



Prediction of economic loss of rice production due to flood inundation under climate change impacts using a modeling approach: A case study in Ha Tinh Province, Vietnam

Pham Quy Giang¹✉

¹Faculty of Land Management, Vietnam National University of Agriculture, Vietnam

✉ **Corresponding author:**

Faculty of Land Management,
Vietnam National University of Agriculture, Vietnam
Email: quygiang1010@vnua.edu.vn

Article History

Received: 24 September 2019

Accepted: 05 November 2019

Published: January - March 2020

Citation

Pham Quy Giang. Prediction of economic loss of rice production due to flood inundation under climate change impacts using a modeling approach: A case study in Ha Tinh Province, Vietnam. *Climate Change*, 2020, 6(21), 52-63

Publication License



© The Author(s) 2020. Open Access. This article is licensed under a [Creative Commons Attribution License 4.0 \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/).

General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate.*

ABSTRACT

The present study was carried out to predict the economic loss of rice production due to flood inundation under climate change impacts using a modeling approach with a case study of Huong Son District in Ha Tinh Province, Vietnam. Extreme precipitation and its return periods were identified by GEV distribution method using historical daily observations and output of MRI-CGCM3 climate

model. The predicted extreme precipitation data was then employed as an input of hydrological models for flood modeling. Finally, a complex approach taking into account depth and duration of inundation and crop calendar was used for the prediction of potential economic loss of rice production. Results of the study show a significant increase in the intensity of extreme precipitation and floods, and the economic loss of rice production would increase significantly as a result of larger, deeper and longer floods. In 2050s, the loss would be 21.02% greater compared to the baseline period. The finding of this study is expected to be valuable scientific information for long-term agricultural planning to tackle with potential flooding threats under climate change impacts.

Keywords: Climate change, flood economic loss, modeling, rice production.

1. INTRODUCTION

In recent decades, natural disasters are being reported with increasing frequency and severity across the globe (CRED, 2013). According to United Nations Office for Disaster Risk Reduction (UNISDR, 2002), the cost of natural disasters worldwide will exceed US\$300 billion annually by 2050 and indeed, this figure was exceeded in 2011 when the cost was more than US\$360 billion. Floods are among the most damaging natural disasters. The International Disaster Database reported that the average annual global cost of flood damage is about US\$90 billions. Natural disasters in general and floods in particular leave developing countries particularly vulnerable, as their capacity to respond is much lesser than developed countries (Mechler, 2003). Figure 1 presents the number of natural disaster worldwide during the period of 1970-2018, where extreme weather and floods are dominant.

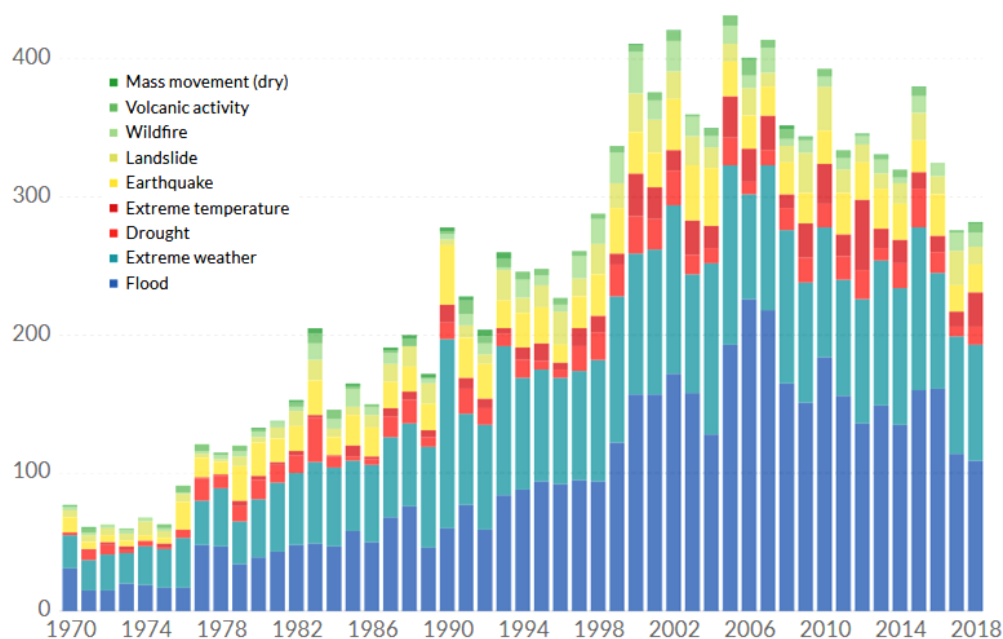


Figure 1 Global reported natural disasters during 1970-2018 (Source: Adapted from EMDAT, 2019)

