Uncertainty Assessment of Climate Change Impacts on Hydrology: A Case Study for the Central Highlands of Vietnam

Dao Nguyen Khoi and Phan Thi Thanh Hang

Abstract This paper focuses on quantifying the uncertainty in climate change and its impacts on hydrology in the Srepok watershed in the Central Highlands of Vietnam. The uncertainty associated with the general circulation model (GCM) structure from a subset of CMIP3 (CCCMA CGCM3.1, CSIRO Mk3.0, IPSL CM4, MPI ECHAM5, NCAR CCSM30, UKMO HadGEM1, and UKMO HadCM3), SRES emission scenarios (A1B, A2, B1, and B2), and prescribed increases in global mean temperature (0.5–6 °C) using the soil and water assessment tool (SWAT) was investigated. For prescribed warming scenarios using HadCM3, linear decreases in mean annual streamflow ranged from 2.0 to 9.8 %. Differences in projected annual streamflow between SRES emission scenarios using HadCM3 were small (−3.8 to −3.3 %). Under the A1B scenario and 2 °C increase in global mean temperature using seven GCMs, there was substantial disparity, of −3.7 to 21.0 % and −6.0 to 16.1 %, respectively. It was concluded that, in the case of the Srepok watershed, the most important source of uncertainty comes from the GCM structure rather than from the emission scenarios and climate sensitivity.

Keywords Climate change · Srepok watershed · Streamflow · SWAT model · Uncertainty

D.N. Khoi (✉)
Faculty of Environmental Science, University of Science,
Vietnam National University, Ho Chi Minh City,
227 Nguyen van Cu Street, District 5, Ho Chi Minh City, Vietnam
e-mail: dnkhoi86@gmail.com

D.N. Khoi
Center of Water Management and Climate Change,
Vietnam National University, Ho Chi Minh City,
IT Park, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam

P.T.T. Hang
Institute of Geography, Vietnam Academy of Science and Technology,
18 Hoang Quoc Viet Street, Cau Giay, Hanoi, Vietnam
e-mail: hangphanvn@yahoo.com

© Springer International Publishing Switzerland 2015

S. Shrestha et al. (eds.), *Managing Water Resources under Climate Uncertainty*,
Springer Water, DOI 10.1007/978-3-319-10467-6_2

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) reaffirmed that global warming is occurring (IPCC 2007). It is widely acknowledged that climate change can affect the spatial and temporal distribution of water resources as well as the intensity and frequency of extreme hydrological events (Bae et al. 2011). Therefore, studies of climate change impacts on hydrology have recently become a hot topic. Evaluating the hydrological impacts of climate change is most commonly based on the use of a hydrological model with climate change scenarios derived from the general circulation model (GCM) forced with emission scenarios (Thompson et al. 2013). However, these results are rarely used by decision-makers and managers in managing and planning water resources because of the existence of uncertainties in assessments of climate change impacts on hydrology and the difficulty of quantifying these uncertainties (Bae et al. 2011).

Vietnam has experienced changes in climate that includes rising air temperatures and more variable precipitation. In the period 1958–2007, the annual average temperature increased by about 0.5–0.7 °C. The annual precipitation decreased in northern areas while increasing in the southern regions. On an average for the whole country, the rainfall over the past 50 years (1958–2007) decreased by approximately 2 % (MONRE 2009). These changes have impacted significantly on the availability of water resources in Vietnam. The studies on impacts of climate change on hydrology have also gained the attention of Vietnamese scientists, and most analyses of these studies in Vietnam have, to date, mainly focused on climate projection forced by individual GCMs or an ensemble of GCMs. For example, Kawasaki et al. (2010) used the HEC-HMS model feeding climate projections from the Japanese Meteorological Agency GCM for the SRES A1B scenario to assess the climate change impacts on water resources in the Srepok watershed. Thai and Thuc (2011) employed MIKE 11/NAM hydrological model and climate change scenarios of the Vietnam Ministry of Natural Resources and Environment (2009) downscaled by MAGICC/SCENGEN and PRECIS model from GCMs to evaluate the impacts of climate change on the flow in Hong–Thai Binh and Dong Nai River Basins. Khoi and Suetsugi (2012a, b) used the SWAT hydrological model and projected climate from an ensemble of four GCMs (CGCM3.1 (T63), GFDL CM2.0, GFDL CM2.1, and UKMO HadCM3) to estimate the projected river discharge in the Be River Catchment. In these studies, the uncertainty associated with the GCM structure has not been investigated yet. In fact, the projection of future climate (especially precipitation) from different GCMs often disagrees even in the direction of change (Kingston et al. 2011).

