Effects of Upstream Discharge and Climate Change on Hydraulic Regime in the Vietnamese Mekong Delta

Duong Tran Anh, Long Phi Hoang, Minh Duc Bui, and Peter Rutschmann

Abstract

The Mekong delta is one of the most complex river deltas in the world. This is due to its large area, crisscrossed network of rivers, canals, streams and ditches. This study quantifies the response of hydraulics in the Vietnamese Mekong Delta (VMD) to upstream discharge changes at Kratie and climate change variabilities of rainfall pattern as well as sea level rise. The 1D hydrodynamic model MIKE 11 is applied to simulate the discharge and the water level at certain number of main stations in the delta. Four scenarios of changing upstream boundary conditions with the predicted precipitation for the 2035–2065 period and sea level rise are employed. We downscaled and applied three bias-correction methods for five General Circulation Models (GCM) including ACCESS 1.0, CCSM4, CSIRO-Mk 3.6, HadGEM and MPI. The results showed that all precipitation projections of GCMs have similar trends of an increase in wet seasons and a decrease in dry seasons. For the hydrological assessment, the flow discharge at Kratie changes from +10% to -20% associated with precipitation variances, the discharge at four considered stations of the VMD will alter significantly for different scenarios. Furthermore, the predicted seasonal discharges of four main stations reduce substantially in the dry season in all scenarios while those increase in large range to smaller one in Hau River in the wet season.

Keyword: Hydraulic regime, Mekong delta, climate change, MIKE 11 modelling.

1. Introduction

The Mekong River basin is playing a major role in Southeast Asia with a length of 4800km and flowing through six riparian countries, including China, Myanmar, Laos PDR, Thailand, Cambodia and the Vietnamese Mekong delta (VMD), which are the core economic sectors encompassing agriculture, fishery, and forestry in the national income (MRC, 2010; Västilä et al., 2010; Dugan et al., 2010). Currently, the Mekong basin is dramatically suffering changes due to population increase and infrastructure development (Varis et al., 2012; Keskinen et al., 2012), which create high pressure on water resources management (Lebel et al., 2005; Piman et al., 2013). Projections of demographical growth and economic expansion lead to shortage and conflict of water resources demand among Mekong countries (Hoanh et al., 2010; Kingston et al., 2011). Moreover, reservoir development, operation and climate change are among major drivers of the future flow regime change in Mekong (Hoanh et al., 2010; Västilä et al., 2010). It is therefore necessary to evaluate and forecast the water resources in current and future conditions for a long-term sustainable development in this river basin.

The aim of our study is to assess the hydraulic regime in VMD by impacts of climate change using GCMs ensemble and changing the upstream discharge of Kratie. To achieve this aim, we selected a set of five GCMs for downscaling precipitation with two RCP scenarios from CMIP5 and applied a statistical downscaling and bias-correction on the GCM outputs. The downscaled GCM data for 2035–2065 and bias correction for daily precipitation were set up as boundary condition for the 1D hydrodynamic-MIKE 11 model to simulate the hydraulic regime on the main rivers. In addition, we used the predicted discharge at Kratie carried out by Hoang et al., (2015) and Lauri et al. (2012) to create different scenarios of the upper part flows. Our approach evaluates the combination of changing upstream discharges, the variabilities of precipitation and sea level rise by impacts of climate change on hydraulic condition in VMD.

2. Study area and Methodology

2.1. The Mekong River basin

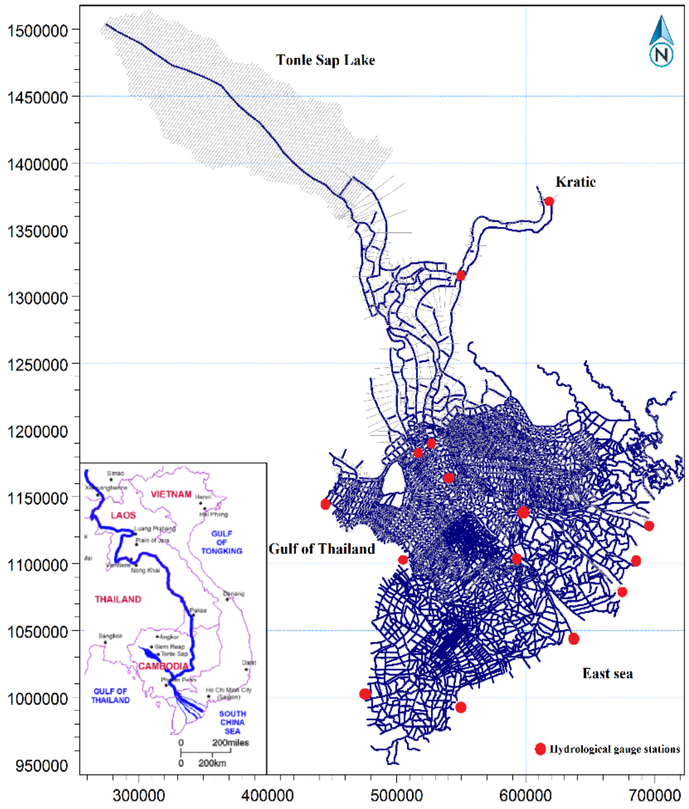


Fig. 1 Mekong river network and study area.

