AN ASSESSMENT OF POTENTIAL CLIMATE CHANGE IMPACTS ON FLOOD RISK IN CENTRAL VIETNAM

Quan Van Dau, MSCE
Department of Civil Engineering,
Khon Kaen University, Khon Kaen, Thailand
Kittiwet Kuntiyawichai, PhD
Department of Civil Engineering,
Khon Kaen University, Khon Kaen, Thailand

Abstract:

Flood is a natural feature of the environment and is also one the most frequent hazardous natural disaster. The impacts of flood are highly devastating and usually causing economic depression and direct damages to the livelihood, properties, and lives of the people. In recent years, the extended flat territory along the long coastline with the tropical cyclone frequency is result of flood problem in the central region of Vietnam. In an attempt to deal with this adversity, this paper aims to manifest the feasibility of assessing flood simulations that corresponds to the impacts of climate change. The system was developed using the outputs of the Hadley Centre Coupled Model, version 3 (HadCM3) for A2 and B2 scenarios and a coupling of hydrological – hydrodynamic models. The results indicated that the weather will become hotter in the future with the increase of temperature between 0.4°C to 2.2°C and 0.19°C to 0.6°C under A2 and B2 scenarios, respectively. On the other hand, the annual rainfall will also increase between 3.3% to 14.5% and 3.6% to 6.8% under A2 and B2 scenarios, respectively. The results also demonstrated that potentially serious increases in runoff and water level under future climate change scenarios. The unanticipated consequences might play a large role in destruction of crops, transportation, water supply, and communities located in the Huong River Basin. Additionally, the outcomes of this study can be applied for the entire Huong River Basin in order to mitigate the flood problems in the future.

Keywords: Food risk, Climate change, HEC – HMS, HEC – RAS, General Circulation Model

Introduction

The increase of cumulative carbon dioxide (CO_2) emissions in the atmosphere is the main factor, which results in global warming. According to the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC), at the end of the century, the global temperatures are likely to increase by 0.3°C to 4.8°C under the Representative Concentration Pathway (RCP) 2.6 to 8.5 scenarios (IPCC, 2013). The impacts of climate change can affect the spatial and temporal distribution of river basins, such as the intensity and frequency of extreme hydrological events (Babel et al., 2011). Over the last decade, the General Circulation Models (GCMs) have been considered as the most common source, which were employed to evaluate the hydrological impact studies. However, the abilities of the models remain limited for instance, the coarse resolution and uncertainty to capture many important regional parameters such as the geographic, atmospheric and clouds. To overcome these problems, various statistical and dynamical downscaling models have been subsequently emerged in recent years that can transfer the coarse spatial outputs to the finer resolution of regional level. At present, there is a great interest in dynamical downscaling methods for the reason that they have higher resolution and additional regional information than the other methods, which enables it to be finer in regional level. These approaches, however, require substantial computational resources, and due to the complexity, the dynamical downscaling methods are highly preferable for the commercial purpose studies. Therefore, statistical downscaling methods are the most common approach to improve the resolution of rainfall for hydrologic application and largely used in anticipated hydrological impact studies under climate change scenarios (Khan et al., 2006).

In this paper, the potential impacts of climate changes in the central region of Vietnam are investigated using the Statistical Downscaling Model (SDSM) based on various emission scenarios. Furthermore, the paper also aimed to evaluate the hydrological processes in the study area by using a coupling hydrological (HEC – HMS) and hydrodynamic models (HEC – RAS).

Study area description

The study concentrated on the Huong River Basin, the largest river in Thua Thien Hue Province, Vietnam. The Huong River Basin has its main length of 104 km and a total area of 2,830 km^2, in which almost 80% of the entire area is mainly mountainous area. The river basin area comprises of three main reservoirs, i.e. Huong Dien, Binh Dien and Ta Trach, which are situated along the tributaries of the Bo, Huu Trach and Ta Trach Rivers, respectively (Fig.1). The Huong River Basin is considered to have the highest rainfall in Vietnam, with the mean annual rainfall of approximately 2,500 mm in the coastal areas and 3,500 mm in the hilly regions of the river basin. In terms of temperature, the annual average temperature ranges from 21°C to 26°C with the highest recorded temperature of 41.3°C. The average humidity is approximately 85% with the lowest values range between 50% to 60% and the highest value is equal to 90%. This area usually impacted by some extreme climatic events every year such as typhoons and tropical cyclones, which are the roots of severe flood and inundation at the downstream of the river basin.