The main objective of this study is to estimate the uncertainty in projection of climate change on hydrology through the application of a range of climate scenarios[1] (obtained from the QUEST-GSI project; Todd et al. 2011) to the SWAT hydrological model; a case study for the Srepok watershed in the Central Highlands

[1] http://www.cru.uea.ac.uk/~timo/climgen/data/questgsi/, accessed June, 2011.

of Vietnam. The climate scenarios were generated from different GCMs, emission scenarios (A1B, A2, B1, and B2), and prescribed warming in global mean air temperature (from 0.5 to 6 °C), including a 2 °C threshold of "dangerous" climate change. Baseline climate was obtained from CRU-TS 3.0 dataset (Mitchell and Jones 2005) for the period 1971 to 2000.

The paper first presents a brief description of the watershed. A detailed description of the SWAT hydrological model and climate change scenarios is then presented. The paper concludes with a presentation of results and a conclusion.

2 Study Area

The Srepok watershed, a sub-basin of the Mekong River basin, is located in the Central Highlands of Vietnam and lies between latitudes 11°45′–13°15′ N and longitudes 107°30′–108°45′ E (Fig. 1). The Srepok River is formed by two main tributaries: the Krong No and Krong Ana Rivers. The total area of this watershed is approximately 12,000 km^2 with a population of 2.2 million (2009). The average altitude of the watershed varies from 100 m in the northwest to 2,400 m in the

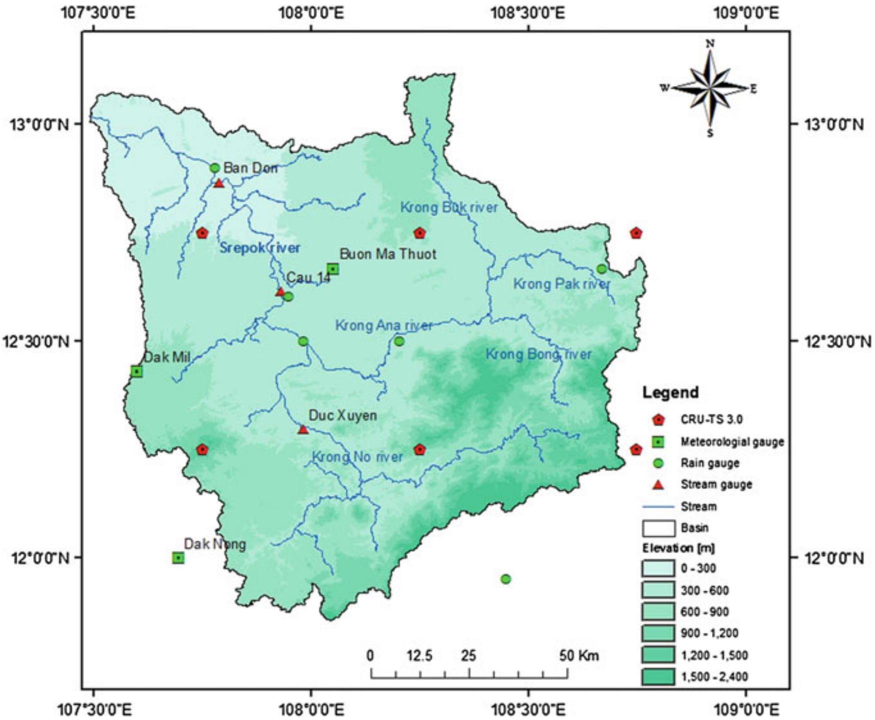


Fig. 1 Location of weather stations and CRU-TS3.0 grid points in the Srepok watershed

southeast. The climate in the area is very humid (78–83 % annual average humidity) with annual rainfall varying from 1,700 to 2,300 mm and features a distinct wet and dry season. The wet season lasts from May to October (with peak floods often in September and October) and accounts for over 75–95 % of the annual precipitation. The mean annual temperature is 23 °C.

