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Forecasted changes in the climate and the river runoff regime in Latvian river basins

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Abstract The hydrological model HBV (*Hydrologiska Byråns Vattenbalansavdelning model*) has been applied to six river basins in Latvia to assess climate change and its impacts on the river runoff regime at the end of the 21st century. Climate change has been predicted by applying the regional climate model RCAO with the driving boundary conditions from the global general circulation model HadAM3H applied for the IPCC scenarios A2 and B2 and the following time periods: 1961–1990 (control) and 2071–2100 (scenario). Changes have been found under both scenarios. Major changes in the future hydro-climate data were forecasted according to the A2 scenario, where the trends of increase are identified for the annual mean air temperature (by 4°C), the precipitation (by 12%) and the evapotranspiration (by 21%), while the river runoff will decrease by 15% at the same time. The changes in the length of the growing season and heavy rainfall have been predicted. Both scenarios forecast changes in the seasonal runoff regime where the major part of the runoff will be generated in winter, followed by spring, autumn and summer. The maximum river discharge will occur in winter instead of spring.

Keywords • Climate change • Hydrological model • River runoff • Forecast scenario • Latvia

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INTRODUCTION

During recent decades, increasing attention has been focused on the studies of the impact of the global climate change on the hydrological cycle in order to evaluate and predict the changes in water resources at various spatial and temporal scales (Rummukainen *et al.* 2003; Andreasson *et al.* 2004; Beldring *et al.* 2008; Yang *et al.* 2010; Thorsteinsson, Björnsson 2011), including in the Baltic region (Jaagus *et al.* 1998; Kriaučiūnienė *et al.* 2008; Kriaučiūnienė *et al.* 2009; Beters, Seņņikovs 2009; Apsīte *et al.* 2011).

The temperature and precipitation are the main factors of the climate that influence the river runoff (Kriaučiūnienė *et al.* 2008; Bolle *et al.* 2008; Wilson *et al.* 2010). It was forecasted in the study by Graham (2004) that, at the end of the 21st century in the Baltic Sea basin, the southern areas will get drier and the northern parts will become wetter and this will deter-

mine the river runoff patterns: decrease in the annual river runoff in the south and increase in the north. The South Eastern Baltic countries, including Latvia, are situated in the middle of both regions and the different used climate models and emission scenarios not always predict significant changes in the annual river runoff. According to Bolle *et al.* (2008) a borderline is identified in the territory of Latvia, where the increase of the annual mean discharge is forecasted in the North and East river basins and partly in the Central and Western river basins of Latvia and decrease of the annual mean discharge is forecasted in the rest of river basins. Dankers *et al.* (2007, 2008) have found stronger increase in the annual river runoff in the Western part of Latvia than in the others. However, on the basis of the latest studies in Latvia by Rogozova (2006), Beters and Seņņikovs (2009), Apsīte *et al.* (2011) and in Lithuania by Kriaučiūnienė *et al.* (2008), the main trend in the climate and river runoff change at the end of the 21st

century is shifted rather towards the southern region forecast of the Baltic Sea basin according to the study by Graham (2004). This leads to the intensification of the hydrological cycle with more precipitation and evapotranspiration under warmer and wetter climate and decrease in the annual river runoff at the end of this century.

The forecasted future changes in the climate and runoff regime in Latvian river basins have not been sufficiently investigated. It is important to use not only different climate models and the emission scenarios of the Intergovernmental Panel on Climate Change (IPCC), but also hydrological models. Therefore, the aim of this study is to analyse and discuss the following: the calibration results of the hydrological HBV model for six different Latvian river basins, changes in the mean annual, seasonal, monthly and maximum river discharge and the climate data, as well as to compare the obtained results with other latest studies in the Baltic countries.

MATERIAL AND METHODS

Geographical setting

The study focuses on six river basins. The river basin locations and characteristics are presented in Figure 1 and Table 1. The river basins differ in size and natural conditions. According to the classification by Glazacheva (Glazacheva 1980), the Dursupe and Imula river basins are located in the Western hydrological district, the Bērze and the Iecava in the Central district, the Vienziemīte and the Salaca in the Northern district. The Salaca river basin is the largest studied basin with the total drainage area 3220 km², where forests cover 46% and lakes account for up to 9% of the territory. The Vienziemīte River basin is the smallest studied catchment (5.92 km²). It is located in

Table 1 Characteristics of studied river basins.

River basin/ hydrological station	Total drainage area, km ²	Studied drain- age area, km ²	Forests, %	Lakes, %	Agricultural lands, %
Imula/ Pilskalni	263	207	47	0.20	53
Dursupe/ Jaunpļavas	138	138	59	0	41
Bērze/Baloži	904	904	31	0.9	68
Iecava/Dupši	1166	519	63	5.6	31
Vienziemīte/ Vienziemīte	5.92	5.92	14	0	86
Salaca/ Lagaste	3420	3220	46	9	46

the Vidzeme Upland, 180 m above the sea level. The rivers Vienziemīte, Imula and partly Bērze can be characterised as upland rivers, but the rivers Salaca, Dursupe and Iecava as lowland rivers.