Report of UNISDR (2009) showed that Vietnam is one of the countries expose the most to floods (Figure 2). In developing countries in general and in Vietnam in particular, flood induced economic loss of agriculture is a serious concern since livelihood of large populations depends on agricultural production. Evaluation of flood damage to agricultural crops is therefore important for post-flood relief and recovery planning as well as for long-term adaptation and mitigation actions in the agricultural sector.

A number of studies have been carried out to evaluate flood induced economic loss of agricultural crops around the world. In Japan, Dutta *et al.* (2003) introduced a mathematical model for flood loss evaluation combining a physically based distributed hydrologic model and a distributed flood loss estimation model. A similar approach employing MIKE FLOOD model combined with damage curves was also applied by Vozinaki *et al.* (2012) to study flood loss in Greece. Penning-Rowsell *et al.* (2013) used a depth-loss relationship to assess flood loss in the Taihu Basin, China. The depth-loss rate was established by asset categories and flood depth based on an existing "flood loss rate", which is a percentage of the pre-flood property value at varying flood depths, and its associated flood damage data from past floods. The gap in these studies is that the impact of climate change on floods, which has become obvious nowadays, was ignored.

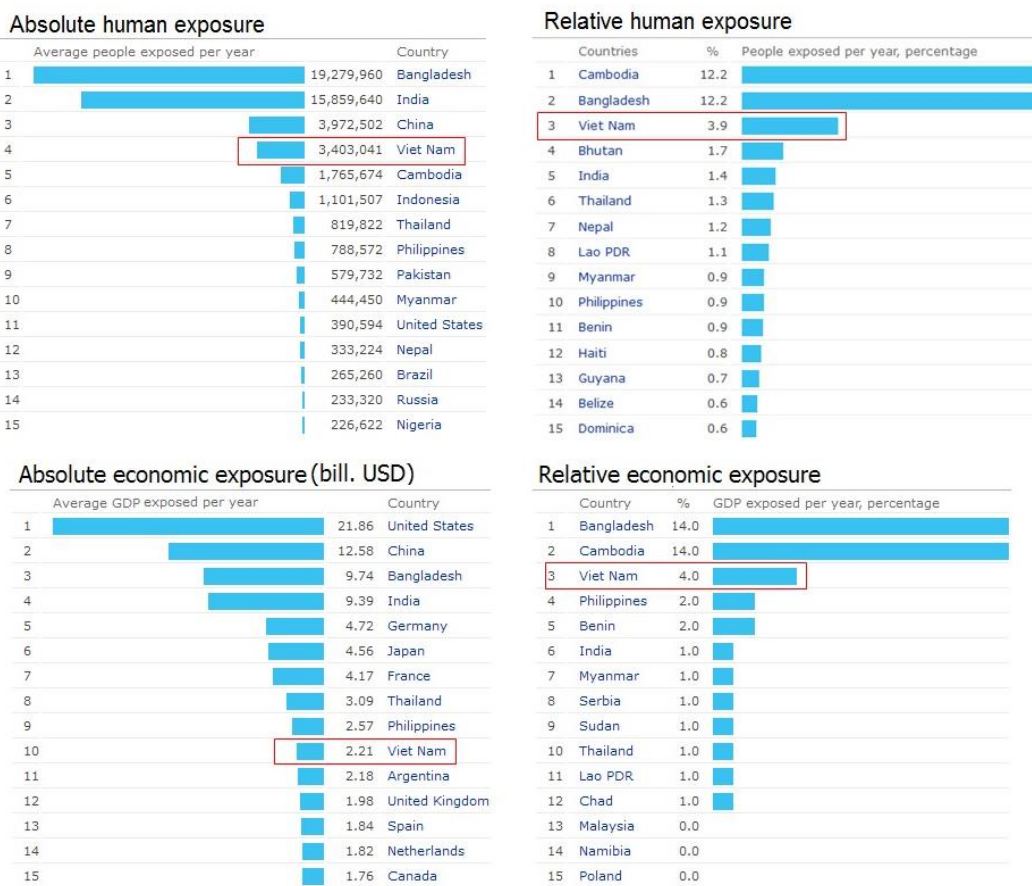


Figure 2 Human and economic exposure to floods (Adapted from *UNISDR*, 2009)