In this watershed, there are two dominant types of soils: grey soils and red-brown basaltic soils. These soils are highly fertile and consistent with the agricultural development. Agriculture is the main economic activity in this watershed of which coffee and rubber production are predominant.

3 Methodology

3.1 The SWAT Hydrological Model

The SWAT model is a physically based distribution model designed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soil, land use, and management conditions over long periods of time (Neitsch et al. 2011). With this model, a catchment is divided into a number of sub-watersheds or sub-basins. Sub-basins are further partitioned into hydrological response units (HRUs) based on soil types, land use, and slope classes that allow a high level of spatial detail simulation. The model predicts the hydrology at each HRU using the water balance equation as follows:

$$\mathrm{SW}_t = \mathrm{SW}_0 + \sum_{i=1}^{t} \left(R_{\mathrm{day}} - Q_{\mathrm{surf}} - E_{\mathrm{a}} - w_{\mathrm{seep}} - Q_{\mathrm{gw}}\right) \tag{1}$$

Where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day 1 (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day *i* (mm H_2O), Qsurf is the amount of surface runoff on day 1 (mm H_2O), E_a is the amount of evapotranspiration on day 1 (mm H_2O), Wseep is the amount of water entering the vadose zone from the soil profile on day 1 (mm H_2O), and Q_{gw} is the amount of water return flow on day 1 (mm H_2O). A detailed description of the different model components can be found in the SWAT Theoretical Documentation (Neitsch et al. 2011).

The input required for the SWAT model includes a digital elevation model (DEM), a land-use map, a soil map, and weather data, which are shown in Table 1. Monthly streamflow data (1981–1990) measured at Duc Xuyen, Cau 14, and Ban Don gauging stations (Fig. 1) obtained from the Vietnam Hydro-Meteorological Data Center were used for calibration and validation of streamflow. Climate data for the Srepok watershed, including monthly minimum and maximum temperature, precipitation, and number of wet days, were obtained from the gridded (0.5° × 0.5°)

Table 1 Input data used in the SWAT model for the Srepok watershed

Data type	Description	Resolution	Source
Topography map	Digital elevation map (DEM)	90 m	SRTM
Land-use map	Land-use classification	1 km	GLCC
Soil map	Soil types	10 km	FAO
Weather	Monthly precipitation, minimum and maximum temperature	0.5°×0.5°	CRU-TS 3.0 Dataset

CRU-TS 3.0 observational dataset (Mitchell and Jones 2005). Monthly data for 6 grid cells (Fig. 1) that cover the watershed were disaggregated to daily data using a weather generator (MODAWEC model, Liu et al. 2009). In the MODAWEC model, daily precipitation was generated using a first-order Markov chain and exponential distribution based on the monthly precipitation and monthly wet days. Daily temperature was determined using a multivariate normal distribution based on monthly means of maximum and minimum temperatures and their standard deviations.

3.2 *Model Calibration and Validation*

In this study, the Nash–Sutcliffe efficiency (NSE) and percentage bias (PBIAS) were used to assess the model performance in flow simulation. The NSE determines the relative magnitude of the residual variance compared with the measured data variance, and the PBIAS measures the average tendency of the simulated value to be larger or smaller than their observed counterparts. The NSE value is defined by

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{N} (O_i - S_i)^2}{\sum_{i=!}^{N} (O_i - \overline{O})^2} \tag{2}$$

and the PBIAS value is defined by

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{N} (O_i - S_i) \times 100}{\sum_{i=1}^{N} (O_i)} \right] \tag{3}$$

Where 'O' is the observed discharge, S is the simulated discharge, and N is the amount of observed discharge data. According to Moriasi et al. (2007), the values of NSE greater than 0.5 and the PBIAS values of less than 25 % indicate satisfactory model performance for flow simulation.

