncertainties related to RCP scenarios reached 31.5% in far future. The same tendency was established in case of maximum discharge of spring floods, when SD was a source of the largest uncertainties in the near future, but increased effect of RCP scenarios in the far future reached all remaining sources and consisted of 41.4% uncertainty in far future. The nature of projections of flash floods of summer-autumn season was similar to Nevėžis River because the largest uncertainties were caused by SD methods and their effect increased up to 50.7% in far future.

Table 3.2. Uncertainties (%) of projections of annual runoff and maximum discharge of spring floods and flash floods of summer-autumn season in the rivers of Minija, Nevėžis and Šventoji according to three sources of origin (RCP, SD and GCM) for the periods of near (2016-2035) and far (2081-2100) future

	Minija (LT-W)		Nevėžis (LT-C)		Šventoji (LT-SE)	
	2016-2035	2081-2100	2016-2035	2081-2100	2016-2035	2081-2100
	Annual runoff					
RCP	16.7	24.3	11.2	24.4	15.7	31.5
SD	38.8	34.7	60.9	51.3	46.2	39.4
GCM	44.5	41.0	27.9	24.3	38.1	29.1
	Maximum discharge of spring floods					
RCP	29.8	28.6	17.0	28.8	27.9	41.4
SD	42.5	48.7	56.2	46.3	41.4	30.8
GCM	27.7	22.7	26.8	24.9	30.7	27.8
	Maximum discharge of flash floods of summer-autumn season					
RCP	23.8	20.9	22.3	16.2	23.3	23.6
SD	51.0	47.5	43.9	56.5	43.0	50.7
GCM	25.3	31.6	33.8	27.3	33.7	25.7

3.9. Recommendations and proposals for the preparation of documents for the protection and management of resources of water bodies

The four consequence classes (CC) of hydrotechnical structures were identified in the documents of Technical Construction Regulation (STR) of Republic of Lithuania (STR 2.02.06:2004 "Hydrotechnical structures. Basic Provisions", Official Gazette, 2004, No. 154-5624). There is shown how to select the probability of extreme discharge for consequence classes, when the probabilistic evaluation itself is performed on the basis of historical observation data without considering the potential trends of climate change (STR 2.05.19:2005 "Engineering Hydrology – Basic Requirements for Calculation", Official Gazette, 2005, No. 116-4215). Therefore, it is very important to know not only the hydrological regime in the past, but also how it can change in the future for maintaining hydrotechnical structures and performing their design work. In this work, the evaluation of projections of floods and their uncertainties, as well as possible errors during such long years of life of hydrotechnical structures, provided an opportunity to recommend not to change the STR requirements for hydrotechnical structures. Moreover, it is proposed to include the probabilistic evaluation of extreme discharges according to the floods projections under climate change conditions in the periods of near (2021-2040) and far (2081-2100) future. The mentioned projections should be created using at least two global climate models from the CMIP5 project, two RCP climate scenarios and two statistical downscaling methods (Table 3.3).

In accordance with paragraph 12 of the directive on the assessment and management of flood risks (2007/60/EC), which refers to the need to draw up flood hazard and risks maps showing potential damage, Lithuania has fulfilled this requirement by creating an interactive "Flood Hazard and Risk Map" (http://potvyniai.aplinka.lt/potvyniai/). These maps contain areas which can be impacted by floods of probability of 0.1, 1, and 10% (only based on the data of historical observations). At the same time, paragraph 14 of the same directive requires that politicians of the country and decision-makers take into account the changes of water resources in the relation to climate change when evaluating the risk of future extreme hydrological phenomena. Therefore, they are inviting to regularly apply new-generation climate scenarios and, if necessary, keep them up to date. Whereas according to Paragraph 14 of Directive 2007/60/EC, Part 2 by December 22, 2019 Flood hazard and risk maps should be reviewed and, if necessary, updated, followed by a review every six years. In accordance with this point, Paragraph 14 of the Floods Directive and Part 4 as well as findings of this study it is recommended to include the projections of future extreme discharge and to display them on the map for the period of near future (2021-2040) using at least two global climate models from the CMIP5 project, two RCP climate scenarios and two statistical downscaling methods (Table 3.3).