The Vietnamese Mekong river stems from Cambodia border, where the river splits into two primary distributaries, namely Tien and Hau rivers with a total area of 19 500 km^2 (MRC, 2007) (Fig. 1). The topography of VMD is relatively flat, most of the elevations are approximately 0.5m to 1.0 m above the mean sea level with complex channels network due to agricultural activities and transportation developments in a long period of time. The total length of the channels network is about 91,000 km. The VMD river network had highly complicated hydraulic conditions, which is influenced by the discharge at Kratie and Tonle Sap Lake and sea level along the South China Sea and Gulf of Thailand. The tidal regime in these seas have semidiurnal and diurnal tides (Nguyen and Savenije, 2006). The tidal amplitude fluctuations in the South China Sea is from 1.0m to 3.5m which leads to changes in daily water levels in the rivers, especially large oscillations in the dry season and significantly affected by the tidal regime (Van et al., 2012). Tien River carries about 80% of the total discharge of the entire delta. Hau River is linked to Tien River by Vam Nao River, and the annual discharge is about 1,500 to 6,500 m^3/s (MRC, 2007).

The hydrological cycle of VMD has specific characteristics driven by tropical monsoon climate with two prevalent directions such as the South-West and the North-East Monsoon (Costa-Cabral et al., 2007; Delgado et al., 2012). The South-East direction prevails from May to September, while the North-East Monsoon is strongly blowing from November to February (Hoang et al., 2015). The hydrological characteristics of VMD with two distinct flows hydrographs have been created from typical monsoon. Lager distributions of the annual discharge are significantly concentrated on the rainy season (July–December). Approximately 75 to 85% of the total annual flow in the rainy season leads to flood in large areas in the downstream delta (MRC, 2005; Hoang et al., 2015). However, the flooding could contribute the high fertile alluviums and fish productivity (Eastham et al., 2008).

2.2. Hydrodynamic model

MIKE 11 model is a commercial software package developed by Danish Hydraulic Institute and most widely applied one-dimensional dynamic model for complex rivers and channel systems. The model system has four editor interfaces including river network, cross sections, boundary conditions, simulation and designing with various modules including hydrodynamic (HD), the Advection Dispersion (AD), Water Quality (WQ), runoff and rainfall, non-cohesive sediment transport, and flood forecasting (DHI, 2007). The solution of continuity and momentum equations are employed as an implicit finite difference scheme with 6-point Abbott's scheme (Abbott and Ionescu, 1967).

2.3. Meteorological and climate data

The daily observed precipitation data during a period of 33 years (1978–2011) was taken from 20 provincial rain gauges of the Southern Regional Hydro-meteorological Center (SRHMC). The daily evapotranspiration is calculated by averaged mean values on of the whole gauging stations in VMD within 3 years (2009–2011). The hourly discharge and water level at ten stations were collected from the SRHMC and Southern Institute of Water Resources Research over a period of 3 years. The water demand for agriculture, industry and domestic use were collected from Southern Institute for Water Resources Planning in the period of 2005-2011. Water level time-series was observed at 10 main stations including Vung Tau, Vam Kenh, Binh Dai, An Thuan, Ben Trai, My Thanh, Ganh Hao, Song Doc, Rach Gia, and Xeo Ro. The hourly discharges were taken from Chau Doc, Tan Chau, Can Tho, and My Thuan stations during 2009 – 2011 for calibration and validation of the model. The cross sections and topography of the entire Mekong basin were obtained from numerous projects from 2005-2010.

The precipitation scenarios were generated from the CMIP5 using five GCMs: ACCESS 1.0, CCSM4, CSIRO-Mk 3.6, HadGEM and MPI (Tab. 1). The daily total precipitation was obtained from an approximately $1.25^o \times 1.9^o$ resolution of five GCMs outputs within two periods of 1978-2001 and 2035-2065. The bilinear interpolation is applied to downscale to $0.5^o \times 0.5^o$ gridded before obtaining bias correction process. Future climate scenarios for precipitation were generated using the best method of bias correction including Linear Scaling, Local Intensity Scaling and Distribution Mapping. Detailed information on three bias correction methods is available in Teutschbein et al., (2012).

2.4. Proposed modelling scenarios

Regarding to the previous study results, the high flood event in 2011 is selected as baseline and making the changes from -20% to +10% to generate four flows at Kratie. In this paper we follow the study of Lauri et al., (2012) and Hoang et al., (2015) (Table 2). The simulation of Lauri et al., (2012) described that the discharge at Kratie between the baseline (1982–1992) and projected time period (2032–2042) ranges from −11% to +15% for the wet season and −10% to +13% for the dry season and the changes in discharge due to planned reservoir operations are 25–160% higher during dry season flows and 5–24% lower flood peaks in Kratie. Hoang et al. (2015) also concluded that the discharge at Kratie is slightly increasing at 5% derived from five GCMs and two RCP4.5 and 8.5 scenarios but this study only simulated hydrological changing by climate change not involving the dam constructions and operations. Moreover, the similar finding pointed out that the discharge will be changed with lower flood peak and higher dry season flows (Kingston et al., 2011; Hoanh et al., 2010; Räsänen et al., 2012a).