Table 2 Hydrological model runs

Model	Scenario	Period	Description
HadCM3	A1B	2006–2100	Hadley centre model
HadCM3	A2	2006–2100	
HadCM3	B1	2006–2100	
HadCM3	B2	2006–2100	
HadCM3	+0.5 °C	2040–2069	0.5–6 °C increase in average global temperature
HadCM3	+1.0 °C	2040–2069	
HadCM3	+1.5 °C	2040–2069	
HadCM3	+2.0 °C	2040–2069	
HadCM3	+2.5 °C	2040–2069	
HadCM3	+3.0 °C	2040–2069	
HadCM3	+4.0 °C	2040–2069	
HadCM3	+5.0 °C	2040–2069	
HadCM3	+6.0 °C	2040–2069	
CCCMA CGCM31	A1B	2006–2100	
CSIRO Mk30	A1B	2006–2100	
ISPL CM4	A1B	2006–2100	
MPI ECHAM5	A1B	2006–2100	
NCAR CCSM 30	A1B	2006–2100	
UKMO HadGEM1	A1B	2006–2100	
CCCMA CGCM31	+2.0 °C	2040–2069	2 °C increase in average global temperature
CSIRO Mk30	+2.0 °C	2040–2069	
ISPL CM4	+2.0 °C	2040–2069	
MPI ECHAM5	+2.0 °C	2040–2069	
NCAR CCSM 30	+2.0 °C	2040–2069	
UKMO HadGEM1	+2.0 °C	2040–2069	
CRU dataset	Baseline	1970–2000	Control run

The SWAT flow predictions were calibrated against monthly flow from 1981–1985 and validated from 1986–1990 at Duc Xuyen, Cau 14, and Ban Don gauging stations. The simulated monthly flow based on station-based data matched well with the observed data for both calibration and validation periods with NSE and PBIAS varying from 0.70 to 0.90 and −8.0 to 3.0 %. In the of CRU dataset, the model performance over the calibration and validation periods for all gauging stations is satisfactory as indicated by the acceptable values of the NSE and PBIAS ranging from 0.52 to 0.66 and −14.5 to 8.3 %. In general, the agreement between the observed and simulated streamflow was calculated using CRU data as input is not as good as that obtained using station-based data. However, the simulated streamflow using CRU data can be considered reasonable. It can be summarised that the calibrated SWAT model can be used to simulate the impact of climate change scenarios.

3.3 Climate Change Scenarios

Future climate scenarios for temperature and precipitation were generated at a monthly scale using the ClimGen pattern-scaling technique described in Osborn (2009) and Todd et al. (2011). Scenarios were generated for (1) greenhouse gas (A1B, A2, B1, and B2) and (2) a prescribed warming of global mean temperature of 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, and 6 °C using HadCM3 GCM as well as (3) A1B emission scenario and (4) prescribed warming of 2 °C ("dangerous" climate change) using six additional GCMs: CCCMA CGCM3.1, CSIRO Mk3.0, IPSL CM4, MPI ECHAM5, NCAR CCSM3.0, and UKMO HadGEM1. These models were chosen following the analyses described by Todd et al. (2011) to span a range of "plausible" different modelled global climate futures (e.g. Indian monsoon weakening/strengthening and magnitude of Amazon dieback). Table 2 summarises the model runs that were evaluated.

4 Results and Discussion

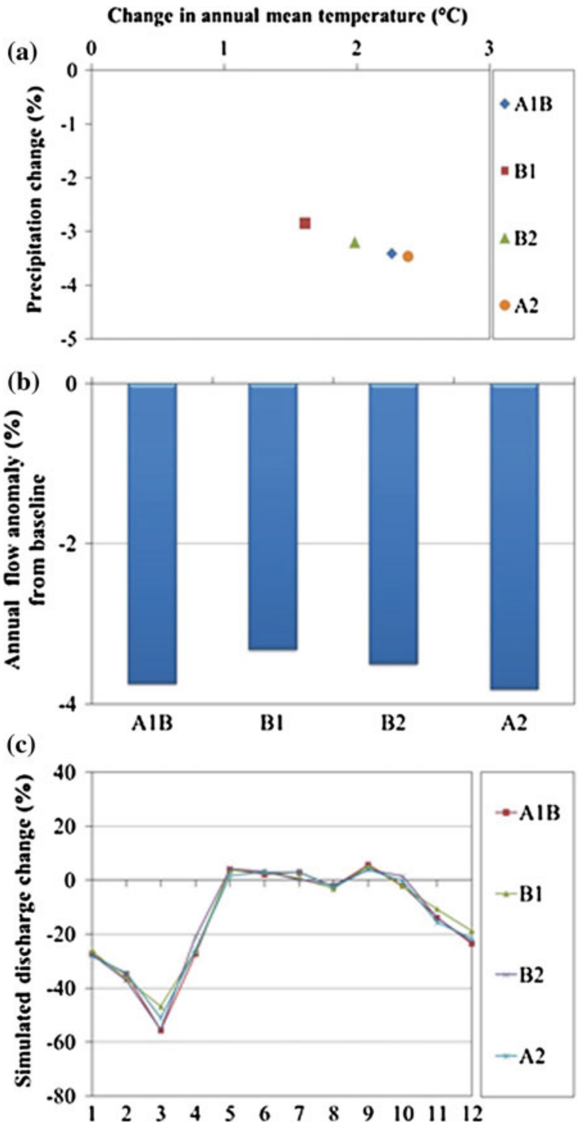
4.1 Uncertainty in Greenhouse Gas Emission Using HadCM3