The HBV hydrological model

The HBV is a semi-distributed conceptual rainfall-runoff hydrological model developed in Swedish Meteorological Institute by S. Bergström (1976). The required input data are meteorological and hydrological data. The model consists of subroutines for snow accumulation and melt, soil moisture accounting procedure, routines for runoff generation and, finally, a simple routing procedure (IHMS 2008).

The statistical criterion R² (Nash, Sutcliffe 1970), mean values and a graphical representation is used in the analysis of the model calibration results. The efficiency criterion R² measures the proportion of the total variance of the observed data as explained by the predicted data. Nash–Sutcliffe efficiencies can range from $-\infty$ to 1. The perfect model results in R² equal to 1. However, normally R² is in the range between 0.8 and 0.95. Naturally, this is only the case when input data are of good quality (IHMS 2008). A more detailed description of the model HBV is presented in other studies (Bergström 1992; IHMS 2008).

The used input data for the hydrological model and statistical methods

For the HBV model calibration and validation, daily measurements of air temperature (°C) and precipitation (mm) at nine meteorological stations and precipitation (mm) at five stations, and long-term monthly average values of evapotranspiration (mm) at two stations (Ķemeri and Zosēni) as well as daily river discharge (m³/s) at six hydrological stations have been used. The location

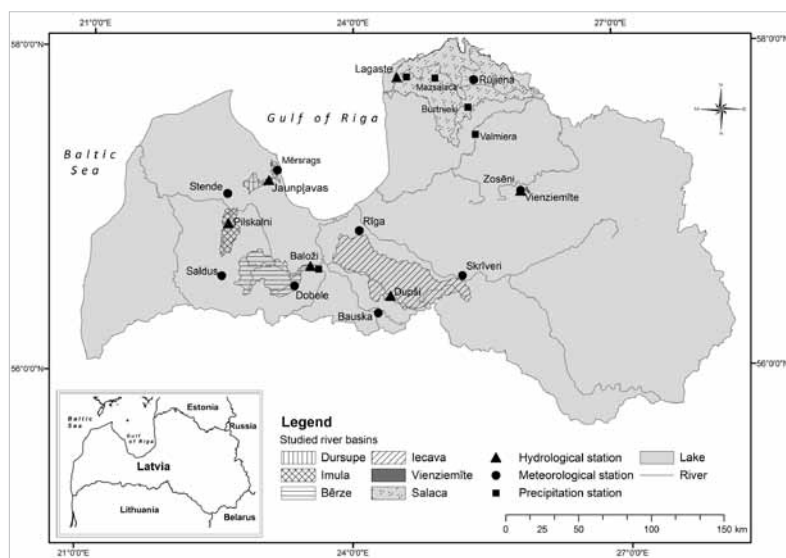


Fig. 1 Location of river basins and hydrological, meteorological and precipitation stations used in the study. Compiled by I. Latkovska, 2012.

of these meteorological and hydrological stations is presented (see Fig. 1). All data are obtained from the Latvian Environment, Geology and Meteorology Centre and VSIA *Meliorprojekts*. In this study, the selected calibration period was from 1961 to 1990, and the validation period covers the proceeding ten years from 1991 to 2000. The period from 1961 to 1990 has been chosen because it could be conditionally described as a period with no considerable changes in hydro-meteorological data series observed. This fact is confirmed by the World Meteorological organization (http://www.wmo.int/pages/prog/wcp/wcdmp/GCDS_1.php). Moreover, the calibration period covers 5 wettest (1962, 1978, 1980, 1981 and 1990) and 3 driest (1964, 1969 and 1976) years in Latvia over the last hundred years. This is a good opportunity to perform the hydrological simulation as it allows the model parameters to respond to extreme values in the process of simulation of future climate scenarios.

The authors have used climate data series (daily temperature and precipitation) as the input data for the hydrological model developed by a separate study (Seņņikovs, Bethers 2009) of the national research program Climate Change Impact on Water Environment in Latvia. Climate changes are predicted by the regional climate model (RCM) Rossby Centre Atmosphere Ocean (RCAO) with driving boundary conditions from the global general circulation model (GCM) HadAM3H applied for the two IPCC scenarios A2 and B2. The full description of the applied downscaling methodology can be found in Seņņikovs and Bethers (2009). The emission scenarios cover a wide range of the main demographic, economic and technological driving forces behind the future greenhouse gas emissions. The climate A2 scenario is a high emission scenario compared to B2, and it is chosen for this study to illustrate the worst case scenarios (Nakicenovic *et al.* 2000). The A2 scenario represents a regionally limited cooperation and a slower adaptation of new technologies with an unstabilized population growth, but the B2 scenario is more environmentally friendly with continuously increasing population, but at a slower rate than in A2 scenario and the emphasis is on the local rather than the global solutions to economic, social and environmental stability issues (Nakicenovic *et al.* 2000). The calculated data series indicate the following: CTL represents the control period 1961–1990 and characterises the contemporary climate conditions, while A2 and B2 represent the period of future scenarios 2071–2100 and forecast future climate conditions. All data series have been interpolated from the grid cross points to the meteorological stations involved in our study.