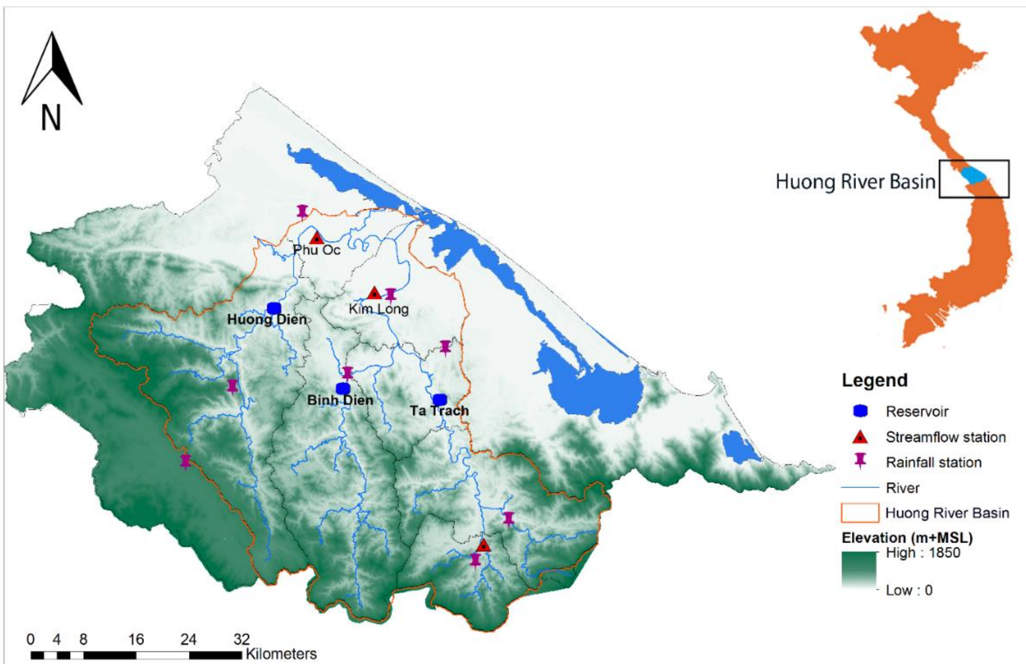


Fig. 1 The Huong River Basin, Vietnam (Thua Thien Hue Hydro-Meteorology and Forecasting Center, Vietnam, 2014)

Materials and methods

Data collection

The meteorological data were obtained from Thua Thien Hue Hydro-Meteorology and Forecasting Center (TTH – HMFC). The daily weather data consist of rainfall, wind speed, maximum and minimum temperatures, and relative humidity during 1976 to 2012. The Digital Elevation Model (DEM) with 10 m*10 m resolution generated from 1:25,000 topographic contour data was used for flood modeling. In addition, land use and soil maps with the scale of 1:50,000 generated in September, 2014 were also obtained from the Department of Resources and Environment of Thua Thien Hue Province, and they were employed to analyze the Curve Number (CN) values in the river basin.

The daily observed predictors were derived from the National Centers for Environmental Prediction (NCEP) reanalysis during the period of 1961 to 2001. The Hadley Centre Coupled Model, version3 (HadCM3) daily outputs for the period 1961 to 2099 were obtained from the Met Office Hadley Centre, England. HadCM3 was selected since the model is extensively used in the Southeast Asia for many climate change impact studies including the central region of Vietnam (Khoi et al., 2015; Mai, 2009; Shrestha et al., 2014); and it also has the ability to simulate for a period of thousand years, as well as showing a little drift in its surface climate (McCarthy et al., 2012). Regarding Vietnam, the population and industrial growth is expected to contribute to a very high concentration greenhouse gases (GHGs) in the later decades of the 21^{st} century (Shrestha et al., 2014). Therefore, the intermediate scenario of the high scenario (A2) and medium scenario (B2) were selected for this study area.

Statistical Downscaling Model (SDSM)

The SDSM model is a multiple regression-based method, which was introduced by Wilby et al. (2002). The model was developed to convert the resolution from large scale predictor variables into local climate variables. For specifying the appropriate predictor variables which were applied for model calibration, the NCEP reanalysis predictors were selected. The predictors were analyzed using correlation analysis and partial correlation analysis to represent the potential utilization of predictor and predictand (rainfall, temperature) relationships. Regarding calibration, rainfall was modeled as a conditional process because the amounts of rainfall depend on wet-day occurrence while the temperature was modeled as an unconditional process. Alternatively, the transformation of the “Fourth roots” was applied to account for the skewed nature of the rainfall distribution.

The World Meteorological Organization (WMO) and the IPCC in the AR1 and AR2 defined the climatological baseline period for 30-year such as the period of 1961 to 1990. Because of the lack of observation data, the period of 1976 to 1990 was used as a baseline period in this study. The model was calibrated and validated separately for daily rainfall, maximum and minimum temperatures, i.e. the period of 1976 to 1990 for calibration and 1991 to 2001 period for validation.

Hydrologic Model HEC – HMS

The Hydrologic Engineering Center – Hydrologic Modeling System (HEC – HMS) model was developed by the US Army Corps of Engineer – Hydrologic Engineering Center. The model was designed to simulate the rainfall – runoff processes and it was widely applied in many hydrological studies (Matthew, 2013). To represent the behavior of the river basin, HEC – HMS contains four main components, i.e. models to compute runoff volume, direct runoff, baseflow and channel flow (Feldman, 2008).

There are several loss methods that are provided in the HEC – HMS model. The loss methods are used to calculate actual infiltration from sub-basins. Among the remaining loss methods, the Soil Conservation Service Curve Number (SCS – CN) method was selected for the event-based simulation due to its simplicity manner. This method also relies on only one parameter, i.e. Curve Number (CN) and accounts for most runoff producing watershed characteristics. In addition, the method provides better results in comparison to the other methods.

The Snyder Unit Hydrograph is well known as a common method used to define how excess rainfall is transformed into runoff in sub-basins, and it was used in this study. The Snyder Unit Hydrograph method has been used worldwide nowadays such as Bender et al., 1961; Safarina et al., 2011; and Singh et al., 2014, especially, the most interesting approach to this method has recently been proposed by Dinh, 2014 and Hoa, 2013 in the same river basin.