However, in other documents the impacts of climate change have been assessed only in the Flood Risk Management Plan Project (Center for Environmental Policy, 2015). In this project, projections of the runoff of the Nemunas River basin was carried out according to the old climate scenarios of SRES group – A1B and B1, which appeared in 2000 and became out-dated after RCP scenarios were released in 2013. The projections were created for the period of 2021-2050 using Water Balance Model (WatBal). The main input data for future runoff projections were taken from the CCLM (COSMO – Climate Limited-area Model) regional climate model and nothing about the adjusting of meteorological parameters using statistical downscaling methods was mentioned. In accordance with 3 and 4 Parts of Paragraph 14, Directive 2007/60/EC, flood risk management plans should be revised in view of the expected impacts of climate change on flood rise and, if necessary, updated by December 22, 2021 and every 6 years thereafter. Taking into account all the principles of projections in the Flood Risk Management Plan, the revised document should include projections of floods in the daily time step for the period of near future (2021-2040) (Table 3.3). The projections should be created according to the output data from at least two global climate models from the CMIP5 project because this study has shown a fairly large uncertainty of projections associated with the selection of a global climate model (one is not enough), at least two newest RCP climate scenarios and two statistical downscaling methods.

EU Water Framework Directive (2000/60/EC) establishing the framework for European Community action in the field of water policy requires that the management plans (MP) for river basin districts (RBD) must be prepared and, if necessary, updated at the latest 15 years after the date of entry into force of this Directive. Lithuania successfully fulfilled the objectives of the agreement and prepared the management plans for the RBD (Environmental Protection Agency, 2015). Having reviewed the current management plans for river basin districts, the methodology and principles that underpin future runoff projections and the impacts of climate change on surface water bodies have been assessed. In river basin district management plans, the climate change was evaluated using the three climate scenarios of the old-generation SRES group (2000) – A1, A2 and B1 for the period of 2011-2020 which is getting to completion. Data of two global climate models (ECHAM5 and HadCM3) were also used. The mentioned models also already have updated versions that are included in the CMIP5 project. According to Part 7 of Article 13 of Directive 2000/60/EC, the Members of the Commitment undertake to review and update the RBD MP every six years. The next period of revision is scheduled to take place in 2021, therefore it is recommended that the updated river basin district management plans should include the runoff projections created according to at least two newest RCP climate scenarios, two global climate models from the CMIP5 project and two statistical downscaling methods (Table 3.3). Even in the management plan of the

Nemunas RBD it is stated that the period of 2011-2020 is too short to identify significant changes in the runoff, consequently it is recommended to use twice longer period of near future (2021-2040) for documentary updates.

It is also important to update the STR and other documents periodically after appearance of new climate scenarios and upgrading of global climate models according to newly proposed periods. Such a decision would help to evaluate thoroughly and objectively all possible threats to the life of people related to the maintenance of hydrotechnical structures during their lifetime.

Table 3.3. Recommendations and suggestions for preparation of documents for the protection and management of resources of water bodies

No.	Document	Current situation	Recommendations
1.	Technical Construction Regulation (STR)	There is shown how to select the probability of extreme discharge for consequence classes, when the probabilistic evaluation itself is performed only on the basis of historical observation data	It is recommended to include the probabilistic evaluation of extreme discharges according to projection under climate change conditions for the periods of near (2021-2040) and far (2081-2100) future. At least two global climate models from the CMIP5 project, two RCP climate scenarios and two statistical downscaling methods should be used for mentioned projections
2.	Flood Hazard and Risk Map	Maps are created according to the data of historical observations	It is proposed to include projections of future extreme discharge and to display them on the map for the period of near future (2021-2040) using at least two global climate models from the CMIP5 project, two RCP climate scenarios and two statistical downscaling methods
3.	Flood Risk Management Plan	The Nemunas River basin was carried out according to the old climate scenarios of SRES group (2000) – A1B and B1. The projections were created for the period of 2021-2050 using Water Balance Model (WatBal). The main input data for future runoff projections were taken from the CCLM regional climate model	The revised document should include projections of floods in the daily time step for the period of near future (2021-2040). The projections should be created according to the output data from at least two global climate models from the CMIP5 project, two newest RCP climate scenarios and two statistical downscaling methods
4.	River Basin District (RBD) Management Plans	The climate change was evaluated using data of two global climate models (ECHAM5 and HadCM3) according to three climate scenarios of SRES group (2000) – A1, A2 and B1 for the period of 2011-2020	Updated RBD management plans should include the runoff projections created according to at least two newest RCP climate scenarios, two global climate models from the CMIP5 project and two statistical downscaling methods for the period of near future (2021-2040)

CONCLUSIONS

The changes of flood patterns in the past were evaluated in this dissertation and according to original methodology the projections of future floods were created for near (2016-2035) and far future (2081-2100).