The T-test at the significance level $p < 0.05$ (Sokal, Rohlf 1995) is used to compare the mean annual, seasonal and monthly values of the mean and maximum discharge, the minimum, mean and maximum temperature, the evapotranspiration and the amount of precipitation between the control period and the scenario. The confidence intervals of 95% is calculated for the hydro-climate data values using the Student's t-distribution with the software R version 2.14.1 (R Development Core Team 2011).

RESULTS

Calibration and validation of the hydrological model

The HBV hydrological model has been calibrated (1961–1990) and validated (1991–2000) for all studied river basins (see Fig. 1). The calibration results present a good connection between the observed and simulated daily discharges as statistical criterion R^2 values vary from 0.72 to 0.82 (Table 2). The best coincidence is obtained for Bērze (Fig. 2) and Salaca river basins. The lowest statistical criteria values are found for Iecava and Dursupe rivers (Table 2). The validation results (values of R^2 vary from 0.69 to 0.80) show that the model HBV responds well in simulation of hydrological process using meteorological observation data.

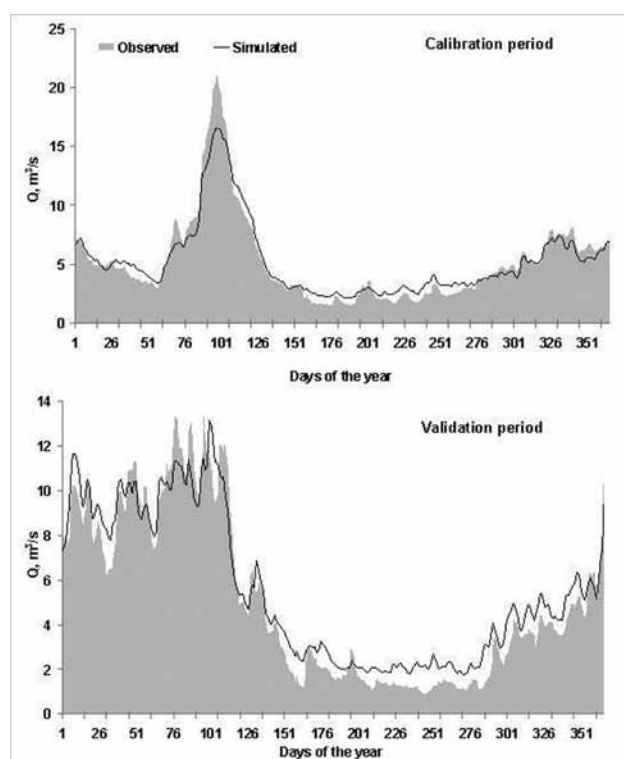


Fig. 2 Observed and simulated long-term mean daily discharge of the river Bērze for the calibration (1961–1990) and the validation (1991–2000) periods. Compiled by I. Latkovska, 2012.

Table 2 The obtained statistical criteria for studied river basins.

River basin	Calibration period (1961–1990)	Validation period (1991–2000)
	R^2	R^2
Imula – Pilskalni ²⁾	0.78	0.75
Bērze – Baloži	0.82	0.80
Iecava – Dupši ²⁾	0.72	0.72
Dursupe – Jaunplavas ¹⁾	0.74	0.69
Vienziemīte – Vienziemīte	0.77	0.70
Salaca – Lagaste	0.80	0.71

¹⁾ Operating since 1980; ²⁾ Closed since 1995

The reasons for the difference between the observed and simulated discharge values are the number and location of the used meteorological stations characterising the spatial and temporal distribution of precipitation and air temperature in the studied river catchments. In the case of the Bērze and Salaca rivers, where more meteorological stations were involved, we have obtained better results of the model calibration and validation. The data quality is another important reason. A homogeneity test should be made for the chosen stations to be able to find if any interruptions in the trends of the stations have occurred. The mean accumulated precipitation for all other stations is plotted on the Y axis against that for the gauge being studied, which is plotted on the X axis. If the slope of the double mass curve changes at some point in the time, this indicates an interruption in the homogeneity. A jag in the double mass curve can be caused by missing values at the observed station or by seasonal differences in the precipitation pattern. The slope of the curve is proportional to the intensity, i.e. if the observed station records exactly as much as means of the rest, the curves follow the diagonal. Generally, the results of homogeneity analysis for input precipitation data were good (Fig. 3). However, we suppose that in some cases the quality of precipitation data could be better.

Changes in climate data

The results of the changes in climate data, such as differences between the scenarios and CTL periods

are summarised (Tables 3, 4, 5). The major significant changes in meteorological parameters have been forecasted in the studied river basins according to A2 scenario, where the annual mean air temperature will increase by 3.9–4.1°C, followed by the increase in precipitation by 9–12% and evapotranspiration by 22–28%. Smaller changes in climate parameters have been identified according to B2 scenario. The increase trend is predicted for all meteorological parameters, but a statistically significant trend is observed for temperature (by 2.6–2.7°C) and evapotranspiration (by 15–27%), as well as precipitation (by 10%) only in two river basins (the Dursupe and the Salaca) according to B2 scenario.