Changes in mean climate associated with different SRES emission scenarios (A1B, B1, B2, and A2) using HadCM3 GCM are shown in Fig. 2a. Increases in mean annual temperature range from approximately 1.6 to 2.4 °C. Projected precipitation decreases by approximately 3 % with small variation between emission scenarios. In the case of the most severe emission scenario, A2, the temperature increase is highest (2.4 °C) and the precipitation decrease is largest (3.5 %) compared with the other scenarios (Fig. 2a). Figure 2b shows the projected changes in annual river discharge projected by HadCM3 for each of the four SRES scenarios. A decrease in annual river flow compared with the baseline is projected under four scenarios. The magnitude of decreases for annual river discharge ranges from 3.3 to 3.8 %. The projected monthly discharge under all four scenarios mostly decreases in the dry season and increases in the rainy season (Fig. 2c).

4.2 Uncertainty in Prescribed Warming Using HadCM3

Figure 3a indicates that the changes in air temperature are projected by HadCM3 to be linear with a rise in global mean temperature. Temperatures increase from 0.34 to 6.93 °C with an increasing global mean temperature of 0.2–6.6 °C. Annual precipitation is projected to decrease, relative to baseline, at a near-linear rate by 1.7–10.8 %.

Fig. 2 Projected changes (%) in **a** annual climate, **b** annual discharge, and **c** monthly discharge for HadCM3 GCM with different emission scenarios



Mean annual river discharge is estimated to decrease under the scenarios of prescribed increases in global mean temperature from 0.5 to 6 °C using HadCM3 (Fig. 3b). Decreases in mean annual river flow with increasing global temperature are nearly linear by 2.0–9.8 %. Figure 3c summarises the changes in monthly discharge for all nine scenarios. The monthly river discharge in the dry season (May–October) decreases dramatically from 1.3 % in October for the 0.5 °C scenario to 97.0 % in March for the 6 °C scenario, and monthly discharge in the wet season (November–April) also changes significantly from −8.4 % in September for