1. Evaluating the changes of flood patterns in the period of 1941-2013, the significant negative trends of maximum discharge (Q_{max}) of spring floods were determined in 12 of 14 water gauging stations (WGS), meanwhile the significant negative trends of Q_{max} of flash floods of summer-autumn season were estimated only in three WGSs. The significant negative trends of Q_{max} of spring floods were established in 32% of WGSs, negative trends – 26% and no trend – 42% according to the data of 31 WGSs in 1961-2013. The significant negative trends of flash floods were determined only in 2 of 31 WGSs in 1961-2013, the trends have not been indicated in remaining WGSs. Any evident changes of both types of floods hadn't been detected in the last decades.
2. The snow water equivalent accumulated before the flood was the main factor determining the magnitude of the spring flood. Analysis of probability distributions showed that the decrease of the spring floods in the hydrological regions of Central and Southeastern Lithuania is closely related to the decrease of the maximum snow water equivalent.
3. According to the newest RCP climate scenarios, the projections of maximum discharges (Q_{max}) in the near and far future indicated the decrease of spring floods and their seasonal redistribution, when some of the spring floods will occur in the winter season. Although the decrease (from -9.1% to -32.4%) of average Q_{max} of spring floods was estimated, but extreme values of rare probability are expected to rise in particular years. According to the projections of flash floods of summer and autumn, the increase (1.3-16.2%) of their average Q_{max} is expected together with the increased probability of extreme discharges.
4. It was determined that statistical downscaling methods had the greatest influence (41.4-56.5%) on the final projections of Q_{max} in evaluating the uncertainties of projections of Q_{max} of spring and flash floods according to three selected sources of uncertainties (global climate models, RCP scenarios and statistical downscaling).
5. The recommendations for the preparation of documents for the protection and management of resources of water bodies were prepared using the results of this study. At least two global climate models, two RCP climate scenarios and two statistical downscaling methods are proposed for flood projecting and risk assessment related to impacts of potential climate change.
6. The original methodology for projections of spring floods and flash floods of summer-autumn season in near and far future was created and it can be applied for the river catchments from the South-Eastern Baltic Sea region with similar physico-geographical and climatic features, like in selected river catchments of this thesis.

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REZIUMĖ

Lietuvos geografinėmis ir klimatinėmis sąlygomis upių potvyniai yra priskiriami ekstremaliems hidrologiniams reiškiniams. Šiame darbe analizuojamus potvynius sudaro pavasario potvyniai bei vasaros ir rudens sezonų poplūdžiai. Jų susidarymą lemia skirtingos formavimosi priežastys. Upių potvyniai yra natūralus, dažniausiai kasmet gamtoje vykstantis reiškinys, o Lietuvos gamtinei zonai ypač būdingi pavasario potvyniai. Sniego tirpsmas yra pagrindinis pavasario potvynius formuojantis veiksnys, o jei atlydžio laikotarpis sutampa su lietumi, tada susidaro itin staigūs, dideli potvyniai. Pavasario potvynių dydį sąlygoja žemės paviršinio sluoksnio įšalas, kuris po žiemos dar būna nespėjęs atitirpti, todėl beveik nevyksta infiltracija ir didžioji dalis paviršinio nuotėkio patenka tiesiai į upes.

Lietuvoje vasaros ir rudens poplūdžius sukelia užsitęsusios arba intensyvios liūtys. Pagrindinė vasaros liūčių priežastis yra po vasaros kaitros atslinkęs šaltas oro frontas arba konvekciniai kamuoliniai lietaus debesys, kurie dažnai pasižymi lokalumu. Svarbiausia sąlyga šiems debesims susiformuoti yra didelis saulės radiacijos kiekis, dėl kurio vyksta intensyvus garavimas iš jūros, ežerų, pelkių bei evapotranspiracija iš dirvos ir augalų. Susidarę kamuoliniai lietaus debesys savyje sukaupia milžiniškus vandens kiekius. Rudens poplūdžius iš esmės formuoja virš vietovės užslinkę gilūs ciklonai, paskui save nešantys gausius kritulius.