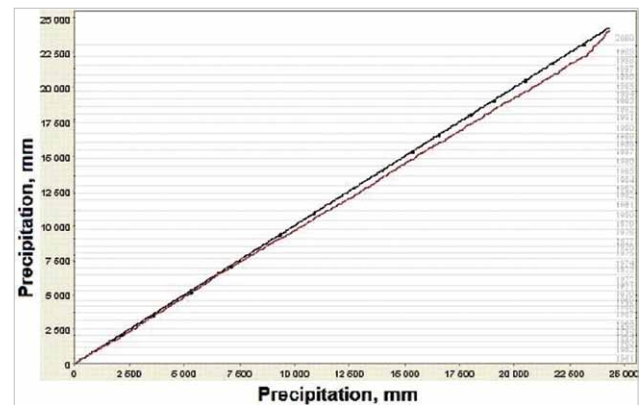


Fig. 3 Homogeneity analysis for input precipitation data for Bērze river basin in time period 1961–2000. X axis – sum of precipitation in analysable meteorological station, Y axis – average precipitation sum in other meteorological stations (line with points). Compiled by L. Kurpniece, 2012.

Table 3 Changes in temperature values (in °C) and duration (in number of days) of growing season (i.e. daily mean temperature exceeding 5°C) between the scenario and control period. Winter season – DJF; spring – MAM; summer – JJA and autumn – SON.

Period or season / scenario	River basin					
	Imula	Dursupe	Bērze	Iecava	Vienziemīte	Salaca
	minimum/mean/maximum temperature					
Annual/A2	8.2/4.1/4.1	8.0/3.9/4.0	9.5/3.9/4.1	9.3/4.0/4.7	9.6/4.1/4.4	9.0/4.0/4.0
DJF / A2	8.1/4.5/4.0	7.9/4.4/3.3	9.3/4.7/3.6	9.1/4.9/3.7	9.6/4.9/3.6	8.9/4.9/3.5
MAM /A2	4.3/4.1/4.2	4.8/3.8/4.1	4.9/3.8/4.1	5.9/3.9/4.2	6.9/4.1/4.5	6.5/4.1/4.5
JJA / A2	3.0/3.6/4.0	2.8/3.3/4.0	2.3/3.1/4.0	2.9/3.1/4.4	3.3/3.1/4.2	2.9/3.0/3.8
SON / A2	5.5/4.2/4.9	4.6/4.0/4.4	5.6/4.1/4.9	6.4/4.2/4.9	6.3/4.2/4.5	6.3/4.1/4.1
Annual/B2	5.4/2.7/1.9	6.3/2.6/1.8	6.8/2.6/1.9	7.2/2.6/1.9	7.3/2.7/2.1	6.9/2.7/1.7
DJF / B2	5.4/3.0/2.9	6.3/3.0/2.1	6.8/3.1/2.7	7.1/3.2/2.3	7.5/3.3/2.5	7.0/3.4/2.7
MAM /B2	4.2/2.7/1.8	4.8/2.6/1.5	4.7/2.4/1.7	6.0/2.8/1.7	6.5/2.9/2.2	6.1/2.9/2.1
JJA / B2	1.7/1.9/1.7	1.7/1.7/1.7	1.0/1.4/1.7	1.6/1.5/1.8	1.7/1.5/1.9	1.7/1.3/1.5
SON / B2	4.5/3.4/3.6	4.3/3.0/2.5	4.7/3.3/3.6	5.1/3.0/2.8	4.5/3.0/2.8	4.8/3.0/2.6
	Length of growing season					
Annual/A2	38	42	39	36	42	42
Annual/B2	36	38	33	33	33	37

All changes of temperature are statistically significant at $p < 0.05$

Table 4 Changes in the amount of precipitation (in %) and heavy rainfall (in number of days) of the period (i.e. in excess of 10 mm per day) between the scenario and control period.

Period or season / scenario	River basin					
	Imula	Dursupe	Bērze	Iecava	Vienziemīte	Salaca
Precipitation						
Annual / A2	11*	12*	12*	9*	10*	12*
DJF / A2	64*	66*	69*	51*	47*	55*
MAM / A2	14	7	13	12	16	11
JJA / A2	-9	-1	-6	-2	-1	3
SON / A2	-2	-2	-3	-8	-6	-2
Heavy rainfall						
Annual / A2	37	59	29	66	120	65
Annual / B2	54	52	44	45	79	59

* Change of amount of precipitation is statistically significant at $p < 0.05$

Table 5 Changes in evapotranspiration values (in %) between the scenario and control period.