A total of six different baseflow methods are available in HEC – HMS model for calculating the actual subsurface flow from sub-basins. The recession baseflow method was considered in this study due to its ability to automatically reset after each flood event; and this method does not conserve mass for each sub-basin. Alternatively, recession baseflow is broadly practiced in many hydrological studies and it can be applied for both event and continuous simulations.

In order to represent a segment of a river, the Muskingum routing method was considered. Employing a simple conservation mass approach to route flow along the river, the Muskingum method is examined as one of the most popular methods at present. Practically, this method worked well for the Huong River Basin based on the outcomes of previous studies, i.e. Dinh, 2014; Hoa, 2013; and Mai, 2009.

Moreover, there were three stations selected to represent the hydrological processes applied to model evaluation, i.e. Phu Oc station, Binh Dien and Ta Trach reservoirs. At Phu Oc station, the observed daily water level data for the period of 2009 to 2010 was used for calibration, and 2011 to 2012 period was used for validation. The observed daily inflow to Binh Dien reservoir during the period of 2010 to 2011 was used for calibration and the year 2012 was used for validation. For Ta Trach Reservoir which was just operated in May 2014, the available observed inflow data for the period of September to October 2014 was used for calibration, while the period of November to December 2014 was used for validation.

Hydrodynamic model HEC – RAS

The Hydrologic Engineering Center – River Analysis System (HEC – RAS) is a hydrodynamic model developed by the US Army Corps of Engineers – Hydrologic Engineering Center. It was designed for flood prone determination and hydraulic analysis of river channel. The model includes four river analysis components. These components include the steady flow water surface profile computations, unsteady flow simulations, sediment transport computations and water quality analysis (Gary, 2010).

The unsteady flow analysis was considered in HEC – RAS model simulation. The discharges at the outlets of Huong Dien, Binh Dien and Ta Trach reservoirs were utilized as the upstream boundary conditions, and tidal water level at Thuan An outlet was employed as the downstream boundary condition.

Two streamflow stations located at the downstream of the river basin, i.e. Kim Long and Phu Oc stations, were chosen to evaluate the performance of the model. The period of 2009 to 2010 was used for calibration and 2011 to 2012 period was used for validation.

Model evaluation criteria

For the assessment of model performances, there are four statistical measures for judging the goodness of fit of model simulations, i.e. determination coefficient (R^2), Nash – Sutcliffe coefficient of efficiency (E_{NS}), Root Mean Square Error (*RMSE*), and Percent Error in Peak (*PEP*).

$$R^2 = \left[\frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \right]^2 \quad (1)$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2} \quad (2)$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (\bar{X}_i - X_i)^2 \right]^{\frac{1}{2}} \quad (3)$$

$$PEP(\%) = 100 \left| \frac{S_{peak} - O_{peak}}{O_{peak}} \right| \quad (4)$$

Where: X_i is observed values; $\bar{X}$ is mean of observed values; Y_i is simulated values; $\bar{Y}$ is mean of simulated values; *n* is total number of value; S_{peak} is simulated peak; O_{peak} is observed peak

Results and discussions

SDSM calibration and validation

In the development of the SDSM model, the selection of appreciate predictor variables is an essential part on climate downscaling. It is done using a correlation analysis to identify a sensible combination of predictors - predictand variables. Higher correlation value (*r*) implies a higher degree of association (Wilby et al., 2007). Generally, the large scale predictor variables and daily rainfall show a very low correlation compared with the temperature. For mean temperature at 2 m predictor variable (*temp*), the correlation value showed a respectable achievement for maximum and minimum temperatures with the predictors (r > 0.70), in addition, results demonstrated a very low correlation value for daily rainfall (r < 0.10). Wilby et al. (2007) has also mentioned that daily rainfall is the most problematic daily variable to downscale since the measure of local sites are relatively poor resolved by regional scale predictors.

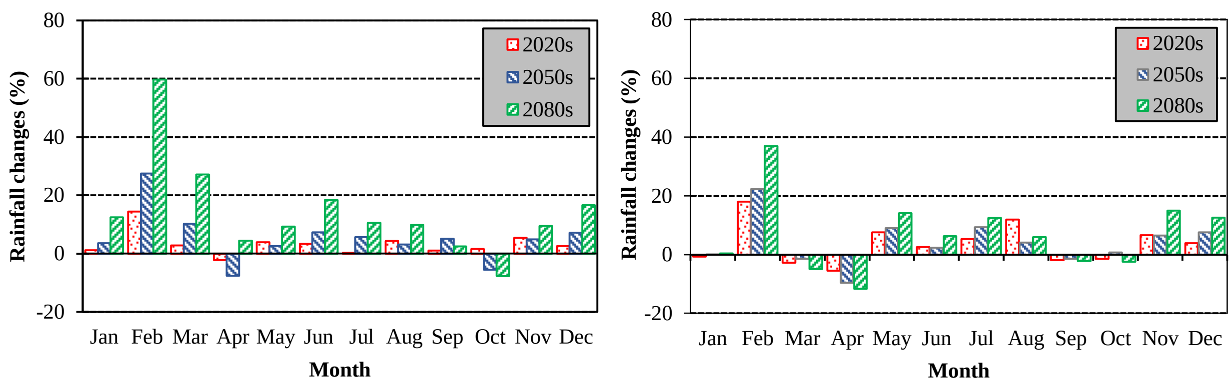
For calibration and validation, the results of mean monthly rainfall and temperature can be summarized in Table 1. It can be seen that the results show a good relationship between the observed and simulated data during the calibration and validation periods. Nevertheless, the SDSM model is limited only on capturing the daily rainfall at individual site due to many regional driving factors such as non-normality of the distribution of daily rainfall and mixed distribution of wet and dry days.

