Modeling future changes in the North-Estonian hydropower production by using SWAT

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ABSTRACT

Climate change is altering temperature, precipitation, and other climatic parameters, affecting sectors dependent on water resources, e.g. energy production. The purpose of this study is to analyze the possible influences of climate change on hydropower potential in North Estonia. In Estonian run-of-river hydropower plants, energy comes mainly from water volume. Thus, changes in hydropower production are related to changes in river runoff. The Soil and Water Assessment Tool (SWAT) model is used to study runoff responses to climate change in Kunda, Keila and Valgejõe river basins. A sequential uncertainty fitting algorithm is used for calibration and validation of hydrological models. Two modeling studies from EURO-CORDEX high-resolution simulations are used: RACMO regional climate model (RCM) from the Netherlands (KNMI) and HIRHAM5 RCM from Denmark (DMI). Hydrological model efficiency is evaluated with coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE) and percent bias (PBIAS). The NSE values range from 0.71 to 0.77 during calibration and validation. The PBIAS reveals no significant bias. Daily discharge data of the baseline period (1971–2000) and the future period (2071–2100) for KNMI and DMI scenarios reveal an overall increase in hydropower potential. Larger changes are predicted by the DMI model, while KNMI prediction is lower, 25% and 45% respectively.

Key words | climate change impact, Estonia, run-of-river, small hydropower plant, SWAT

INTRODUCTION

Small hydropower (SHP) has been a source of electricity generation in Europe since the beginning of 20th century. SHP represents about 9% of renewable and 1.2% of the total electricity generation in the European Union (Kougias *et al.* 2014). In 2010, Estonia had 47 SHP plants with a total installed capacity of 8 MW, the aim is to have 55 plants with a total installed capacity of 9 MW by 2020 (Liu *et al.* 2013). A renewable energy support scheme is interested in increasing the number of small or micro hydropower plants as a feed-in tariff or a fixed premium is legally meant to be paid by the utility (Liu *et al.* 2013). However, there exists a contradictory standpoint by public organizations referring to the very low hydropower share of total electricity production (less than 0.5%) in Estonia (Punys & Pelican 2007) and to the environmental considerations, i.e. the migration of fish being blocked or adversely affected by the hydraulic structures. Thus, an evaluation of the impacts of climate change on river discharge will provide valuable information to policy makers.

Estonian topography is relatively flat and rivers have small average slopes. There are over 7,000 rivers and streams in Estonia, however discharge of less than 50 rivers exceeds 2 m^3/s, and only 14 rivers discharge over 10 m^3/s (Raesaar 2006). Thus, as the hydroenergetic potential is proportional to the head and the rate of discharge of the water, large hydropower plants with a high dam and large reservoir for flow regulation cannot be utilized in Estonia. Nevertheless, there are many rivers suitable for small and micro hydro power plants. For example, in northern Estonia where the steep escarpment of the Baltic Klint is cut through by river valleys.

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Thus, due to the conditions described, hydro power plants in Estonia are mainly small, except the Narva Hydropower station which is owned by the Russian Federation and is operating in the border river. Small scale hydro power plants (SHP) are defined as 'run-of-river' plants which do not require a large impoundment of water, with little or no control of discharge, sometimes implementing diversion schemes to utilize the natural topographic gradient (Kumar *et al.* 2011). The energy comes mainly from the water volume and not from the head of water (Gaudard & Romeiro 2014).

SHPs are believed to be 'clean' and 'green' compared to large hydropower plants (Kumar *et al.* 2011), having conditionally low environmental impact (Gaudard & Romeiro 2014). However, lately this perception has been questioned (Premalatha *et al.* 2014). Estonian SHPs are facing many administrative barriers (ESHA 2012). To build and operate a hydropower plant, one needs a *Permit for the special use of water* (concession) which defines the permit owner's rights and obligations. The licensing procedure for the sector is time consuming. The authorization procedure takes from 4 months to 4 years. Concessions have a duration of only 5 years. Minimal residual flow is prescribed in the water use licensing procedure and is defined as a fraction of flow duration curve (95%). Mitigation measures, i.e. constructing fish passes, are often requested (ESHA 2012).

The 'run-of-river' hydropower plants are particularly dependent on river discharge. Thus, changes in pattern and amount of available water have a profound effect on hydropower generation. Possible changes in future water storage will differ from region to region around the globe. Li *et al.* (2015) used regional climate model (RCM) RegCM4 as a driving force to investigate the potential impact of climate change on hydrology over continental Southern Africa. By using the results from an ensemble of 16 or more CMIP3-CGCMs (coupled global climate models), Zhang *et al.* (2015) investigated how future changes in temperature and precipitation might influence total runoff in the headwaters of the Yellow River basin.