For the climate change scenarios in terms of precipitation, two RCPs were selected namely RCP4.5 and RCP8.5. The RCP4.5 is a medium to low scenario assuming a stabilization of radiative forcing to 4.5 Wm^2 by 2100 (Thomson et al., 2011). The RCP8.5 is a high climate change scenario assuming a rising radiative forcing leading 10 to 8.5 Wm^2 by 2100 (Riahi et al., 2011). To simplify and reduce combined scenarios, we selected an average of the predicted sea level rise, an increasing 23 cm during the period of 2030-2040 and 35 cm within 2050 – 2060 (MONRE, 2012).

Tab. 1 Downscaled GCMs, emission scenarios used, and spatial resolution of each GCM.

GCM	Country	Emission Scenarios	Spatial Resolution
ACCESS 1.0	Australia	RCP 4.5, 8.5	$1.25^o \times 1.875^o$
CCSM4	NCAR/USA	RCP 4.5, 8.5	$0.94^o \times 1.25^o$
CSIRO-Mk 3.6	Australia	RCP 4.5, 8.5	$1.875^o \times 1.875^o$
HadGEM2-ES	Hadley/UK	RCP 4.5, 8.5	$1.25^o \times 1.875^o$
MPI-ESM-LR	Germany	RCP 4.5, 8.5	$1.875^o \times 1.875^o$

Tab. 2 Four scenarios of changing of discharges and sea level rise, and precipitation scenarios.

Scenarios	Sea level rise (cm)	Changes upstream discharge	Precipitation scenarios
Scen. 1	23	+10%	RCP 4.5, 8.5
Scen. 2	23	-10%	RCP 4.5, 8.5
Scen. 3	35	-15%	RCP 4.5, 8.5
Scen. 4	35	-20%	RCP 4.5, 8.5

2.5. Boundary conditions

Boundary conditions used for the MIKE 11 model include discharge at Kratie for the mainly upper boundary and sea water level in both West and East sea for lower boundary; wind, rainfall, and evapotranspiration for whole domain. Sea water levels used for prediction defined from the mean average forecasted tide in both East and West Seas for the period of 2009-2011. The precipitation from upstream Kratie was calculated and transferred to runoff by using NAM model and rainfall in VMD is also converted to runoff by NAM model. The water demand in VMD for 120 sub-basins was updated until the year of 2010 by Southern Institute for Water Resources Planning. Model boundary conditions extend a period of 2009-2011. The observed data is provided for calibration and validation during two periods from January to December 2011, and January 2009 to December 2010, respectively.

For initial condition, we run the model before simulation period to obtain steady flow, whereby the water level at different locations in river networks vary from 0.2 m to 0.5 m and set up the global value of water depths is 1.5 m. The initial discharge at main stations are set up as different values from 50 – 10,000 m^3s^{-1} based on multi-annual calculations.

2.6. Model calibration and validation

Flows in the entire VMD were calibrated by adjusting Manning coefficient for three main areas namely upper, middle and near the sea parts, the results are shown in Table 3. Chau Doc, Tan Chau, Can Tho, and My Thuan gauging stations were used as the main calibration points, which are the most important stations with considerable good accuracy. The matching between simulated and observed discharges and water level was evaluated using the Nash-Sutcliffe efficiency coefficient E (Nash and Sutcliffe, 1970), root mean square error (RMSE) and correlation coefficient (R). The robustness of the model calibration was carried out for the year 2011, since an extreme flood had occurred this year. The maximum values of E, RMSE and R are 0.93, 0.46, and 0.98 respectively whereas the minimum values are 0.85, 0.19 and 0.91 respectively for water level. Fig.2 shows exemplary the scatter plots of calibrated daily water level at Tan Chau (a) and Chau Doc (b). The calibrated model was then checked by validating the period of 2009 - 2010 using calibrated parameters, and comparing the fit from the validation period to the calibration period results for all stations. For the discharge at these four stations, the model underestimated flows in the dry season, and computed discharge peaks do not always matched the measured peaks (Fig. 3). For the validation period, the agreement between modelled and observed discharges is not quite good at the two middle stations (Vam Nam and Long Xuyen). Generally, the agreement between observed and modelled time series is satisfied for both the calibration and validation periods.