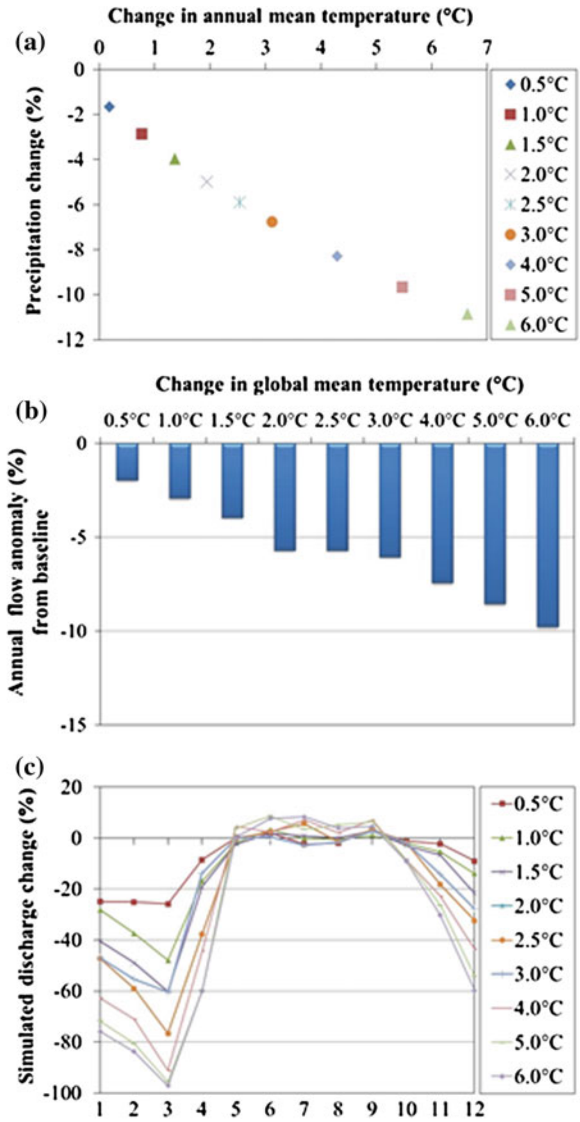


Fig. 3 Projected changes (%) in **a** annual climate, **b** annual discharge, and **c** monthly discharge for HadCM3 prescribed warming scenarios

the 6 °C scenario to 8.7 % in July for the 5 °C scenario. Uncertainty in predicted monthly river discharge increases with a rise in global mean temperature from the range of −26.0 to 2.0 % for the 0.5 °C scenario to the range of −97.0–4.3 % for the 6 °C scenario.

4.3 Uncertainty in the GCM Structure for the A1B Emission Scenario

Figure 4a shows the projected changes in climate associated with the A1B scenario from seven different GCMs. The projected annual temperature increases for all GCMs under the A1B scenario with the range from 1.1 to 2.3 °C. Projected changes

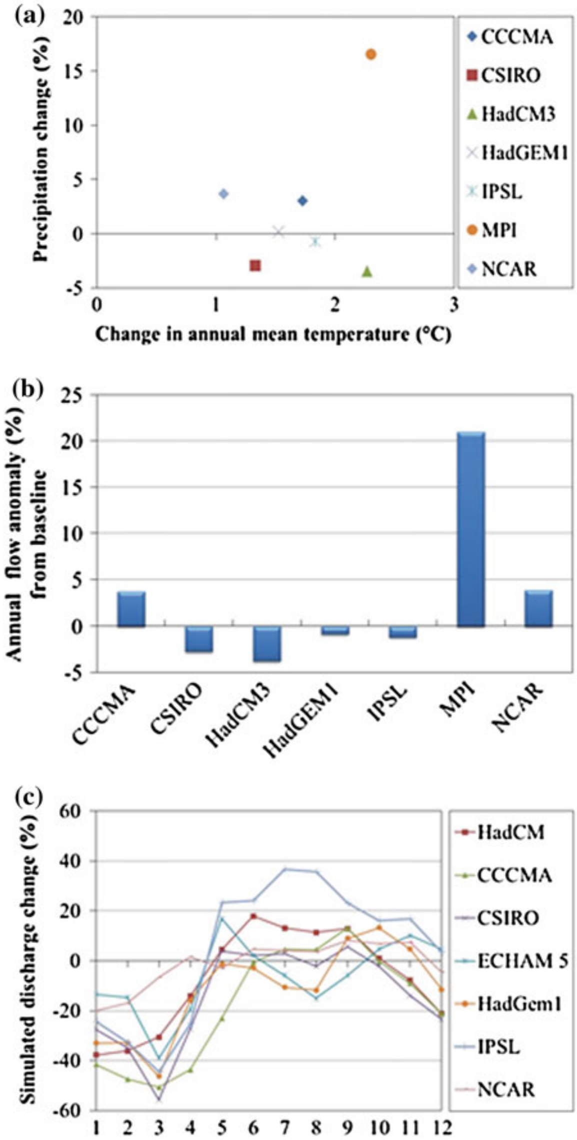


Fig. 4 Projected changes (%) in **a** annual climate, **b** annual discharge, and **c** monthly discharge under SRES A1B across 7 GCMs

in annual precipitation are small (within ± 4 %) for most GCMs except MPI GCM which shows a high increase (16.6 %).