Table 1 Summary of calibration and validation results for mean monthly rainfall and temperature at Hue station

Predictand	Calibration		Validation	
	R^2	RMSE	R^2	RMSE
Maximum temperature	0.99	0.05	0.99	0.70
Minimum temperature	0.99	0.06	0.88	1.06
Rainfall	0.98	1.91	0.88	3.72

Downscaling of rainfall and temperature for future emission scenarios

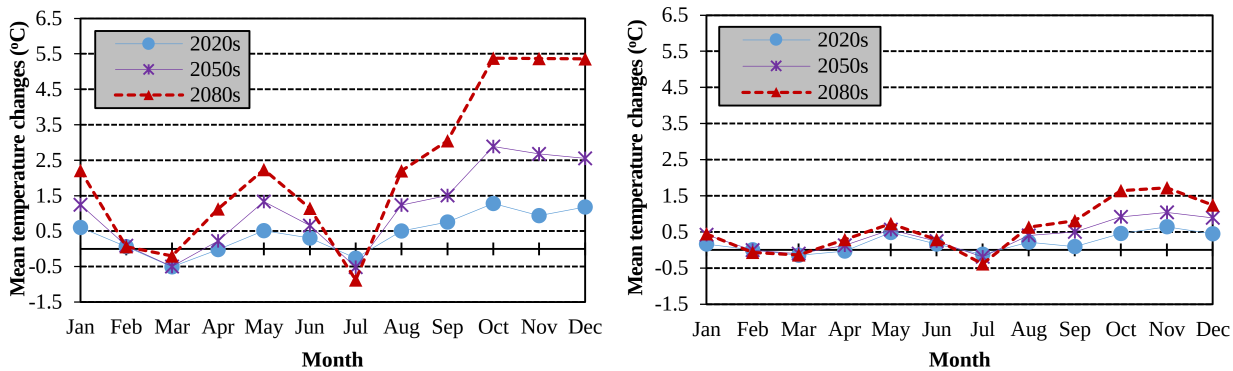
In terms of projected rainfall, the results indicate an increase trend for future mean annual rainfall in the Huong River Basin under A2 and B2 scenarios (Fig. 2). During the rainy season, the mean monthly rainfall tends to decrease by approximately 2.4% to 8.5% in October and increase by 3% to 16.8% in November to December. In summer, the rainfall will increase at a high rate of 60% in February for A2 scenario. The overall results demonstrated that the mean annual rainfall will increase between 3.3% to 14.5% under A2 scenario and 3.6% to 6.8% under B2 scenario during the decades of 2020s to 2080s in comparison to the baseline period.



(a) (b)

Fig. 2 Mean monthly rainfall changes for the decades of 2020s, 2050s and 2080s in comparison to the baseline period under (a) A2 scenario and (b) B2 scenario

In view of temperature, the results suggested that the weather will be hotter in the future, in particular along the coastline areas (Fig. 3). During the rainy season, the temperature will increase by 5.3°C and 1.68°C under A2 and B2 scenarios, respectively. In summer, the simulations reveal that the temperature will increase between 0.5°C to 2.2°C in May and slightly decrease between 0.2°C to 0.4°C in July based on A2 and B2 scenarios, respectively. It was observed that the mean annual temperature will increase between 0.4°C to 2.2°C and 0.19°C to 0.6°C during the decades of 2020s to 2080s under A2 and B2 scenarios, respectively.

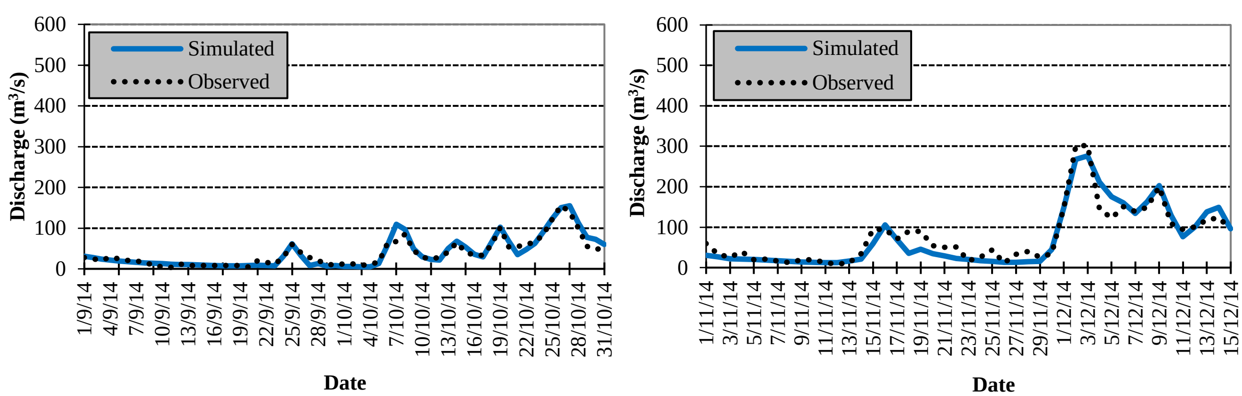


(a) (b)