Tab. 3 Calibrated Manning's coefficient in distinct parts of basin

Components	**Manning's range**	**Remark**
1. Main Tien and Hau river	n = 0.017- 0.03	
- Upstream river	n = 0.028-0.03	Chau Doc to Long xuyen
- Middle delta	n = 0.022-0.026	Long xuyen to Can Tho
- Near the sea	n = 0.017-0.022	Dai Ngai to Tran De
2. Primary channels	n = 0.022-0.030	
3. Field channels	n = 0.028-0.032	
4. Floodplain	n = 0.028-0.032	

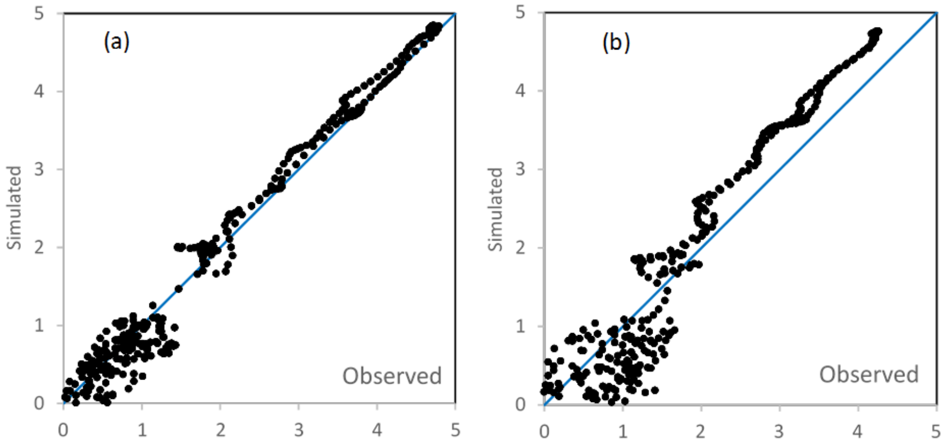


Fig. 2 Scatter plots of calibrated daily water level at Tan Chau (a), and Chau Doc (b)

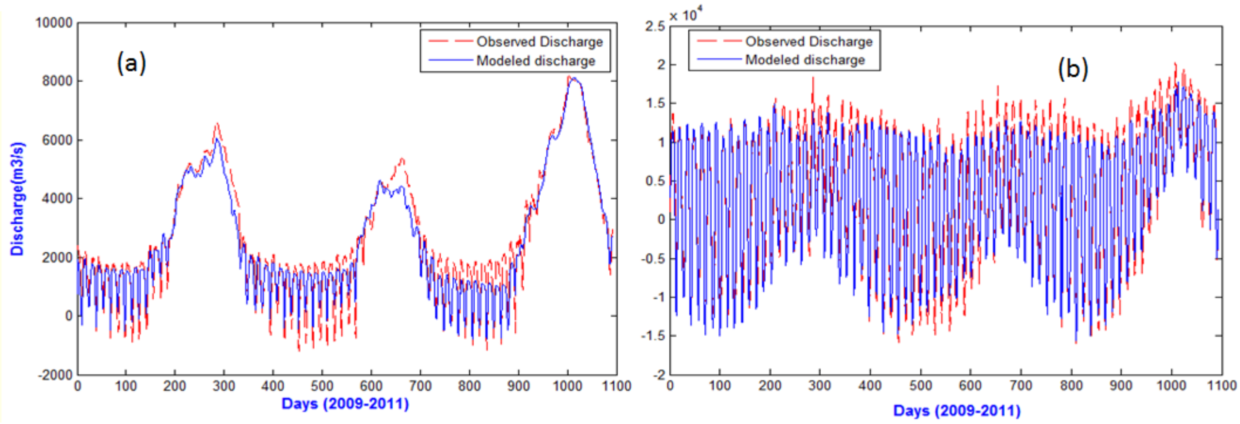


Fig. 3 Calibration and validation of daily discharge at Chau Doc (a) and Can Tho (b) for the period (2009 - 2011)

3. Results

3.1. Impact of climate change on precipitation

We analyzed future changes in precipitation projected by the GCMs and RCPs by comparing between the observed monthly baseline (1978 - 2001) and the predicted future line (2036 - 2065) period by applying statistical downscaling and bias correction methods (Teutschbein et al., 2012). Tab.4 shows the statistical performances of bias correction for five GCMs. In general, the predicted monthly precipitation in VMD due to climate change is projected to decrease in dry seasons (Jan – June) and increase in rainy seasons (July – Dec.) (Fig. 4). All five GCMs project higher monthly precipitation in the RCP8.5 compared to the RCP4.5. For instance, the RCP8.5 ensembles show an increase of 6.1% to 57.13% in rainy season and a decrease in -0.66% to -31.28% in dry season whereas the RCP4.5 ensembles project an increase of 8.03% - 34.33% in rainy seasons and a decrease of -6.1% to -19.79% in dry seasons. The trends of five GCMs differ among the individual GCMs and RCPs. GCM-CSIRO-RCP4.5 and HadGEM-RCP8.5 predict lowest average precipitation in dry seasons while the ACCESS-RCP4.5 and RCP8.5 project highest increase of +88.52%. The tendency of projected precipitation are relatively similar between individual GCM and scenarios, but extraordinary forecasting had resulted in CSIRO-GCM both RCP4.5 and RCP8.5 scenarios. It is therefore clear that the scenarios also show larger range of basin-wide precipitation changes under the RCP8.5 (i.e. between -87.39% and +88.52%) compared to that under the RCP4.5 (i.e. between -19.79% and 34.33%).