Šiuo metu vyrauja nuomonė, kad klimato kaita yra tarsi šalutinis antropogeninės veiklos produktas. Klimato kaita ateityje prognozuojama pagal CO_2 ir kitų šiltnamio efektą sukeliančių dujų emisijos scenarijus, kurie priklauso nuo tolimesnės žmonių ūkinės, socialinės ir ekonominės raidos. Atsižvelgiant į tai, vienas iš pagrindinių aplinkos inžinerijos tikslų yra mažinti antropogeninės veiklos padarinius. Prognozuojant potvynių pokyčius ateityje klimato kaitos sąlygomis, būtų galima įvertinti jų poveikį žmonių gyvenamajai aplinkai ir žalą. Tik atlikus detalią potvynių kaitos analizę, galima numatyti problemų sprendimo būdus, pasiūlymus ir rekomendacijas. Klimato kaitos sąlygomis pasikeitęs Lietuvos upių hidrologinis režimas turės įtakos hidrotechninių statinių projektavimui, statybai bei priežiūrai. Dėl nepastovaus upių režimo, vandeningumo persiskirstymo ir sunkiai prognozuojamų ekstremalių hidrologinių reiškinių, apsaugos priemonių parinkimas ir įgyvendinimas, siekiant mažinti pavojaus riziką klimato kaitos sąlygomis, taps tikru XXI a. iššūkiu. Ekstremalių hidrologinių reiškinių galimi pokyčiai, susiję su klimato kaita, palies žmonių socialinę ir ekonominę aplinką.

Minėtiesiems iššūkiams spręsti yra siūlomi įvairūs būdai, tačiau visų pirma reikia sukurti tikslingą metodiką, kuri padėtų kruopščiai atrinkti tinkamiausius sprendimo būdus. Kalbant apie potvynius, svarbu detaliai išanalizuoti praeityje vykusius procesus tam, kad geriau suprastume kaip pasikeis hidrologiniai procesai ateityje. Visų pirma, keičiantis globalaus klimato,

kartu ir regioninio klimato sąlygoms, keičiasi ir hidrologinis upių režimas. Vadovaujantis skirtingais klimato kaitos scenarijais, yra sudaromos būsimų potvynių kaitos prognozės. Turint apibendrintus tyrimų rezultatus, galima teikti rekomendacijas, kurios padėtų išvengti arba maksimaliai sumažintų ekstremalių hidrologinių reiškinių poveikį klimato kaitos sąlygomis. Ypač svarbu įvertinti prognozuojamų potvynių padarinius, kurie gali būti susiję su pastatytų hidrotechninių statinių apgadinimais, taip pat statyba bei eksploatacija. Šiems statiniams didžiausią žalą gali padaryti retos pasikartojimo tikimybės potvyniai. Įvertinus šių potvynių tikimybę ir mastus klimato kaitos sąlygomis, galima teikti siūlymus bei rekomendacijas naujai statomiems hidrotechniniams statiniams.

Darbo aktualumas

Direktyva 2000/60/EB, nustatanti Bendrijos veiksmų vandens politikos srityje pagrindus, ir Europos potvynių vertinimo ir valdymo direktyva (Direktyva 2007/60/EB) reikalauja, kad šalių politikai ir asmenys, priimantys sprendimus, vertindami būsimų potvynių riziką, atsižvelgtų į vandens telkinių išteklių pokyčius, susijusius su klimato kaita ir siūlo reguliariai atnaujinti prognozes taikant naujos kartos klimato scenarijus.

Darbo objektas

Lietuvos upių pavasario potvyniai bei vasaros ir rudens sezonų poplūdžiai.

Darbo tikslas

Įvertinti Lietuvos upių pavasario potvynių bei vasaros ir rudens sezonų poplūdžių kaitos dėsningumus pagal daugiamečius duomenis ir atlikti šių hidrologinių reiškinių prognozę pagal naujausius klimato scenarijus taikant hidrologinį modeliavimą bei, įvertinus potvynių pokyčius ir jų riziką, pateikti rekomendacijas ir pasiūlymus vandens telkinių išteklių apsaugos ir valdymo dokumentams ruošti.