There have been several studies generalizing the impacts of climate change on hydropower by using the delta change approach (e.g. Lehner *et al.* 2005; Carless & Whitehead 2013; Gaudard & Romeiro 2014). Also the spatial resolution has been coarse (Lehner *et al.* 2005). The main objective of this study is to use daily generated climate data from the EURO-CORDEX (Coordinated Downscaling Experiment – European Domain) project and detailed spatial information to study future changes in the North-Estonian hydropower production.

METHODOLOGY

To evaluate the potential changes in hydropower production, the following main actions are taken (Figure 1). First, basins are selected and parameterized. Various data such as land use, elevation and soil are acquired. Secondly the historical climate and discharge (1970–2010) for hydrological model calibration and validation is obtained from the national weather service. Then all mentioned data are adjusted to hydrological model SWAT which is used to model river discharges for the historical period. Different model efficiency evaluation criteria are used to calibrate and validate the model against measured discharge to get a representative hydrological model for study areas. The

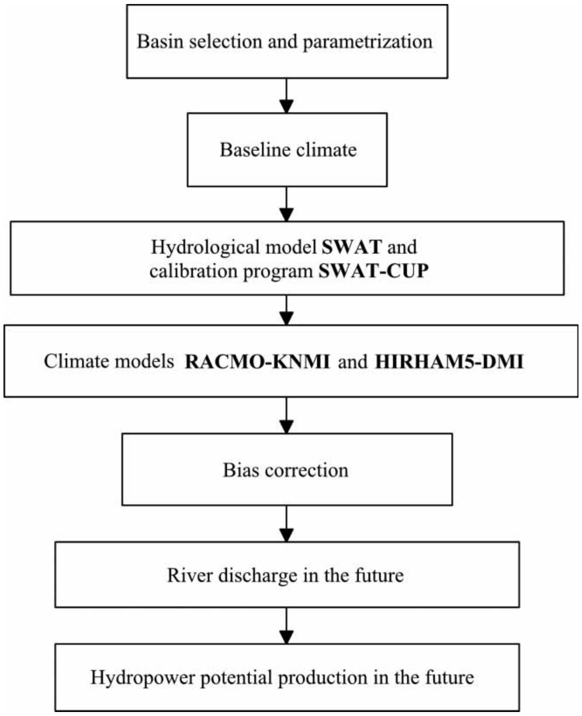

Figure 1 | Conceptual framework of the study to model future changes in the North-Estonian hydropower production.

RCM models RACMO-KNMI and HIRHAM5-DMI outputs (precipitation and temperature) are bias corrected. Bias corrected climate is used as input for the calibrated hydrological model, to model river discharges for the future period. Finally, the hydropower potential is calculated and the change is evaluated.

Site description

Keila, Kunda and Valgejõe River basins are chosen as study areas to represent climate change impacts on hydropower potential in North Estonia. The location of river basins are presented in Figure 2. Each of the river basins drain into the Gulf of Finland.

Keila has the largest watershed among the three study areas (Table 1). According to the land use and land cover database Estonian National Topographic Database, most common land use types in the three study basins being arable land, forested land and wetland. The dominant land use for all study areas is arable land, covering around 45–60% of the area. Kunda basin is only covered 5% by wetland, while the corresponding land use coverage in Keila and Valgejõe are 12% and 16%, respectively. Forested land accounts for 28%, 40% and 44% of the land surface in Keila, Kunda and Valgejõe, respectively. All case-study regions have relatively flat slopes, with an average slope of around 1%.

The average annual measured precipitation in Keila, Kunda and Valgejõe is 725 mm, 644 mm and 701 mm,