Tab. 4 Statistical performances of bias correction for five GCMs

GCM-Models	Can Tho			Chau Doc		
	RMSE (mm)	**MAE**	**R**	**RMSE (mm)**	**MAE**	**R**
ACCESS	8.30	5.85	0.994	6.90	4.65	0.992
CCSM	6.05	4.12	0.996	3.22	2.20	0.998
CSIRO	5.37	3.84	0.997	48.15	17.57	0.924
HadGEM	5.79	4.23	0.997	5.50	3.30	0.995
MPI	5.90	4.63	0.998	5.93	5.04	0.994

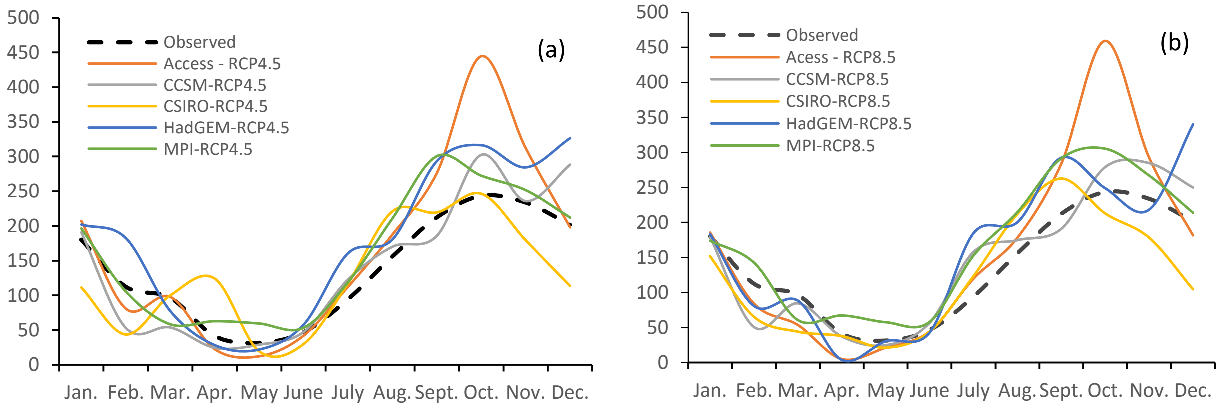


Fig. 4 Observed data for the period (1978 - 2001) and predicted precipitation at Can Tho station using RCP4.5 (a) and RCP8.5 scenarios (b) for the future (2036 - 2065)

3.2. Change in the flow regime with different scenarios

a) Scenario 1: The discharge at Kratie increase of 10% and sea level rise of 23 cm.

We consider the discharge at Kratie with the extreme flood event in 2011 as the baseline and we simulate the hydrodynamic situation for the duration (2035 – 2065). Fig. 5a presents the daily discharge at four main stations namely Chau Doc, Tan Chau, Can Tho, and My Thuan. Generally, the model underestimated substantially the discharge in the dry season at Tan Chau, My Thuan and Can Tho stations, whereas the model overestimates the discharge at Chau Doc station during monsoon period and has a contrasting tendency in dry season. For instance, the different ranges of monthly discharges largely vary from -20.2% to 122.23%, -5.04% to +19.71%, -18.06% to +18.12% and -39.55% to +117.80% comparing to the baseline at Chau Doc, Tan Chau, My Thuan and Can Tho stations, respectively (Tab.5). The predicted discharge at Chau Doc exhibits an increase from 9.18% to 122.23% during the wet reason. The three remaining stations (Tan Chau, Can Tho and My Thuan) have a similar decreasing trend for daily discharge in both dry and rainy seasons. In general, the annual flows of all stations tend to decrease upto 9.55%, 30.33%, 38.18% and 42.29% in Chau Doc, Tan Chau, My Thuan and Can Tho stations, respectively.

Fig. 6a shows changes in the computed daily water level comparing to the baseline under scenario 1. Overall, the model forecasts higher water level at Tan Chau and Chau Doc stations during rainy season and lower in dry season with a range between 0.04m and 0.5 m (for rainy season) and from -0.03 m to -0.41 m for dry season. The decreasing of water level at Long Xuyen and Can Tho ranges from 0.1 m to 0.3 m and 0.08m to 0.23 m, respectively.

b) Scenario 2: The discharge at Kratie decreases 10% and sea level rise of 23 cm

The results of the simulation under scenarios 2 presented in Fig. 5b and Fig. 6b, show the differences of forecasted discharges and water levels at the considered stations in Tien and Hau rivers. In this scenario, the discharges at Tan Chau, Can Tho and My Thuan decrease dramatically in both dry and wet seasons whereas the discharge at Chau Doc only decreases in dry season and increases up to 32.92% during the wet season. The changes of the daily discharge at these stations vary from -11% to -94.34%, -6.78% to -89.80%, -5.43% to -87.46% for Tan Chau, Can Tho and My Thuan, respectively. In addition, the relative changes of annual discharges reduce to -38.17% at Tan Chau, followed by -48.39% at Can Tho and -51.18% at My Thuan (Tab. 5). The water levels at Tan Chau and Chau Doc decreased with average values of 0.2m and 0.19 m in the dry season, respectively, while the predicted water levels at Long Xuyen, Can Tho and My Thuan decreased with average values of 0.46 m, 0.2 m, and 0.15 m in the rainy season, respectively.