Fig. 3 Mean monthly temperature changes for the decade of 2020s, 2050s and 2080s in relation to the baseline period under (a) A2 scenario and (b) B2 scenario

Hydrologic HEC –HMS model evaluation

The calibration and validation processes were performed in order to prove the reliability and stability of the model. As shown in Fig. 4, the comparisons between the simulated and observed discharges show a good agreement in terms of trends and magnitudes, except a certain period of November 18-19, 2011 which illustrate a clear difference due to the effect of tropical northeast monsoon that caused anomalous rainfall distribution as reported by (VTC14, 2014). In Table 2, the *PEP* values vary from 1% to 8.5%, 1% to 10% and 14% to 20% during the calibration and validation periods for Ta Trach, Binh Dien and Phu Oc stations, respectively. Furthermore, based on the E_{NS} and R^2 statistical values, it can be seen that the HEC – HMS model performed well during the calibration and validation processes.



a) b)

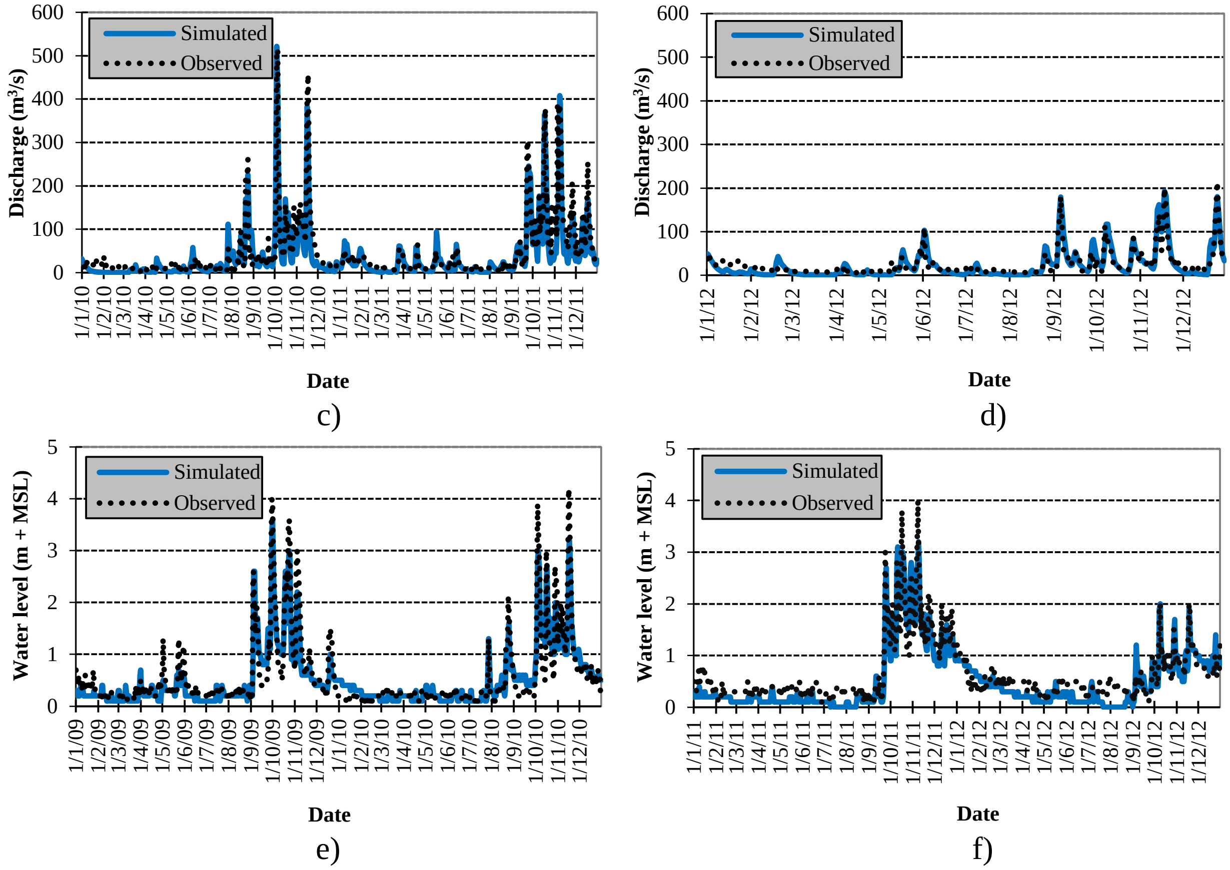


Fig. 4 The HEC – HMS model calibration results (a, c, e) and validation results (b, d, f) at Ta Trach, Binh Dien, and Phu Oc stations, respectively

Table 2 Statistical indices of HEC – HMS model performance

Station	Calibration		Validation	
	R^2	E_{NS}	R^2	E_{NS}
Phu Oc	0.85	0.84	0.85	0.78
Binh Dien	0.85	0.83	0.84	0.77
Ta Trach	0.94	0.91	0.91	0.89

HEC – RAS model for flood mapping

The HEC – RAS and HEC – HMS models were coupled externally in this study. In details, HEC – HMS model calculated discharges at the outlet of each sub-basin, which were used as the upstream boundary conditions for HEC – RAS model. A total 79 cross sections were imported into HEC – RAS model, together with the 10 m * 10 m DEM for HEC – RAS river network. The calibration of HEC – RAS model was performed manually by adjusting the Manning's n values for each reach along the main river and using both graphically and statistically to evaluate the model performance.