Period or season / scenario	River basin					
	Imula	Dursupe	Bērze	Iecava	Vienziemīte	Salaca
Annual / A2	25*	24*	23*	22*	28*	28*
DJF / A2	353*	292*	319*	427*	805*	495*
MAM / A2	46*	46*	42*	32*	64*	46*
JJA / A2	-2	-1	-2	2	-1	9*
SON / A2	20*	25*	21*	21*	28*	35*
Annual / B2	18*	17*	16*	15*	27*	19*
DJF / B2	195*	152*	169*	219*	789*	272*
MAM / B2	31*	32*	27*	23*	60*	32*
JJA / B2	0.4	0.09	-0.3	1	-0.4	6*
SON / B2	23*	21*	24*	17*	31*	24*

* Change is statistically significant at $p < 0.05$

The average increase in the annual mean minimum temperature by 8.0–9.6°C is forecasted according to A2 scenario and by 5.4–7.3°C according to B2 scenario. Also, the length of the growing season, when the daily mean temperature exceeds 5°C, will increase from 36 to 42 days according to A2 scenario and from 33 to 38 days according to B2 scenario. We also define heavy rainfall as precipitation exceeding 10 mm per day. The number of days with heavy rainfall during a period of thirty years will increase from 37 to 120

days according to A2 scenario and from 44 to 79 days according to B2 scenario. Hence, the days with heavy rainfall will occur more frequently.

The seasonal analysis of the mean air temperature indicate a statistically significant increase in all seasons, but the most significant increase is forecasted for winter (DJF) and autumn (SON) seasons, i.e. by 4.4–4.9°C and 4.0–4.2°C accordingly based on A2 scenario, and by 3.0–3.4°C for both seasons based on B2 scenario. At the same time, the smallest change in temperature is predicted for summer (JJA), i.e. by 3.0–3.6°C according to A2 scenario and by 1.3–1.9°C according to B2 scenario accordingly. Similar significant changes in seasonal patterns can be forecasted for all river basins in relation to the mean maximum and mean minimum temperature according to both scenarios, although the maximum temperature will increase at a higher rate during autumn, and the minimum temperature will increase during winter and autumn. This can be seen from the example of the Imula river basin (Fig. 4).

For both scenarios A2 and B2 the following trends have been identified in the precipitation and evapotranspiration data series: the increase in the first half of the year, and the decrease in the second half of the year. A statistically significant increase in precipitation is predicted during the winter season (DJF) for all studied river basins, i.e. by 47–69% based upon to A2 scenario and by 27–38% based upon B2 scenario accordingly, while in other seasons the forecasted increase or decrease trends are not significant. The changes of evapotranspiration in the annual cycle and seasonality are much more linked to temperature. Therefore, the statistically significant increase in the evapotranspiration under both scenarios is observed for

the winter season, followed by spring and autumn. No statistically significant change for evapotranspiration is forecasted for summer. A typical distribution of the mean monthly air temperature, evapotranspiration, precipitation values and their changes between the

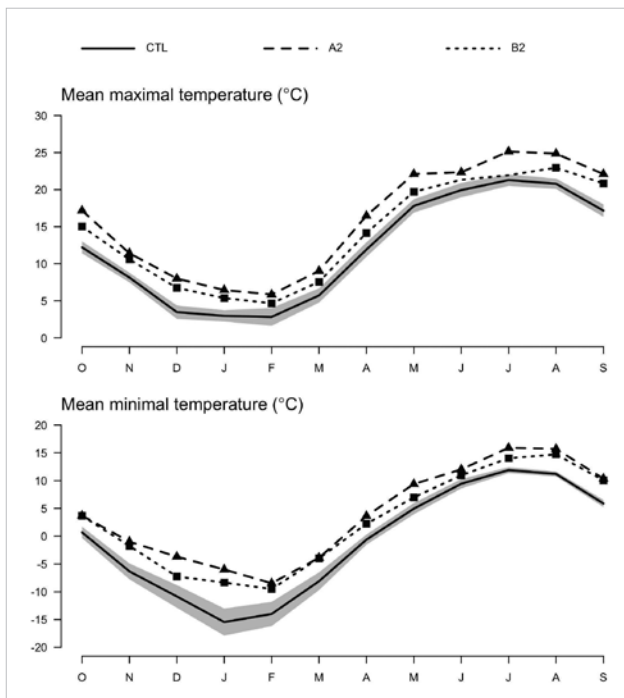


Fig. 4 Changes in seasonal patterns of the mean maximal and mean minimal temperature in case of the Imula river basin. The grey area shows 95 % confidence interval for the mean values of control period; this note refers also to the Figures 5, 6 and 7. Compiled by D. Elferts, 2012.

climate scenarios and control periods can be seen from the example of the Bērze river basin (Fig. 5).

Changes in river runoff

The simulation results of the HBV hydrological model indicated that the river runoff regime will change according to both scenarios – A2 and B2 in all the 6 river basins (Fig. 6). As mentioned above, regarding the temperature and the precipitation, also the major changes in river runoff are predicted according to A2 scenario. The mean annual discharge is predicted to decrease by 8–15% according to A2 and by 3–18% according to B2 scenario. However, a statistically significant decrease (by 18% according to B2 scenario) is observed only for the Vienziemīte river basin (Table 6). As it can be seen in Fig. 6, the major change in the seasonal river runoff was identified between winter and spring streamflows. In winter, due to the increase of the air temperature and precipitation, the statistically significant increase in the river runoff is predicted: by 34–93% based upon A2 scenario (observed for all river basins) and by 17–46% based upon B2 (observed only for the rivers Vienziemīte and Imula) accordingly, followed by a 26–40% decrease in spring river runoff according to A2 scenario (observed for all river basins) and 13–33% decrease according to B2 scenario