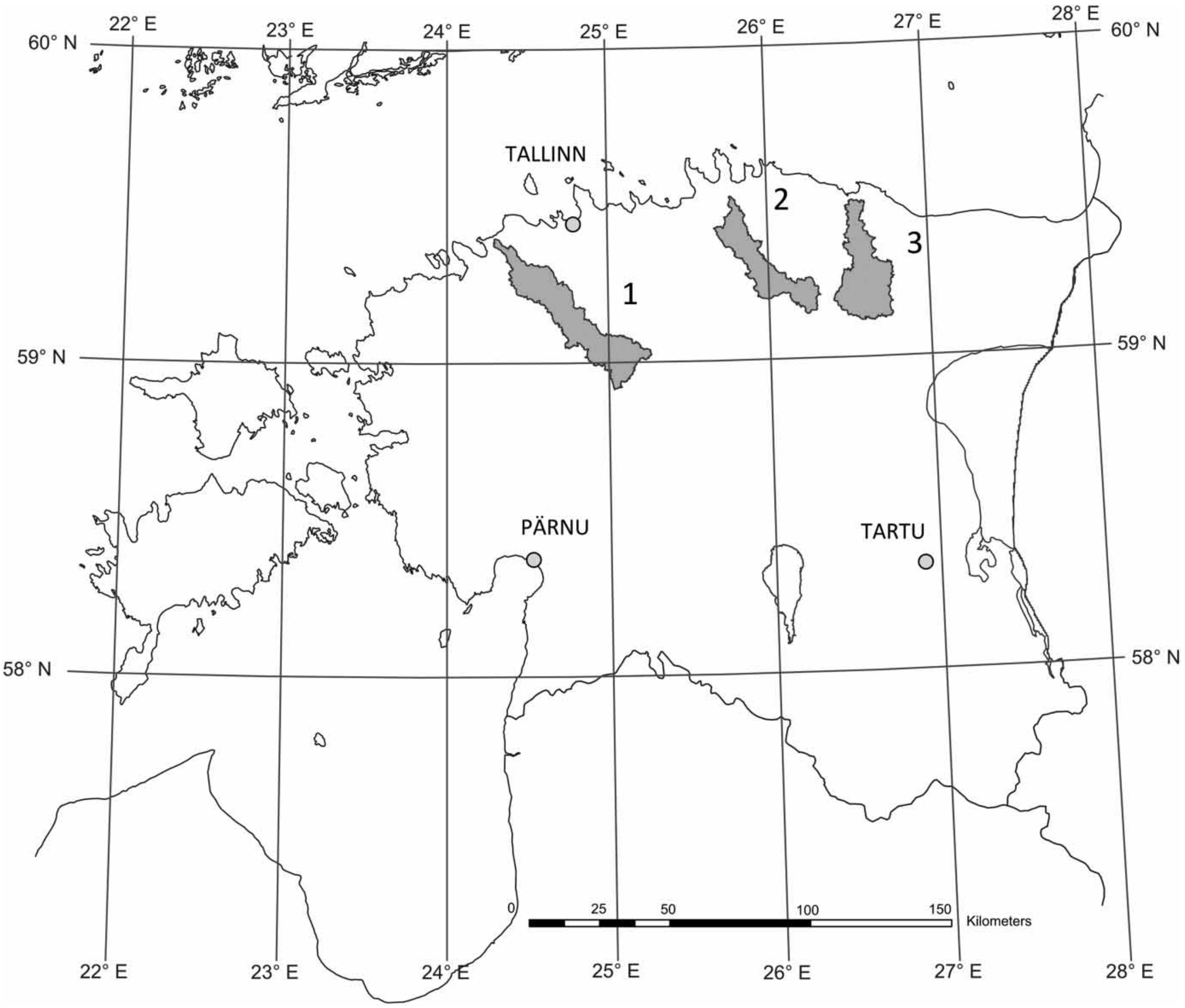

Figure 2 | Study area locations: 1-Keila; 2-Valgejõe; and 3-Kunda River basins.

respectively. Around 20% of precipitation is snowfall. Long-term average actual evapotranspiration rate is around 400 mm per annum. The average annual temperature during the baseline period 1971–2000 was 4.5 °C. The coldest month is February, with an average temperature of –6.6 °C, followed by January with an average temperature of –6.2 °C. The warmest month is July, with an average temperature of 15.8 °C.

Kunda river is the most challenging for simulation, since its flows are significantly affected by karstic aquifer. It is estimated that groundwater contributes over 50% of flow to the river discharge (HELCOM 2011). In Estonia, the typical river hydrograph has peak discharges in spring and fall, from which the spring is more abundant in water due to snow melt. Observed daily discharge data for the period 1970–2010 are available in all three study basins, which are used for model calibration and validation.

The first fully automatic hydropower plant was built in 1893 on Kunda River, where a Francis turbine with capacity of 210 kW was installed. Today Kaplan reaction turbines have been installed in all three plants. The SHP characteristics of the three basins are provided in Table 1.

Climate change

Climate impact assessment requires scenarios of future climate to be translated into potential changes in the quantity and timing of river runoff. Modeling results from the EURO-CORDEX project (Jacob *et al.* 2013) are used as future climate data input. EURO-CORDEX is part of CORDEX initiative (Giorgi *et al.* 2009), which coordinates regional downscaling of CMIP5 project to all terrestrial regions of Earth. Different institutions run their climate models on a similar grid within the EURO-CORDEX project, and make data available on the same grid. Therefore, it is possible to conduct a common model evaluation (Kotlarski *et al.* 2014) and provide common climate projections for climate change impact, adaptation and mitigation studies (Giorgi *et al.* 2009). Within the EURO-CORDEX project, models are being run with two resolutions: 50 and 12 km, and both cover all European land areas, the Black Sea, the Mediterranean Sea and Iceland. For the current project, two modeling studies are used from EURO-CORDEX high-resolution simulations: RACMO model with the boundaries from EC-EARTH r1i1p1 ensemble member from the Netherlands (KNMI) (Van Meijgaard *et al.* 2008) and HIRHAM5 model with the boundaries from EC-EARTH r3i1p1 ensemble member from Denmark (DMI) (Christensen *et al.* 2007).