Darbo uždaviniai

1. Įvertinti upių potvynių kaitos dėsningumus ir nustatyti pagrindines šių reiškinių formavimosi sąlygas.
2. Sukurti upių potvynių prognozavimo metodiką klimato kaitos sąlygomis.
3. Taikant sukurtus hidrologinius modelius pasirinktoms upėms, atlikti potvynių prognozę bei įvertinti galimus jų pokyčius XXI a. pagal pasirinktus klimato scenarijus.
4. Įvertinti upių nuotėkio ir potvynių prognozių neapibrėžtumus, susijusius su klimato scenarijų, globalaus klimato modelių ir tinklelio raiškos didinimo metodų parinkimu.

5. Pateikti rekomendacijas ir siūlymus vandens telkinių išteklių apsaugos ir valdymo dokumentams ruošti.

Ginamieji disertacijos teiginiai

- Ateityje prognozuojama pavasario potvynių maksimalių debitų mažėjimo tendencija, tačiau atskirais metais išlieka tikėtini ekstremalūs potvyniai.
- Prognozuojami vidutiniai maksimalūs šiltojo sezono poplūdžių debitai didėja, kartu daugėja ir ekstremalių debitų pasikartojimo atvejų.
- Globalaus klimato modeliai, klimato scenarijai ir statistiniai tinklelio raiškos didinimo metodai yra pirminiai potvynių prognozių neapibrėžtumų šaltiniai, kurių parinkimas daro reikšmingą įtaką galutinėms ekstremumų prognozėms.

Darbo naujumas ir pritaikomumas

Klimato kaitos įtaka potvyniams iki šiol yra mažai vertinta. Tik potvynių rizikos vertinimo ataskaitoje, UBR ir UBR potvynių rizikos valdymo planuose buvo įvertinta klimato kaita pagal SRES (angl. *SRES – Special Report on Emissions Scenarios*, 2000) grupės scenarijus, kurie tapo nebeaktualūs po RCP (angl. *RCP – Representative Concentration Pathways*) scenarijų pasirodymo 2013 m. Statybos techninio reglamento dokumentuose (STR 2.02.06:2004 ir STR 2.05.19:2005) nurodoma, kaip pagal hidrotechninių statinių pasekmių klases pasirinkti ekstremalių debitų tikimybes, tačiau tikimybinis vertinimas atliekamas pagal daugiamečius duomenis, neįvertinant galimų klimato kaitos tendencijų. Todėl šiame darbe RCP klimato scenarijų pagrindu sukurta prognozavimo metodika, patikrinta Lietuvos sąlygomis, leis įvertinti galimą klimato kaitos poveikį vandens telkiniams ir pateikti rekomendacijas bei pasiūlymus galimoms pasekmėms švelninti.

Doktorantūros studijų laikotarpiu dalis rezultatų buvo pritaikyta vykdant Nacionalinės programos projektą „Klimato kaitos ir kitų abiotinių aplinkos veiksnių poveikio vandens ekosistemoms vertinimas" (2015–2018). Lietuvos upių nuotėkio ir potvynių prognozės ir jos neapibrėžtumo įvertinimas padės tiksliau nustatyti galimas Lietuvos upių sezoninių bei ekstremalių hidrologinių reiškinių ribines vertes pagal naujausius klimato scenarijus ir leis pateikti rekomendacijas bei pasiūlymus vandens telkinių išteklių apsaugos ir valdymo dokumentams (UBR ir UBR potvynių rizikos valdymo planai, potvynių grėsmės ir rizikos žemėlapiai, statybos techninis reglamentas) ruošti. Sukurta darbo metodika ir rezultatai bus naudingi vykdant esamus ir būsimus mokslinius projektus vertinant klimato kaitos įtaką hidrologiniams ekstremumams.

Publikacijos

Disertacijos tema paskelbtos 2 publikacijos „Clarivate Analytics“ duomenų bazėje „Web of Science Core Collection“ referuojamuose leidiniuose ir 1 publikacija priimta tai pačiai duomenų bazei priklausančiame žurnale. Viena publikacija yra paskelbta leidinyje, kuris registruotas SCOPUS duomenų bazėje. Pristatyti 8 pranešimai tarptautinėse konferencijose, iš kurių 2 vyko užsienyje.