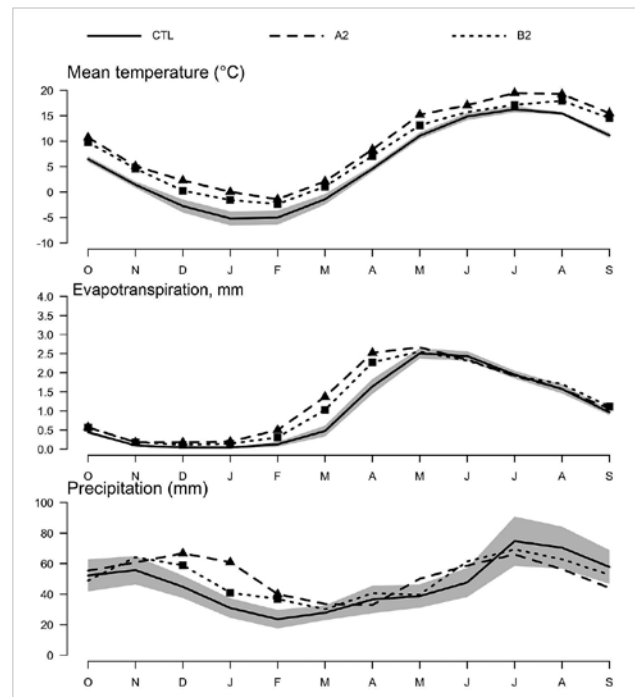


Fig. 5 Annual cycle of hydrological year and changes of mean air temperature, evapotranspiration and amount of precipitation in the Bērze river basin. The black triangle and square for the respective scenario present statistically significant changes in monthly mean value of the parameter. Compiled by D. Elferts, 2012.

(observed for the rivers Iecava and Vienziemīte). The highest increase in the runoff is forecasted for January

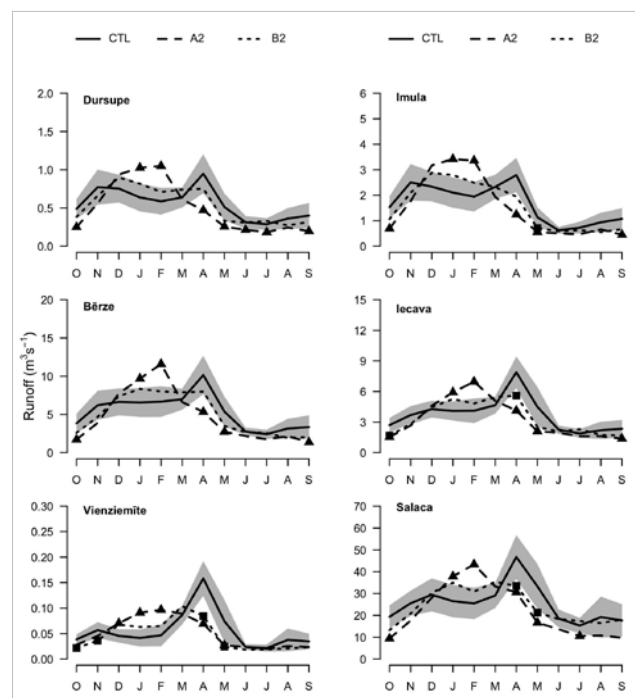


Fig. 6 River hydrograph of a hydrological year from October to September for the control (CTL) and 2 scenario (A2 and B2) periods in studied river basins. The black triangles and squares for the respective scenarios indicate statistically significant changes in the monthly mean value of the parameter. Compiled by D. Elferts, 2012.

and February, and the highest decrease is predicted for April and May. According to the forecasts of climate changes in the second half of the year, in most cases the decrease in the river runoff is predicted according to both scenarios. However, more considerable changes in the river runoff are predicted for the autumn season (especially for September and October) and according to A2 scenario (by 26–48%).

In all river basins similar changes are also forecasted in the seasonal mean maximum discharge (Fig.

the results are the same for the river Salaca; and the result is lower for the river Vienziemīte. Moreover, for both hydrological models one of the drawbacks of the calibrating of the model based upon daily observations is that the resulting hydrographs tend to be somewhat smoothed, as runoff peaks are dampened in the model, while low flows tend to be overestimated. We have obtained comparatively good calibration results for the small and large river basins and calibration periods from 11 to 30 years which allow the use of the

hydrological model HBV in further study.

In order to compare the results of our studies with other recent studies (Rogozova 2006; Kriaučiūnienė *et al.* 2008; Beters, Sennikovs 2009; Kurpniece *et al.* 2010; Apsite *et al.* 2011) done in the East Baltic countries we have searched for similar studies dealing with predicted changes in the river runoff regime based on the climate data series taken from the RCM RAO. In an earlier study done in Latvia by Rogozova (2006), the results from two Latvian river basins, namely, the Irbe

Table 6 Changes in mean annual runoff (in %) between the scenario and control period.