While it could be argued that using the full available ensemble from EURO-CORDEX would be more informative, authors decided that two models are enough for the current study, as they already give quite different results and the analysis of a full model ensemble is a topic for further studies. RCP4.5 climate change (Figure 3) scenario was selected, as it is the baseline scenario in CMIP5 project and is supported by 20 climate modeling groups.

Climate models in general are mathematical representations based on physical principles which estimate higher for some climate variables (e.g. temperature) than for others (e.g. precipitation) (IPCC 2001). RCMs are known to be biased, causing even more uncertainties in the future hydropower potential change prediction. Despite biases, RCM's still produce variables which are physically coherent. Muerth *et al.* (2013) found that bias correction of regional climate simulations provide a closer to reality representation of the climate in the use of hydrological models.

For the whole study region, both initial climate projections have cold biases year round. A larger bias is found during the spring and summer period, where it is around −2 °C according to RACMO-DMI and −3 °C according to HIRLAM5-KNMI. Both projections have cold biases of less than –1 °C for the rest of the period.

Table 1 | Physical and power characteristics of hydropower plants

Basin	Plant name	Area (km^2)	Capacity (kW)	H (m)	Hydrometrical station	Residual flow (m^3/s)
1. Keila	Keila Joa SHP	678	365	6.2	Keila	0.64
2. Valgejõe	Nõmmeveski SHP	405	370	8.6	Vanaküla	0.76
3. Kunda	Kunda SHP	492	336	6.4	Sämi	1.44

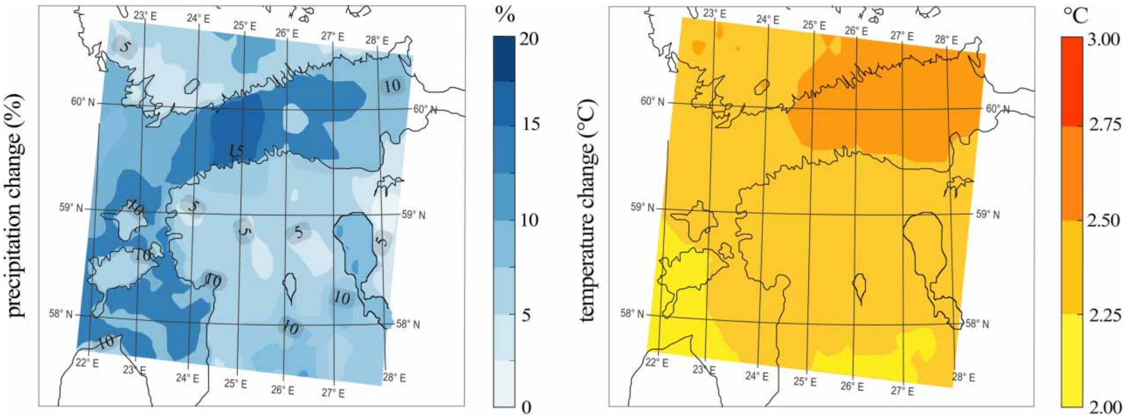

Figure 3 | Difference between the average precipitation (left) and temperature (right) in the period 2071–2100 and in the period 1971–2000 obtained from the RCP4.5 model for the study area.

The precipitation amounts in RACMO-DMI are overestimated in winter and spring, while HIRLAM5-KNMI overestimates in winter and underestimates during summer months. In terms of average annual precipitation, there is a clear overestimation of around 100 mm by RACMO-DMI model. There is a tendency of both climate model projections to simulate too many low-intensity rain events.

Near-surface air temperature is modified by monthly additive correction. The local intensity scaling method (LOCI) (Widmann *et al.* 2003; Schmidli *et al.* 2006) is used as a bias correction method for precipitation. The LOCI method improves the possible positive bias towards wet-day frequencies, thus reducing excessive drizzle days and improving the overall hydrological cycle in the model. Both bias correction methods were used for their simplicity. Bias corrected temperature and precipitation for both historical projections are shown in Figures 4 and 5, respectively. It is assumed that the modeled climate bias behavior does not change with time. Named bias correction methods are used for future climate, which is used as input data for SWAT to model possible hydropower potential change in the future.

According to the output of both climate model projections, it is estimated that the average temperature will increase by 1.9 °C in KNMI and by as much as 2.5 °C in DMI by 2100 compared to the baseline period. The projected mean monthly temperature and precipitation are summarized in Figures 6 and 7. The most significant increase in temperatures is likely to happen during the winter months, where temperature of around 5 °C higher are predicted. No relevant changes in the average temperature will happen during summer months according to both climate models.