Projected changes in annual river discharge show a substantial variation between GCMs as shown in Figs. 4b. Six GCMs (CCCMA, CSIRO, HadCM3, HadGEM1, IPSL, and NCAR) suggest that the river flow will change by small amounts (−3.7 to 3.9 % change compared with the baseline) while the MPI GCM shows a large

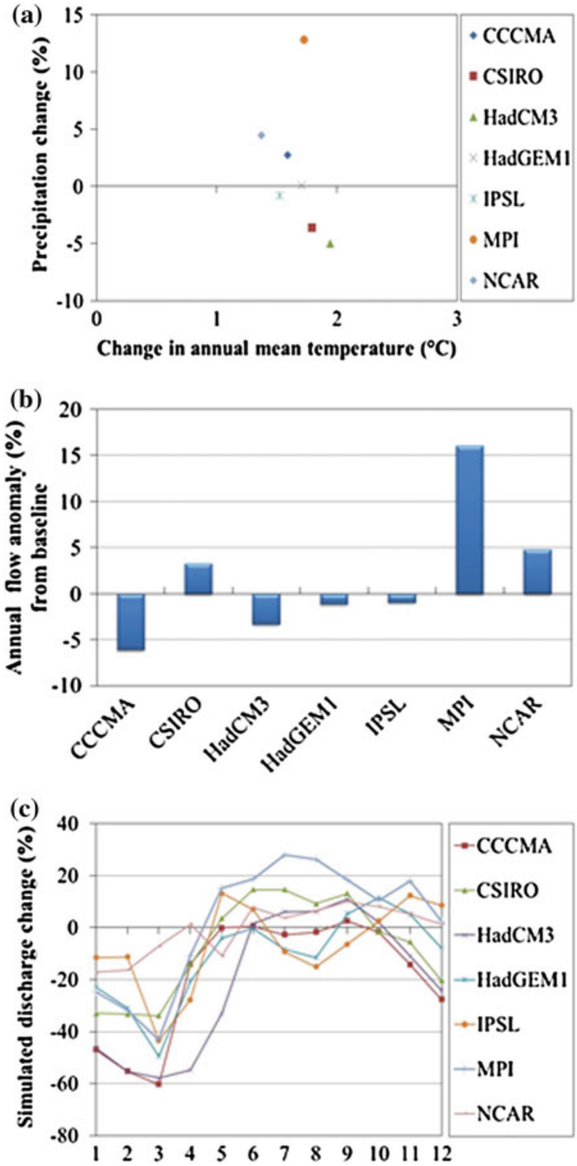


Fig. 5 Projected changes (%) in **a** annual climate, **b** annual discharge, and **c** monthly discharge under 2 °C warming scenario across 7 GCMs

increase of 21.0 % in river flow. Figure 4c shows that the projected increase or decrease in river discharge is evenly distributed over the year, high disparities in the wet season and small disparities in the dry season.

4.4 Uncertainty in the GCM Structure for a 2 °C Rise in Global Mean Air Temperature

Results from the seven different GCMs for the 2 °C prescribed warming in global mean temperature are shown in Fig. 5a. For annual temperature, all GCMs show increases of close to 1.8 °C, with variations between GCMs. The rise ranges from 1.4 °C for NCAR to 1.9 °C for HadCM3. Differences in annual precipitation between GCMs are larger than for temperature. The CCCMA, HadGEM1, MPI, and NCAR show an increase in precipitation of 3.0, 0.2, 16.6, and 3.7 %, respectively, whereas the CSIRO, HadCM3, and IPSL show decreases from 0.7 to 3.7 % (Fig. 5a).

Projected changes in mean annual river discharge under the prescribed increase in global mean temperature of 2 °C range considerably over the seven GCMs from −6.0 % (CCCMA) to 16.1 % (MPI); four GCMs (CCCMA, HadCM3, HadGEM1, and IPSL) predict slight decreases (0.9–6.0 %) in annual river flow, three GCMs (CSIRO, MPI, and NCAR) predict substantial increases (3.3–16.1 %) in annual river discharge (Fig. 5b). Figure 5c shows the projected changes in monthly discharge. The monthly river discharge shows high disparities in the wet season and small disparities in the dry season. In the case of the change in monthly discharge between GCMs, NCAR shows the smallest variation (−17.2–10.2 %) and MPI shows the largest (−43.2 to 28.0 %).