Period or season / scenario	The river basin					
	Imula	Dursupe	Bērze	Iecava	Vienziemīte	Salaca
Annual / A2	-9	-10	-11	-11	-8	-15
DJF / A2	56*	52*	46*	40*	93*	34*
MAM / A2	-40*	-36*	-35*	-34*	-42*	-26*
JJA / A2	-29	-33*	-27	-18	-16	-34*
SON / A2	-43*	-39*	-48*	-36*	-26	-41*
Annual / B2	-6	-3	-7	-9	-18*	-5
DJF / B2	28*	22	19	17	46*	18
MAM / B2	-20	-13	-14	-20*	-33*	-17
JJA / B2	-23	-6	-14	-3	-30	-2
SON / B2	-25	-18	-30	-29*	-37*	-17

* Change is statistically significant at $p < 0.05$

7). Similarly to the mean annual river discharge, major considerable changes are forecasted according to A2 scenario, where the maximum discharge will increase by 26–45% in winter and decrease by 28–44% in spring and by 22–39% in autumn (Table 7).

The forecasted changes in the river hydrograph of the monthly mean and mean maximum discharges are presented in Figures 6 and 7. It is pronounced that in future two main periods will be distinguished in the river hydrograph, instead of the current four periods, i.e. a high flow period from November to April and a low flow period from May to October. In some cases the typical autumn discharge peaks will disappear, but the spring discharge peaks will shift to an earlier time, i.e. to February according to A2 scenario and mostly to December or March according to B2 scenario. It could mean that the winter low flow period will disappear, and the summer flow period will be more intense depending on the scenario.

DISCUSSION

Having analysed the calibration results and river runoff simulation of the HBV model in this study and the METQ2007BDOPT model by Apsite *et al.* (2011) regarding the same river basins, generally, we have obtained a slightly better calibration results with the HBV model for the rivers Imula, Bērze, Iecava;

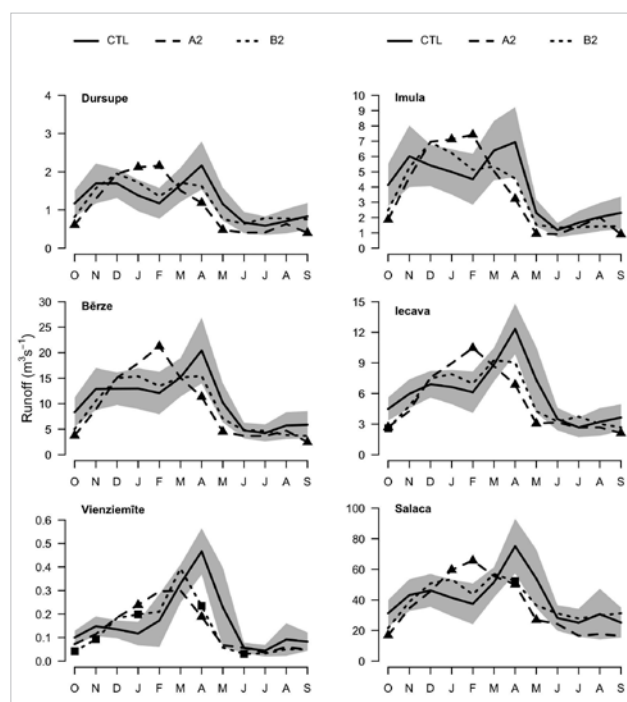


Fig. 7 Changes in the mean maximum discharge of a hydrological year for the control (CTL) and 2 scenario (A2 and B2) periods in studied river basins. The black triangles and squares for the respective scenarios indicate statistically significant changes in the monthly mean value of the parameter. Compiled by D. Elferts, 2012.

and the Gauja, have been compared, and the climate data series are based on the RCM RCAO using two different GCMs and emission scenarios (A2, B2) and the hydrological model HBV. She identified both increase (by 15% to 17% in case of using GCM ECHAM4/OPYC3) and decrease (by 7% to 2% in case of using GCM HadAM3H) trends in annual river runoff. It is concluded that the prediction of runoff changes may depend on the chosen GCM and the emission scenario in RCM RCAO.

In the studies by Bethers and Seņņikovs (2009) and Apsite *et al.* (2011), the prediction of runoff changes and the climate data series used was based on the RCM RCAO deriving from GCM HadAM3H and different emission scenarios (A2, B2). Bethers and Seņņikovs (2009) have predicted changes in river runoff regime with the hydrological model "MIKE Basin" for four river basins (Abava, Bērze, Salaca and Dubna) and using only emission A2 scenario. They have also concluded that there will be decrease in both the annual river runoff (but not more than by 25%) and the maximum river discharge (but not more than by 20%), and the regional differences in runoff will disappear or become smoother in the territory of Latvia.