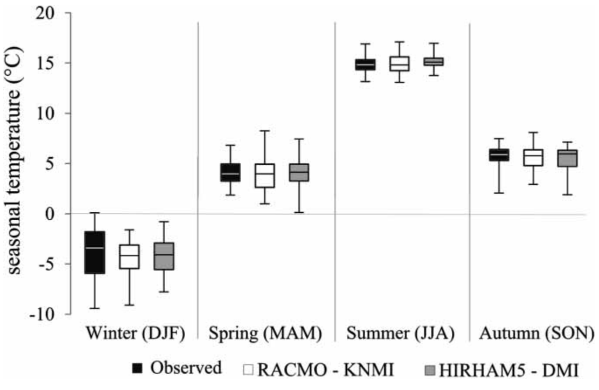

Figure 4 | Box plot showing bias corrected climate models (RACMO and HIRHAM5) ability to simulate baseline period (1971–2000) temperature seasonally.

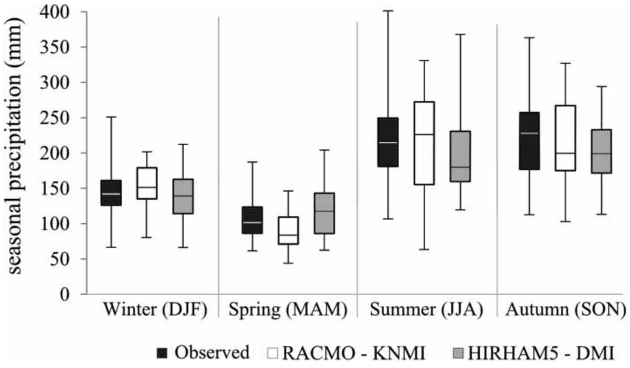

Figure 5 | Box plot showing bias corrected climate models (RACMO and HIRHAM5) ability to simulate baseline period (1971–2000) precipitation seasonally.

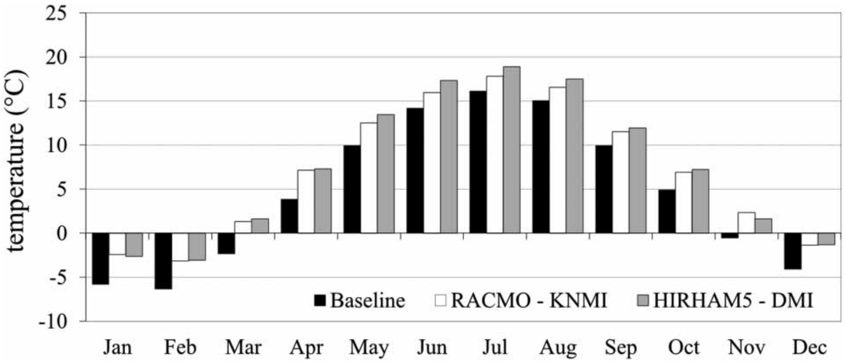

Figure 6 | Projected mean monthly temperature according to RACMO-KNMI and HIRHAM5-DMI climate models for 2071–2100 compared to the baseline period 1971–2000.

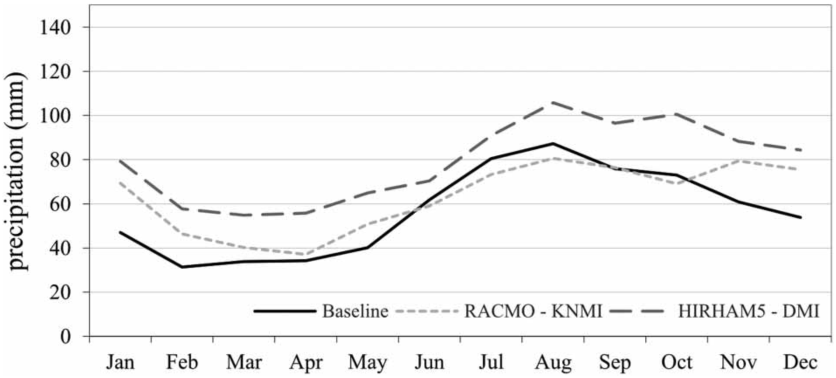

Figure 7 | Projected mean monthly precipitation according to RACMO-KNMI and HIRHAM5-DMI climate models for 2071–2100 compared to the baseline period 1971–2000.

KNMI tends to predict lower changes in temperature, compared to DMI. The DMI model predicts an overall 30% increase in precipitation, which means potentially higher flows throughout the year. The KNMI model predicts an overall 10% increase in precipitation, except for the summer months, where a slight reduction in monthly precipitation is expected. This suggests a reduction in summer runoff.