For calibration and validation processes, the results indicated that HEC – RAS model performed well in simulating water levels at Phu Oc and Kim Long stations (Fig. 5). Based on statistical indices as summarized in Table 3, it can be concluded that HEC – RAS model is suitable to simulate flood regimes in the Huong River Basin (note: a rather low correlation for validation at Phu Oc station might be explained by the effect of unprecedented levels of overflow from the Bo River which influenced its flow pattern).

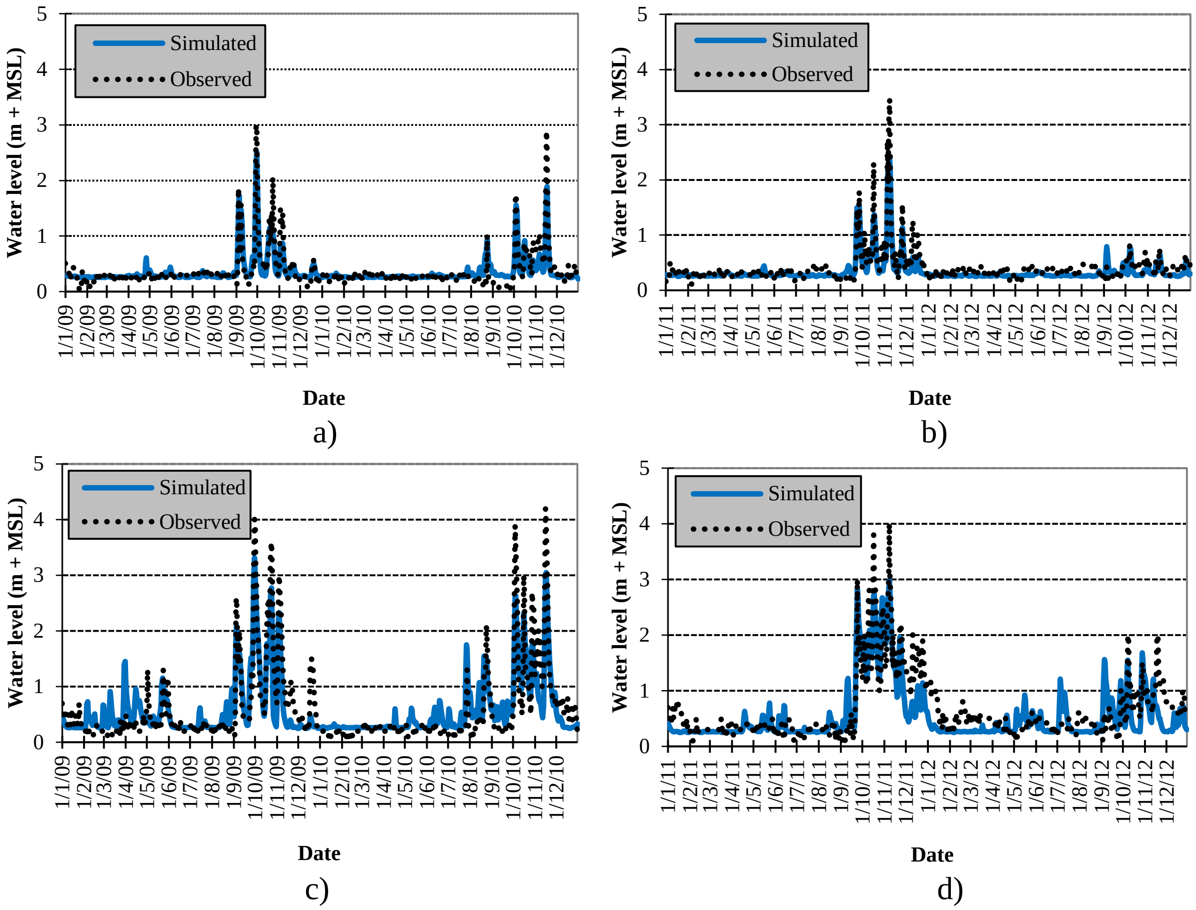


Fig. 5 The HEC – RAS model calibration results (a, c) and validation results (b, d) at Kim Long and Phu Oc stations, respectively

Table 3 Statistical indices of HEC – RAS model performance

Station	Calibration		Validation	
	R^2	E_{NS}	R^2	E_{NS}
Phu Oc	0.74	0.73	0.67	0.64
Kim Long	0.78	0.77	0.79	0.74

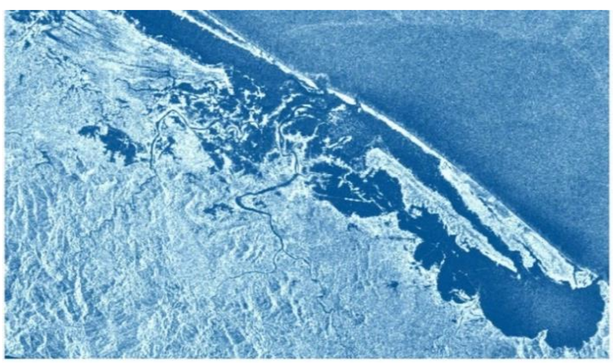
Flood simulation under the impacts of climate change

The A2 scenario was considered as the worst case projected high CO_2 emissions, and was used as input to flood simulations. As illustrated in Table 4, the results show trends in increasing water level and discharge at Phu Oc and Kim Long stations under the impacts of climate change. This can logically lead to increase in flood occurrences in the Huong River Basin in the future. In addition to this, the flood inundation mapping in the decades of 2020s to 2080s were delineated in order to identify the flood prone areas of the Huong River Basin as presented in Fig. 6.