5 Conclusions

Uncertainty on the impact of climate change on the streamflow in the Srepok watershed in the Central Highlands of Vietnam associated with seven CMIP3/IPCC-AR4 GCMs, four emission scenarios, and prescribed increase of 0.5–6 °C in global mean temperature was investigated. In the case of a single GCM, HadCM3, streamflow decreases under both SRES emission scenarios (3.3–3.8 %) and prescribed increases in global mean temperature (2.0–9.8 %). In considering the GCM structure using the priority subset of seven GCMs, the projected changes in the streamflow under the A1B scenario range from −3.7 to 21.0 %. Under a 2 °C rise in global mean temperature, the projected changes in river discharge vary from −6.0 to 16.1 %. The above results indicate quite clearly that the greatest source of uncertainty regarding the impact of climate change on streamflow is the GCM structure (choice of GCM). This result is in accordance with the findings of Khoi and

Suetsugi (2012a, b) who conducted a similar study for the Be River Catchment in the south of Vietnam. The considerable disparity in projected streamflow produced by different GCMs emphasises the importance of using multi-model evaluations of climate change impacts on streamflow. This will help with future such studies in this area.

In the future, it will be necessary to perform other tests in various study areas of Vietnam to support the results and conclusions drawn from this research. Furthermore, the uncertainties of using different hydrological models and downscaling methods should be investigated to provide a useful guideline for evaluating the uncertainties in studies of climate change impacts on hydrology.

Acknowledgments This research is funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number "105.06-2013.09" and by the Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number "C2014-18-18."

References

Bae DH, Jung IW, Lettenmaier DP (2011) Hydrologic uncertainties in climate change from IPCC AR4 GCM simulations of the Chungju Basin, Korea. J Hydrol 401:90–105

IPCC (2007) The physical science basis: contribution of working group i to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Kawasaki A, Takamatsu M, He J, Rogers P, Herath S (2010) An integrated approach to evaluate potential impact of precipitation and land-use change on streamflow in Srepok River Basin. Theor Appl GIS 18(2):9–20

Khoi DN, Suetsugi T (2012a) Hydrologic response to climate change: a case study for the Be River Catchment Vietnam. J Water Clim Change 3(3):207–224

Khoi DN, Suetsugi T (2012b) Uncertainty in climate change impacts on streamflow in Be River Catchment Vietnam. Water Environ J 26:530–539

Liu J, Williams JR, Wang X, Yang H (2009) Using MODAWEC to generate daily weather data for the EPIC model. Environ Model Softw 24:655–664

Kingston DG, Thompson JR, Kite G (2011) Uncertainty in climate change projections of discharge for Mekong River Basin. Hydroly Earth Syst Sci 15:1459–1471

Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25:693–712

MONRE–Vietnam Ministry of Natural Resources and Environment (2009) Climate Change, Sea Rise Scenarios for Vietnam, Hanoi

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE 50:885–900

Neitsch AL, Arnold JG, Kiniry JR, Williams JR (2011) Soil and water assessment tool, theoretical documentation version 2009. Texas water resources institute technical report No. 406. Texas A&M University, Texas

Osborn TJ (2009) A user guide for ClimGem: a flexible tool for generating monthly climate datasets and scenarios, Climate Research Unit, University of East Anglia, Norwich

Thai TH, Thuc T (2011) Impacts of climate change on the flow in Hong—Thai Binh and Dong Nai river basins Vietnam National University. J of Sci Earth Sci 27:98–106

Thompson IR, Green AI, Kingston DG, Gosling SN (2013) Assessment of uncertainty in river flow projections for the Mekong River using multiple GCMs and hydrological models. J Hydrol 486:1–30

Todd MC, Taylor RG, Osborn TJ, Kingston DG, Arnell NW, Gosling SN (2011) Uncertainty in climate change impacts on basin-scale freshwater resources—preface to the special issue: the QUEST-GSI methodology and synthesis of results. Hydrol Earth Syst Sci 15:1035–1046

http://www.springer.com/978-3-319-10466-9

Managing Water Resources under Climate Uncertainty
Examples from Asia, Europe, Latin America, and Australia
Shrestha, S.; Anal, A.K.; Salam, P.A.; van der Valk, M. (Eds.)
2015, XLII, 438 p. 160 illus., 95 illus. in color., Hardcover
ISBN: 978-3-319-10466-9