Hydrological model and inputs

The Soil and Water Assessment Tool (SWAT) (Arnold *et al.* 1998; Neitsch *et al.* 2005) was applied to simulate hydrologic processes in the three study basins. SWAT is a physically-based, semi-distributed hydrological model, which uses process-based equations to simulate different hydrologic responses. Although the model time step is daily, SWAT was designed as a long-term yield model and is not designed to simulate single-event flood accurately.

One of the reasons for selecting the SWAT model was that it has been widely and successfully used in snowmelt regions to simulate the hydrologic response (e.g. Abbaspour *et al.* 2007; Ahl *et al.* 2008). Furthermore it has also been used around the world for the estimation of climate impacts (e.g. Marshall & Randhir 2008; Ficklin *et al.* 2009; Franczky & Change 2009). The SWAT model has not been widely used as a tool for evaluating hydropower potential change (Haguma *et al.* 2014; Song *et al.* 2014).

SWAT requires a significant amount of data and parameters for development and calibration. These include a digital elevation map (DEM), land use map, soil map and weather data. Climate inputs consist of precipitation, solar radiation, maximum and minimum temperature, wind speed and relative humidity. In a SWAT model, a watershed is subdivided into a number of sub-basins, which are then further subdivided into hydrologic response units that consist of homogeneous land use, slope and soil characteristics.

In this study the daily maximum and minimum temperature, wind speed, humidity and solar radiation data are available for all study basins. Daily precipitation data were used from six meteorological stations. Daily discharge data are available for Kunda, Keila and Valgejõe river hydrological stations. A high-resolution DEM with a 10 m grid size derived from light detection and ranging was used. Due to the absence of realistic land use change scenarios in study basins, the same land use map was implemented in current study. This uncertainty has to be considered, while analyzing the results.

The SWAT model was calibrated and validated with the SWAT CUP software. For this the SUFI2 (Sequential Uncertainty Fitting) algorithm was used. In SUFI2, parameter uncertainty takes into account the various uncertainty sources like rainfall, measured data, etc.

Model evaluation criteria

Three different efficiency criteria are used to evaluate the model performance. These include: coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE) and relative BIAS (PBIAS).

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})^2}} \right)^2 \tag{1}$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2} \tag{2}$$

$$PBIAS = \frac{\sum_{i=1}^{n} (O_i - P_i)}{\sum_{i=1}^{n} O_i} \times 100\% \tag{3}$$

In the equations, O is measured and P modeled discharge values, n is the length of the time series. One of the major drawbacks of R^2 (Equation (1)) is the fact that only the dispersion is quantified. Thus a model which systematically over- or underestimates will still result in good R^2 values. This is the main reason why R^2 cannot be considered as a sole criteria.

The NSE (Equation (2)) is a normalized statistic that determines the relative magnitude of the residual variance ('noise') compared to the measured data variance ('information') (Nash & Sutcliffe 1970). As stated by Sevat & Dezetter (1991) NSE is the best objective function for reflecting the overall fit of a hydrograph. NSE is very sensitive to peak flows, at the expense of better performance during low flow conditions. Since the objective is to model hydropower potential change, where low flow does not play a key role, NSE and R^2 are appropriate to be used as qualitative model evaluation criteria.

PBIAS (Equation (3)) measures the average tendency of the simulated data to be smaller or larger than their observed data counterparts (Gupta *et al.* 1999). Simulation results are 'unsatisfactory' when PBIAS is larger than 25%. Values below 10% are considered to be 'very good'. Values ranging from 10% to 25% are rated from 'good' to 'satisfactory' during calibration and validation (Van Liew *et al.* 2007).

Hydropower

In Estonia most of the hydropower plants are classified as low head, with a head below 10 m. The energy comes mainly from the water volume and not from the head of water. In all study basins, Kaplan reaction turbines are installed. These are most suitable for low-head sites because of their higher specific speeds and flat efficiency curve where part-load performance is an important factor.

Kaplan turbine works between 30 and 100% of the maximum design discharge. These turbines have a high hydraulic efficiency in the range 70 to over 90%. Study basins plants are considered typical run-of-rivers with almost no storage capacity, thus electric output depends on the available water. During high flow periods, some of the potentially available hydropower cannot be harvested, while during low flow periods, the generating capacity will be low or no hydroelectricity is generated. The general formula for any hydropower system calculation is:

$$\mathrm{P} = \eta \times \rho \times \mathrm{g} \times \mathrm{Q} \times \mathrm{H} \tag{4}$$

where P is the mechanical power which is produced at the turbine shaft (watts), η is the hydraulic efficiency of the turbine, g is the acceleration due to gravity (m/s^2) and ρ is the density of water volume (kg/m^3), Q is the flow rate passing through the turbine (m^3/s) and H is the effective pressure head (m).

According to Equation (4) the changing flow rate and the hydraulic efficiency are functions from flow rate. These are the main parameters affecting the energy outcome from run-of-river hydropower plants. Thus a change in river flow rate, means a change in hydropower. In hydropower calculations, some limitations must be taken into account.