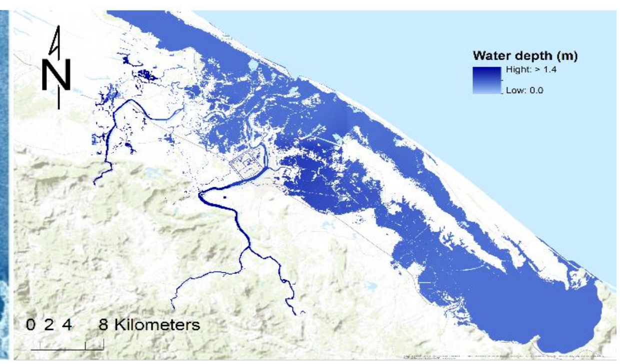
Table 4 Maximum water levels and discharges under A2 scenario

Period	Phu Oc		Kim Long	
	H_{max} *(m+MSL)*	Q_{max} *(m^3/s)*	H_{max} *(m+MSL)*	Q_{max} *(m^3/s)*
2020s	1.39	224.53	0.83	434.52
2050s	1.58	267.67	0.87	462.99
2080s	2.01	380.88	1.15	604.03

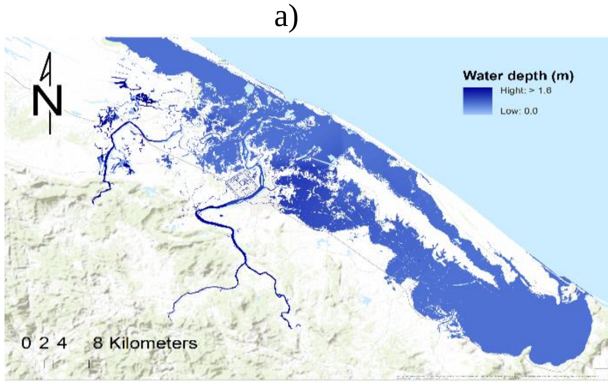
Where: H_{max} is the maximum water level *(m+MSL)*; Q_{max} is the maximum discharge at selected cross section *(m^3/s)*



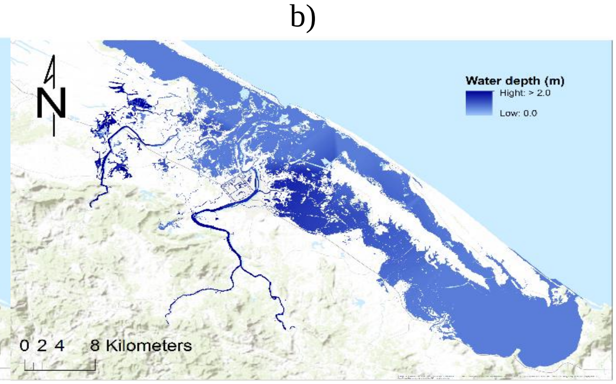
a)



b)



c)



d)

Fig. 6 Flood inundation extent of the Huong River Basin based on (a) satellite imagery taken on 11th June 1999 (b) HEC – RAS delineated flood inundation extent for the decade of 2020s (c) HEC – RAS delineated flood inundation extent for the decade of 2050s (d) HEC – RAS delineated flood inundation extent for the decade of 2080s under A2 emission scenario

Flood damage area assessment under future emission scenarios

Flood damages were analyzed by integrating the land use map with the flooded inundation zones using the ArcGIS modelling. Based on the outcomes of this investigation, it was indicated that there is a medium rate increase of the flood areas in the future (Table 5). For instance, during the decades from 2020s to 2080s, the flood damage area were extended from 501.83 to 514.31 km^2 respectively. Moreover, the results evinced that a large percentage of the flood damage in the area downstream of the river basin due to low elevation, contains of the water body area (about 43 %) and agriculture area (approximately 33.4 %).

Table 5 Flood damage area according to land use under future emission scenarios

Land use Types	2020s		2050s		2080s	
	Area *(km^2)*	*%*	**Area** *(km^2)*	*%*	**Area** *(km^2)*	*%*
Water body	218.42	43.52	219.12	43.38	221.03	42.98
Urban area	12.59	2.51	12.61	2.50	12.95	2.52
Rural area	35.92	7.16	36.5	7.23	37.19	7.23
Forest	3.41	0.68	3.49	0.69	5.04	0.98
Agriculture	167.66	33.41	168.7	33.40	171.9	33.42
Miscellaneous land	9.4	1.87	9.62	1.90	9.87	1.92
Orchard	47.42	9.45	47.89	9.48	48.98	9.52
Other	7.01	1.40	7.14	1.41	7.35	1.43
Total	**501.83**	**100.00**	**505.07**	**100.00**	**514.31**	**100.00**

Conclusions

An assessment of flood simulation under the impacts of climate change was carried out in the Huong River Basin. The results demonstrated that the application of coupling of HEC-HMS hydrological – HEC-RAS hydrodynamic models and the HadCM3 model under A2 and B2 emission scenarios for estimating the potential impacts of climate change provided a realistic finding for the Huong River Basin. From the main finding of this study, it was observed that the weather will be hotter in the future, which ranges between 0.4°C to 2.2°C and 0.19°C to 0.6°C for A2 and B2 scenarios, respectively. On the other hand, the overall results implied that the annual rainfall will increase from 3.3% to 14.5% and 3.6% to 6.8% under A2 and B2 scenarios, respectively, in the decades to come. The increase of temperature and rainfall will significantly influence discharges and water levels in the future. As a result, the flood risk will be more intensive in terms of its frequencies and magnitudes of damage and could be more extreme in the future. The unforeseen flood events might cause negative impacts, including loss of human life, damage to property, destruction of crops, loss of livestock, etc. whereas floods might positively play an important role in maintaining key ecosystem functions and biodiversity in natural systems of the Huong River Basin. Finally, the outcomes of this study can be used as a guideline for adaptation measures under climate change impacts in the other parts of Vietnam.