Tab. 5 Changes in annual river discharges at four stations for the period 2035 – 2065 relative to the baseline 2011.

Scenarios	**Relative changes of annual discharge (%)**				**Relative change of annual water level (m)**			
	Tan Chau	**Chau Doc**	**Can Tho**	**My Thuan**	**Tan Chau**	**Chau Doc**	**Can Tho**	**My Thuan**
Scen. 1	-30.33	-9.550	-38.18	-42.29	0.39	0.03	-0.01	0.04
Scen. 2	-38.17	-23.48	-48.39	-51.18	0.09	-0.25	-0.08	-0.01
Scen. 3	-40.64	-27.23	-51.27	-54.03	0.10	-0.24	0.02	0.08
Scen. 4	-42.88	-30.89	-53.94	-56.33	0.02	-0.31	0.01	0.07

c) Scenario 3: The discharge at Kratie decreases 15% and sea level rise of 35 cm

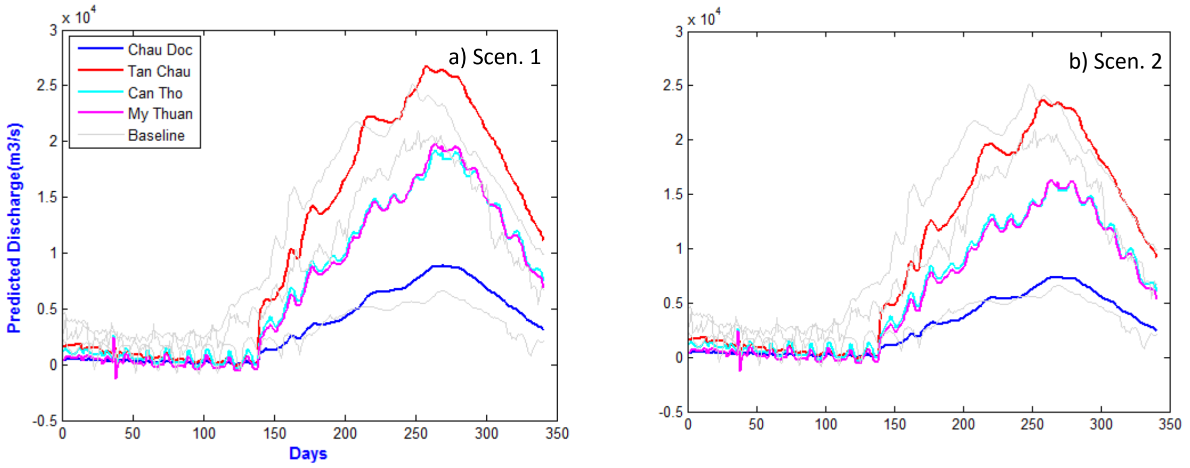
To examine the effect of climate change by changing the precipitation and sea level rise associated with flow variances in the upstream part of VMD, the simulations were carried out with the boundary condition described in the scenario 3. Generally, the annual discharges at all considered stations slightly reduce compared to the results of scenario 2. The differences of relative changes between scenario 2 and 3 are from 2.45% to 3.75%. The water levels at all considered stations slightly increase approximately 0.06 – 0.10 m compared to scenario 2. The tidal level is the main driving force for changing the water level at near sea stations (i.e. Can Tho and My Thuan).

d) Scenario 4: The discharge at Kratie decreases 20% and sea level rise of 35 cm

Under an extreme scenario, the discharge at Kratie will decrease 20% and sea level rise 35 cm at downstream boundary. Figs. 5d and 6d present the discharges and water levels at different stations. The flow discharges at these stations decrease substantially in dry seasons with a large range between -69.16% and -100.21% (Tab. 6), while in wet seasons the discharges slightly reduce roughly from 7.67% to 29.75%, except at Chau Doc station with an increasing of 7.25%. For instance, the discharge at Can Tho reduces up to 100% comparing to the baseline 2011.

Tab. 6 Changes in seasonal river discharges at four stations for the period 2035 – 2065 relative to the baseline 2011.

Scenarios	**Relative changes in dry season (%)**				**Relative changes in wet season (%)**			
	Tan Chau	**Chau Doc**	**Can Tho**	**My Thuan**	**Tan Chau**	**Chau Doc**	**Can Tho**	**My Thuan**
Scen. 1	-66.46	-65.75	-99.54	-79.70	5.81	46.66	23.17	-4.88
Scen. 2	-68.03	-68.00	-99.95	-81.25	-8.32	21.03	3.17	-21.11
Scen. 3	-68.75	-68.47	-100.10	-82.52	-12.52	14.01	-2.45	-25.55
Scen. 4	-69.16	-69.09	-100.21	-82.92	-16.60	7.25	-7.67	-29.75