Darbo struktūra ir apimtis

Disertaciją sudaro įvadas, šeši skyriai (literatūros apžvalga, metodika, hidrometeorologinių duomenų bazės sudarymas, potvynių vertinimas pagal daugiamečius duomenis, hidrometeorologinių rodiklių prognozės analizė XXI a. pagal įvairius klimato scenarijus, rekomendacijos ir pasiūlymai vandens telkinių išteklių apsaugos ir valdymo dokumentams ruošti), išvados, literatūra ir mokslinių publikacijų disertacijos tema sąrašas. Darbo apimtis – 121 puslapis, tarp jų 40 paveikslų ir 20 lentelių. Literatūros sąraše pateikta 170 literatūros šaltinių.

Išvados

Disertaciniame darbe buvo įvertinti potvynių kaitos dėsningumai praeityje ir pagal pasiūlytą originalią potvynių prognozavimo metodiką buvo sudarytos jų prognozės artimai (2016–2035 m.) ir tolimai (2081–2100 m.) ateičiai.

1. Įvertinus potvynių kaitos dėsningumus praeityje, nustatyta, kad 1941–2013 m. laikotarpyje reikšmingi neigiami pavasario potvynių maksimalių debitų (Q_{max}) trendai buvo 12 iš 14 vandens matavimo stočių (VMS), o reikšmingi neigiami vasaros ir rudens sezonų poplūdžių Q_{max} trendai aptikti vos trijose VMS. 1961–2013 m. laikotarpiu pagal 31 VMS duomenis, reikšmingi neigiami pavasario potvynių Q_{max} trendai nustatyti 32 % VMS, neigiami trendai – 26 %, o 42 % VMS – jokių trendų. Vertinant 1961–2013 m. šiltojo sezono poplūdžių Q_{max} trendus, tik 2 iš 31 VMS buvo nustatyti reikšmingi neigiami, o likusiose VMS trendai nenustatyti. Paskutiniaisiais dešimtmečiais aiškių potvynių ir poplūdžių Q_{max} tendencijų neaptikta.
2. Svarbiausias veiksnys, lemiantis pavasario potvynių dydį, prieš pat potvynį susikaupusios maksimalios vandens atsargos sniege. Tikimybinių skirstinių analizė parodė, kad Vidurio ir Pietryčių Lietuvos hidrologiniuose rajonuose pavasario potvynių dydžio mažėjimas glaudžiai susijęs su maksimalių vandens atsargų sniege sumažėjimu.
3. Prognozuojant maksimalius debitus (Q_{max}) pagal naujausius klimato scenarijus, nustatytas pavasario potvynių Q_{max} mažėjimas bei jų sezoninis persiskirstymas, kai dalis pavasario potvynių vyks žiemą. Nors ateityje nustatytas pavasario potvynių vidutinio Q_{max} mažėjimas, kuris sudarys nuo -9,1 % iki -32,4 % lyginant su foninio laikotarpio norma, tačiau atskirais metais

didės retos tikimybės ekstremalių potvynių Q_{max}. Pagal sudarytas trijų upių vasaros ir rudens sezonų poplūdžių prognozes, ateityje numatomas vidutinio Q_{max} augimas (1,3–16,2 %) bei išauga ekstremalių debitų tikimybė.

4. Vertinant ateities maksimalių debitų prognozių neapibrėžtumus, susijusius su trimis pasirinktais neapibrėžtumo šaltiniais (globalaus klimato modeliai, RCP klimato scenarijai ir tinklelio raiškos didinimo metodai), nustatyta, kad tinklelio raiškos didinimo metodai turi didžiausią įtaką (41,4–56,5 %) pavasario potvynių ir šiltojo sezono poplūdžių prognozių neapibrėžtumui.

5. Taikant šio darbo rezultatus, buvo paruoštos rekomendacijos vandens telkinių išteklių apsaugos ir valdymo dokumentams rengti. Prognozuojant potvynius ir vertinant pavojaus riziką, susijusią su galimais klimato kaitos padariniais, siūloma naudoti ne mažiau kaip du globalaus klimato modelius, du RCP klimato scenarijus ir du tinklelio raiškos didinimo metodus.

6. Sukurta originali pavasario potvynių bei vasaros ir rudens sezonų poplūdžių prognozavimo metodika artimai ir tolimai ateičiai. Ši metodika gali būti pritaikyta pietryčių Baltijos jūros regiono upių baseinams, turintiems panašias fizines–geografines ir klimatines sąlygas, kaip ir šiame darbe tirti upių baseinai.

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