Hydropower plants in Estonia must guarantee a minimal residual flow (e.g. through the spillway), i.e. water cannot be extracted while river runoff is lower than minimal residual flow. The upper threshold for energy generation is limited by a maximum flowrate of the turbine. Thus the available water for energy generation is the range between the maximum flow rate of the turbine and available water for consumption. For efficiency reasons of the Kaplan turbines, only higher than 30% of the first turbine's maximum flow rate is extracted for energy generation. Technical parameters of hydropower plants and limitations by water permits have been implemented in the present study.

RESULTS

Calibration and validation of the hydrological model

A period of 1970–2010 is used to model the hydrology, from which the first 2 years are left for the model warm-up. The SWAT model is calibrated (1972–1997) and validated (1998–2010) for all study basins. Qualitative and quantitative statistical methods are utilized for model performance evaluation. Calibration and validation results reveal a good fit between the observed and simulated daily discharges (Table 2). Statistical criteria NSE values range from 0.71 to 0.77. The best fit between the observed and simulated flows are found in the Keila basin (Figure 8), where NSE values are 0.77 and 0.72 for calibration and validation, respectively.

Table 2 | SWAT model calibration and validation results

	Keila	Valgejõe	Kunda
R^2	0.78	0.75	0.77
NSE	0.77	0.74	0.73
PBIAS	0.5%	−1.4%	−3.2%
R^2	0.73	0.72	0.75
NSE	0.72	0.71	0.72
PBIAS	1.9%	−3.3%	−8.5%

Validation results show that the SWAT model can effectively represent the hydrological processes in the study basins. PBIAS reveals almost no bias for Keila river basin. PBIAS values for Kunda and Valgejõe indicate a slight model bias towards overestimation, however model performance is still considered 'very good' (Van Liew *et al.* 2007). Thus, the water balance for study basins is physically representative by the SWAT model.

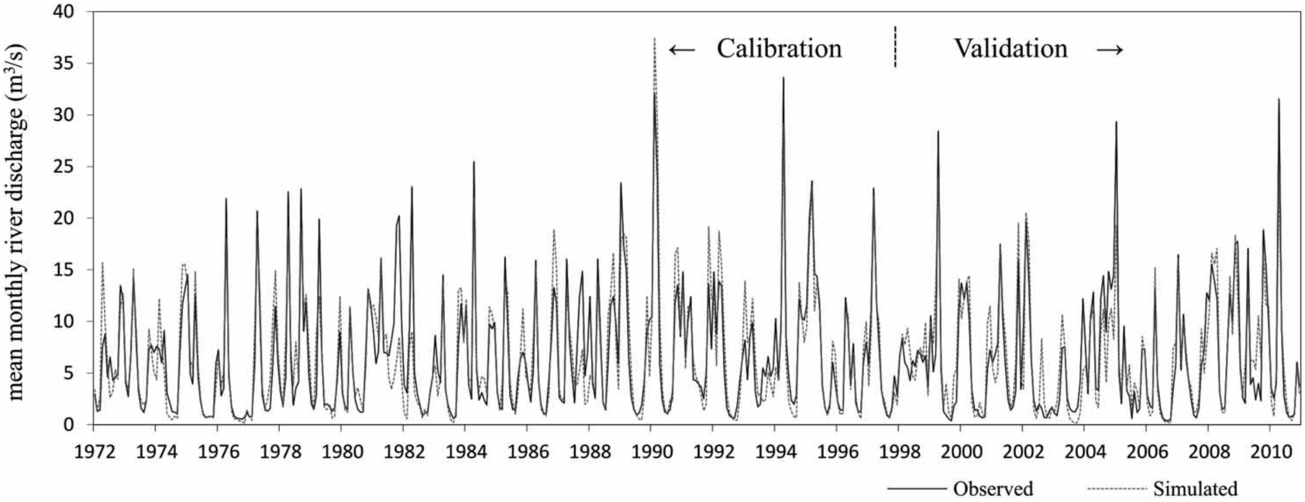

Figure 8 | Observed and simulated mean monthly discharge in Keila River for the calibration (1972–1997) and validation (1998–2010) period.

Tolson & Shoemaker (2004) stated that SWAT is not designed to simulate a single extreme event and the model usually underestimates largest flow events. A similar tendency is observed in this study. However, this underestimation does not significantly affect hydropower harvesting in the current study, because peak flows exceed maximum flowrate of the turbines.

Potential change of hydropower by 2100

The simulation results of the SWAT hydrological model indicate a change in river runoff for both climate scenarios. The mean increase in annual discharge of 15% and 55% was predicted for North Estonia by climate projections KNMI and DMI, respectively (Table 3). The spring peak in the study basins tends to occur earlier and be smaller compared to the baseline period. This pattern was more pronounced in the DMI climate projection, resulting from an increase in precipitation (Figure 7) and lesser winter snow accumulation. A significant increase in autumn discharge was projected by the same model.