Acknowledgements

The author would like to acknowledge the generous financial support of the Khon Kaen University Scholarship for ASEAN and GMS Countries' Personnel program. The author's thanks are also extended to the Thua Thien Hue Hydro-meteorology Forecasting Center for its support in providing the meteorological data.

References

Babel, M., Agarwal, A., Swain, D., & Herath, S. (2011). Evaluation of climate change impacts and adaptation measures for rice cultivation in Northeast Thailand. *Climate Research, 46*(2), 137-146. doi: 10.3354/cr00978

Bender, D. L., & Roberson, J. A. (1961). The use of a dimensionless unit hydrograph to derive unit hydrographs for some Pacific Northwest basins. *Journal of Geophysical Research, 66*(2), 521-528. doi: 10.1029/JZ066i002p00521

Dinh, N. (2014). Research on changes of some hydraulic and hydrological factors of the Huong River system's downstream under the impact of irrigation and hydropower constructions and climate change. *Science Technology and Enviromental, 42*, 17.

Feldman, A. D. (2008). Hydrologic Modeling System HEC-HMS. (pp. 155). Hydrologic Engineering Center, HEC 609 Second St. Davis, CA.

Gary, W. B. (2010). HEC-RAS, River Annalysis System Hydraulic Reference Mannual (Vol. 4.1, pp. 411). US Army Corps of Engineers Hydraulogic Engineering Center, 609 Second Street Davis, CA 95616-4687

Hoa, P. (2013). Flood forecasting in Huong River Basin using the HEC-HMS model. Thua Thien Hue-Hydro-meteorology and Forecasting Vietnam (V. D. Quan, Trans.).

IPCC. (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley ed., pp. 1535). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Khan, M. S., Coulibaly, P., & Dibike, Y. (2006). Uncertainty analysis of statistical downscaling methods. *Journal of Hydrology, 319*(1–4), 357-382. doi: dx.doi.org/10.1016/j.jhydrol.2005.06.035

Khoi, D., & Hang, P. (2015). Uncertainty Assessment of Climate Change Impacts on Hydrology: A Case Study for the Central Highlands of Vietnam. In S. Shrestha, A. K. Anal, P. A. Salam & M. van der Valk (Eds.), *Managing Water Resources under Climate Uncertainty* (pp. 31-44): Springer International Publishing.

Mai, D. T. (2009). *Flood prediction model for Huong River and Vu Gia-ThuBon River basins in Central Vietnam.* (PhD thesis), Vrije Universiteit Brussel, Belgium.

Matthew, J. F. (2013). Hydrologic Modelling System HEC-HMS. Quick start guide (Vol. 4, pp. 50). U.S Army Corps of Engineers, Hydrologic Engineering Center, 609 Second St. Davis , CA 95616.

McCarthy, M. P., Sanjay, J., Booth, B. B. B., Krishna Kumar, K., & Betts, R. A. (2012). The influence of vegetation on the ITCZ and South Asian monsoon in HadCM3. *Earth Syst. Dynam., 3*(1), 87-96. doi: 10.5194/esd-3-87-2012

Safarina, A. B., Salim, H. T., Hadihardaja, I. K., & Syahril BK, M. (2011). Clusterization of Synthetic Unit Hydrograph Methods Based on Watershed Characteristics. *Academic Journal, 11* (6), 76.

Shrestha, S., Deb, P., & Bui, T. (2014). Adaptation strategies for rice cultivation under climate change in Central Vietnam. *Mitigation and Adaptation Strategies for Global Change*, 1-23. doi: 10.1007/s11027-014-9567-2

Singh, P. K., Mishra, S. K., & Jain, M. K. (2014). A review of the synthetic unit hydrograph: from the empirical UH to advanced geomorphological methods. *Hydrological Sciences Journal, 59*(2), 239-261. doi: 10.1080/02626667.2013.870664

VTC14. (2014). Weather forecasting on November 17, 2014: Rainfall in the central region of Vietnam. Retrieved from http://vtc14.vn/tt-6h/thoi-tiet-sang-ngay-17-11-2014--mien-trung-co-mua-tren-dien-rong-t34889.html

Wilby, R. L., Dawson, C. W., & Barrow, E. M. (2002). SDSM — A decision support tool for the assessment of regional climate change impacts. *Environmental Modelling & Software, 17*(2), 145-157. doi: dx.doi.org/10.1016/S1364-8152(01)00060-3

Wilby, R. L., Dawson, C. W., & Barrow, E. M. (2007). Using SDSM version 4.2 – A decision support tool for the assessment of regional climate change impacts. . Department of Geography Loughborough Unuiversity, UK.