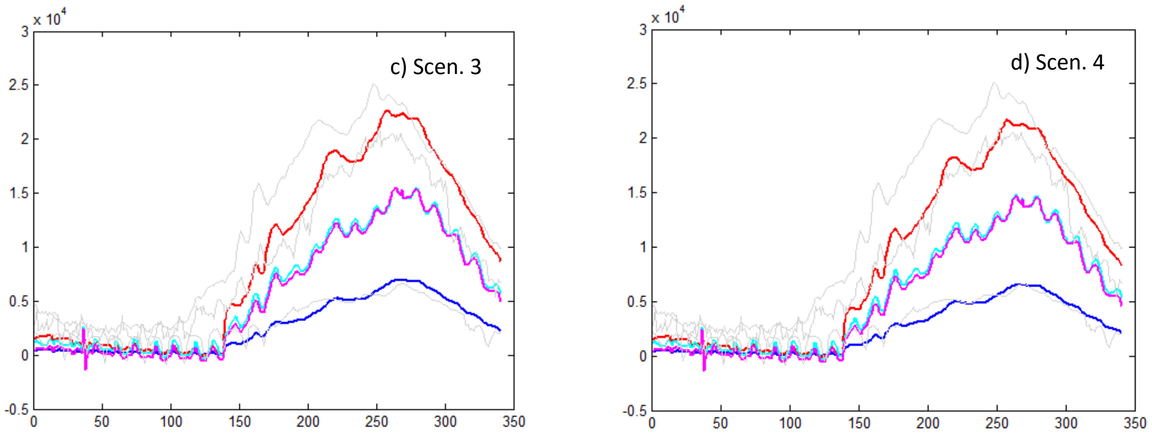


Fig. 5 Predicted discharges at four main stations in the period of 2035 – 2065 for different scenarios

4. Discussion

4.1. Impact of climate change on precipitation

Climate change leads to alter the rainfall patterns on global scale in general and in the Mekong delta in particular (Lauri et al., 2012; Hoanh et al., 2010). Precipitation is the primary driving force to change the runoff and surface water hydraulic regime at basin level. According to the downscaled results and bias correction of the GCMs used in this paper, precipitation in VMD is broadly prognosticated to decrease during dry season and to increase during wet season (Fig. 4). However, the downscaled results of the five different GCMs show large differences in the predicted results for all RCP simulations. It indicates high uncertainty not only in the magnitude, but also in the direction of hydrological behaviors due to climate change. It is therefore necessary to apply ensembles of GCMs and RCP scenarios to cover appropriate ranges of climate change (Christensen et al., 2006).

This study provides the updates and insight of climate change in VMD driven by five CMIP5-GCMs and different downscaled and bias correction methods. Furthermore, the results also contribute to the ongoing study of the effect of climate change on salinity intrusion in Hau River by using 2D-hydrodynamic models. In general, our derived precipitation downscaled from five GCMs and three bias correction methods are in line with the results conducted by most previous studies (Hoanh et al., 2010; Lauri et al., 2012; Västilä et al., 2010) for the entire VMD. It should be mentioned, that Hoanh et at. (2010) and Västilä et al. (2010) only used one GCM, so that their results did not reflect the considered uncertainties. Kingston et al. (2011) and Eastham et al. (2008) compared different GCMs, however non-downscaling model was applied to reduce the bias and uncertainties.