Table 3 | Projected changes in runoff and hydropower potential

		Change (%)	
Hydroclimate	**Baseline**	**RACMO KNMI**	**HIRHAM5 DMI**
Keila River at Keila-Joa			
Mean annual runoff	6.8 m^3/s	10.0	54.2
Mean winter hydropower	305 kW	25.6	34.3
Mean spring hydropower	332 kW	7.7	19.6
Mean summer hydropower	99 kW	40.4	68.6
Mean autumn hydropower	237 kW	8.2	39.9
Mean annual hydropower	243 kW	16.8	34.1
Kunda River at Kunda Silla			
Mean annual runoff	5.2 m^3/s	21.5	57.5
Mean winter hydropower	127 kW	63.7	109.2
Mean spring hydropower	218 kW	26.4	24.5
Mean summer hydropower	73 kW	11.3	9.4
Mean autumn hydropower	118 kW	21.3	24.5
Mean annual hydropower	134 kW	32.1	42.6
Valgejõe River at Nõmmeveski			
Mean annual runoff	3.4 m^3/s	18.5	52.8
Mean winter hydropower	134 kW	69.6	122.3
Mean spring hydropower	218 kW	10.3	22.6
Mean summer hydropower	72 kW	32.0	42.7
Mean autumn hydropower	138 kW	5.3	57.4
Mean annual hydropower	141 kW	26.0	57.4

Coherence between changes in annual discharge and hydropower potential was evident with some exception. Flowrates exceeding installed hydro plant capacity cannot be used for hydropower harvesting. Keila River SHP is a good example of this behavior: hydropower potential is predicted to rise 17% and 34%, according to the KNMI and DMI climate projections, respectively. The projected changes in the hydropower potential were higher in Kunda and Valgejõe. Generally, significant increase in winter hydropower potential is modeled in SHP, where installed capacity is available (Table 3). Kunda SHP revealed a lower increase in hydropower potential for summer months, compared to Keila and Valgejõe SHP.

The amount of uncertainty involved in modeling of Kunda is higher because the physical groundwater system of the karst aquifer may behave unexpectedly.

DISCUSSION

Climate-induced changes in temperature and precipitation are the driving factors in modeling river runoff. According to the climate projections used, the impact on future river discharge in North Estonia can be remarkable. In the Baltic states, Bolle *et al.* (2008) found that annual river runoff is forecasted to increase in North Latvia, which agrees with the results of the current study. However another study by Apsite *et al.* (2010) predicts a decrease in annual river runoff. Contradicting results in Latvian river runoff can be explained by the use of different climate models, scenarios and assumptions. Kriaučiūnienė *et al.* (2008) predicted a remarkable increase in Lithuanian winter river runoff due to the shortening of the snow period, while spring runoff peak decreases and shifts to an earlier period by the end of the century.

A comprehensive study of the climate change impact on the hydropower potential in Europe by Lehner *et al.* (2005) suggests an increase in the hydropower potential in North Europe by the end of 21st century. In Finland and Sweden, the increased runoff will give potentially 19%

higher hydropower in both countries. Our results are in agreement with the findings of Lehner *et al.* (2005) who found an increase of 29% in Estonia whereas slightly higher hydropower potential was found in the current study with a mean value of 35% for North-Estonian study basins (Table 3).

High flow periods could be better exploited by increasing the number of turbines at SHP, i.e. increasing the installed capacity.

Future simulations do not take into account changes caused by climate change itself, e.g. land use and vegetation. El-Khoury *et al.* (2015) and Song *et al.* (2014) studies showed that land use change can influence future river discharge considerably. Combining the impacts of climate change, land use, technology and policy will help to improve prediction quality. In spite of the uncertainties in hydropower potential modeling, the results provide a sound basis to energy policy makers for river management in North Estonia.

CONCLUSIONS

In this study the impact of climate change on water resources in North Estonia was assessed. Keila, Kunda and Valgejõe study basins were selected, and basin scale hydrology was modeled with the hydrological model SWAT. Two different climate projections (RACMO-KNMI and HIRHAM5-DMI) were bias corrected and used as input for calibrated hydrological models. Change in hydropower potential for run-of-river hydropower plants was calculated from modeled river discharges.

Modeling results indicate an annual increase in water discharge and thus hydropower potential increases in all study basins due to the changes in climate. High flow periods could be better exploited by increasing the number of turbines at SHP. It can be concluded that the climate change impact on hydropower potential in North Estonia is likely to be positive.

The results provide a sound basis for energy policy makers towards river management in North Estonia. For future work, it is recommended to implement different land use change scenarios, taking into account developments in technology and policy.

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