More detailed analysis of the changes in the climate and hydrological parameters are provided in the study by Apsite *et al.* (2011) regarding the same river basins, except the Dursupes river basin, and the same climate data series are used. The hydrological modelling is performed with the model METQ2007BDOPT which, like the model HBV, belongs to the group of conceptual rainfall-runoff models. Generally, it has detected the same trends in the hydro-climate data in both annual and seasonal analysis, and regional distinction as well. However, there are instances which do not comply with our study results. In the above mentioned study (Apsite *et al.* 2011), the higher values of the increasing annual evapotranspiration (in particular, by 37–41% according to A2 scenario and 20–24% according to B2 scenario) and the most considerable changes in the second half of a year – in summer and autumn – have been predicted. This could be explained by the fact that different approaches are used for the calculation of the evapotranspiration data series and the structure of hydrological models, i.e. the HBV and the METQ2007BDOPT in the studies. Also, this fact could explain a slightly higher percentage in the predicted reduction of the annual (some seasonality as well) river runoff by Apsite *et al.* (*ibid.*), i.e. 13 to 24% according to A2 scenario and by 2 to 11% according to B2 scenario. Contrary to our study results, no change according to A2 scenario and an insignificant 10 % increase according to B2 scenario, for example, in the mean annual runoff for the Bērze River has been identified.

Kurpniece *et al.* (2010) has also found that the forecasted changes in the hydrological processes of river basins are closely related to meteorological conditions. In this study the future climate forecast is based on the climate models of the Denmark Meteorological Institute HIRLAM-ECHAM5, Norwegian Meteorological Institute HIRLAM-HadCM3 and Sweden

Meteorological and Hydrological Institute RCA3-BMC with the emission scenario A1B for the study period 2021–2050. The HBV model is calibrated and validated for the Aiviekste and Daugava river basins at the hydro power station Pļaviņas. The results have demonstrated that according to all the three scenarios for the period 2021–2050 the annual runoff will increase by 19–27%. The most remarkable increase in runoff is found for winter (DJF) season (by 30–70%). All scenarios indicate the decrease in runoff for the period April–May (by 6–39%), except the RCA3-BMC scenario which indicated a small increase of the runoff in the Daugava River in April.

If we compare the results of the recent studies carried out in other South-East Baltic countries in relation to climate change impact on hydrological processes the study by Kriaučiūnienė *et al.* (2008) in Lithuania should be mentioned. In the study of the Nemunas river basin, the climate data series from two GCMs – ECHAM5 and HadCM3 with different emission scenarios (A1B, A2 and B1) in feeding of the hydrological model HBV have been used for the five study periods from 2011 to 2100 (10 years each). Although different climate models and emission scenarios are applied, Kriaučiūnienė *et al.* (2008) study results are similar to our study results, i.e. the average annual runoff of the Nemunas River should decrease. Using different emission scenarios in Latvia and Lithuania, warmer winters are forecasted resulting in a considerable increase in river runoff due to the increase in the amount of precipitation when evapotranspiration is not very high. In addition, a considerable decrease in spring runoff and maximum discharge are also identified. Both increasing and decreasing tendencies of the Nemunas River runoff are predicted for summer and autumn (Kriaučiūnienė *et al.* 2008).

All the above mentioned studies have recognized that the increase of river runoff will be important during winter seasons due to the shortening of the period with snow and ice cover and the increase of the length of the growing season; also the spring runoff maximum will mostly decrease and shift to earlier periods. However, there are different predictions concerning the total annual river runoff, where the decrease of runoff is predicted in all the studies with the exception of the study by Rogozova (2006) in case of using GCM ECHAM4/OPYC3 in the RCM RCAO and Apsite *et al.* (2011) for the Bērze river basin, and these results comply with the results of our study.

CONCLUSIONS

In this research climate change impacts on hydrological processes in six Latvian river basins have been studied based on the regional climate model Rossby Centre Atmosphere Ocean from SMHI with driving boundary conditions from the global general circulation model HadAM3H and two IPCC emission scenarios A2 and B2 for the control period of 1961–1990 and the future period of 2071–2100.

Simulation results of the HBV hydrological model indicate that the river runoff regime will change according to both scenarios in all river basins. The decrease of the mean annual runoff due to significant increase in annual mean air temperature, precipitation and evapotranspiration is forecasted. If both scenarios are compared, a smaller change in climate parameters is identified according to B2 scenario. As regards the seasonal results, the major part of river discharge will be generated in winter due to warmer and wetter climate conditions, followed by spring, autumn and summer seasons. Similar to the situation with mean annual river discharge, the maximum discharge will increase in winter and decrease in spring and autumn, and major considerable changes are forecasted according to A2 scenario.

For both scenarios, A2 and B2, the increase in precipitation and evapotranspiration in the first half of the year and the decrease in the second half of the year have been identified. The increase of the annual mean air temperature is forecasted in all months, in addition, the days with heavy rainfall will occur more frequently during the year and the prolongation of the growing season is expected.

The comparison of the results of our study and other studies done in the Baltic countries indicate that, generally, we have detected the same trends in meteorological and hydrological data in both annual and seasonal analysis. The main tendency is as follows: a significant increase of the runoff during winter seasons due to the shortening of the period with snow and ice cover and the increase of the length of the growing season. Therefore, the spring discharge maximum will mostly decrease and shift to earlier periods.

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