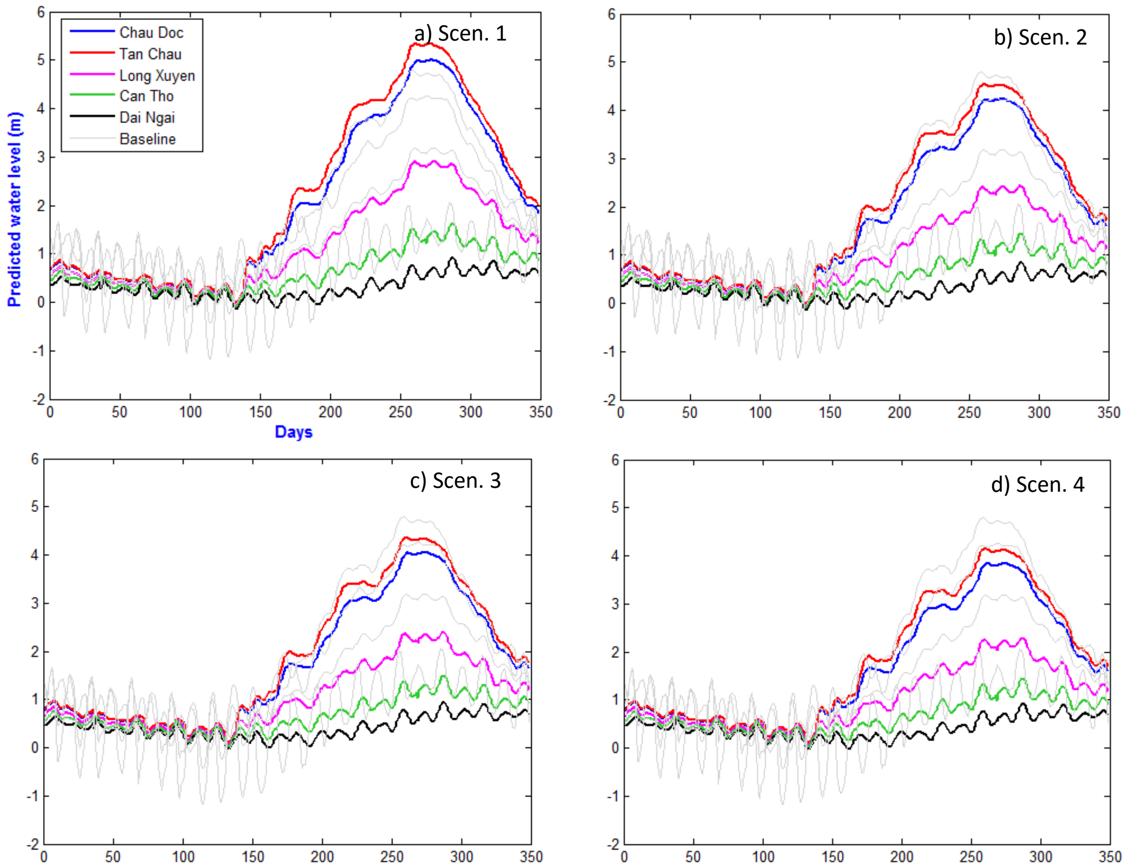


Fig. 6 Predicted water levels at main stations in the period of 2035 – 2065 for different scenarios

4.2. Impact of both upstream flows and climate change

We consider four scenarios with different flow discharges at Kratie based on the study of Lauri et al., (2012), who conducted a research considering impacts of climate change and reservoirs operation both separate and cumulative assessment. The annual changes of flows varied from a decrease of 4% to an increase of 12% indicated in their work. These results have a good agreement with those obtained by Hoanh et al. (2010). Our results show the large differences of discharges at the four considered stations applying all RCP scenarios. For example, the discharge in Hau River tends to increase from 7.25% to 46.66% for four scenarios in the wet season and to decrease about 67.8% in the dry season, while at other stations (i.e. Tan Chau, Can Tho, and My Thuan) the flow discharges may decrease significantly in both dry and wet season for scenarios 2, 3, and 4.

The two available studies (Van et al., 2012 and Manh et al. 2014) have been conducted for sediment dynamics and flood propagation in VMD. However, it is impossible to compare their results with our results because the time horizons of these studies are different. For instance, Manh et al. (2014) used a baseline of 2000-2010 and a future period of 2050-2060 and Van et al. (2012) applied a baseline of 2000 and forecasted period of 2050 whereas our study employed baseline of 2011. Moreover, Manh et al. (2014) concentrated mostly on sediment transport while Van et al. (2012) more focused on the short time of spatial flooding in monsoon season. Even so, to some extent, the increasing trends of flooding during wet season are similar to those received by these both studies due to sea level rise and precipitation increases.

5. Conclusions

From our results we found that within the timescale used in this study (1978–2001 vs. 2035–2065), climate change leads to increase the predicted precipitation for all GCM outputs. Nevertheless, the calculated ranges depend not only on individual GCMs but also on RCP scenarios and locations. We also found that under the two RCP scenarios applied, RCP4.5 and RCP8.5, there are significant variabilities in downscaled results and bias-correction of precipitation for five GCMs data. In general, all precipitation projections of GCMs have a similar trend with an increasing rates in wet seasons and a decreasing in dry seasons. Although the precipitation forecasting of few GCMs remains uncertain, it can be concluded that VMD will suffer more drought in dry seasons and higher flood in rainy seasons with a degree of confidence. This highlights the importance of using GCMs and RCPs ensembles when assessing the possible climate change impacts on the hydraulic regime in VMD.

Our study also shows that, the impacts of the upstream flow discharge in four scenarios are a driving force to the changes of hydraulic regime in the VMD while sea level rise at downstream has smaller effect. In this study, we combined the upper flow variabilities and precipitation alterations. The findings showed that, the flow at Kratie changes from +10% to -20% combined with precipitation variances, the discharge at four main stations will alter from -2.45% to -100.21% for different scenarios. Furthermore, the predicted seasonal discharges will reduce substantially in dry season in all scenarios while the discharges will increase significantly in the wet season in Hau River.

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Authors' addresses

Duong Tran Anh MSc.
Lehrstuhl für Wasserbau und Wasserwirtschaft, TU München
Arcisstraße 21, D-80333 München
tran.duong@tum.de

Long Phi Hoang MSc.
Earth System Science group, Wageningen University, the Netherlands
long.hp2002@gmail.com

Dr.-Ing. Dipl.-Math. Minh Duc Bui
Lehrstuhl für Wasserbau und Wasserwirtschaft, TU München
Arcisstraße 21, D-80333 München
bui@tum.de

Prof. Dr. Peter Rutschmann
Lehrstuhl für Wasserbau und Wasserwirtschaft, TU München
Arcisstraße 21, D-80333 München
peter.rutschmann@tum.de