In Vietnam agriculture contributes a round one quarter to the country's Gross National Product (GDP). However, agricultural production is frequently threatened by increasingly severe climate change and floods (Pham *et al.*, 2014). The United Nation Office for Disaster Risk Reduction (2009) stated that Vietnam is among the countries most affected by floods, meanwhile Standard and Poor's (2014) ranked Vietnam as the world's second most vulnerable country to climate change. The concern for agricultural production in the future is therefore becoming more onerous. Among Vietnamese agricultural crops, rice is the most popular as it is grown throughout the country and is a major product for export. However, it is likely the most flood-affected crop due to its low-land cultivation location (Pham, 2018). Thus, the main aim of this study was to predict the magnitude of future floods under the impact of climate change and their damage to rice production in Vietnam by a complex approach combining climate modeling, hydrological modeling and flood damage modeling. The area selected as a case study for this study was Huong Son, a district in the north central region which is considered as the hotspot of flooding in Vietnam due to high frequency and severity of floods. The results of this study is expected to useful information for long-term agricultural planning to tackle with potential flooding threats to rice production under climate change impacts.

2. METHODOLOGY

The methodology for predicting flood induced economic losses of rice production under climate change impacts involves projection of extreme precipitation under MRI-CGCM3 climate model, simulation of flood inundation using hydrological model and calculation of economic loss based on inundation depth and duration using Geographical Information System. The projection of extreme precipitation with MRI-CGCM3 was run under Representative Concentration Pathway (RCP) 8.5, which presents the highest level of radiative forcing for 2100 relative to pre-industrial values (+8.5 W/m²). RCP8.5, together with RCP2.6, RCP4.5, and RCP6.0 are the four greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5). The four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenarios (RCP8.5) (Weyant *et al.*, 2009; IPCC, 2014).

2.1. Extreme precipitation projection and flood modeling

In this study, long-term historical precipitation daily data date back to more than 50 years with volume resolution of 0.1mm were employed for Generalized Extreme Value (GEV) analysis in combination pattern scaling method to predict extreme precipitation in 2050s following the approach introduced by Ye and Li (2011). The probability density function for the GEV distribution with location parameter μ , scale parameter σ , and shape parameter γ is:

$$F(x; \sigma, \gamma, \mu) = \begin{cases} \exp\left(-\left\{1 + \gamma \frac{x - \mu}{\sigma}\right\}^{-1/\gamma}\right), & \text{if } 1 + \gamma \frac{x - \mu}{\sigma} > 0, \gamma \neq 0 \\ \exp\left(-\exp\left\{-\frac{x - \mu}{\sigma}\right\}\right), & \text{if } x \in R, \gamma = 0 \end{cases} \quad (1)$$

where the shape parameter γ determines the type of GEV distribution. There are three types of distribution called Fréchet, Gumbel, and Weibull corresponding to $\gamma < 0$, $\gamma = 0$, and $\gamma > 0$, respectively. The GEV function parameters for the General Circulation Model (GCM) baseline and future periods were estimated using the Probability Weighted Moments (PWM) method (Landwehr *et al.*, 1979) for each GCM grid (x,y). In this study, MRI-CGCM3 climate model, which was developed by Meteorological Research Institute of Japan, was employed. MRI-CGCM3 is an overall upgrade of the MRI-CGCM2 series. This climate model is a core subset of MRI's earth system model MRI-ESM1 (Yukimoto *et al.* 2011). MRI-CGCM3 consists of the atmosphere-land model (MRI-AGCM3), the ocean and sea ice model (MRI.COM3), and the aerosol model (MASINGAR mk-2). These component models are coupled with a simple and flexible coupler "Scup", which enables user to make a variety of combinations of the component models with arbitrary resolutions and grid coordinates.

The MIKE FLOOD model was then used for flood modeling using the projected extreme precipitation derived from GEV analysis. MIKE FLOOD integrates the one-dimensional model MIKE 11 and the two-dimensional model MIKE 21 into a single, dynamically coupled modeling system. This coupled tool exploits the best features of both MIKE 11 and MIKE 21. Lateral links are used, enabling the overbank flow simulation between the river channel and the floodplain area. A lateral link allows a string of MIKE 21 cells to be laterally linked to a given reach in MIKE 11, either a section of a branch or an entire branch. The maximum floodwater depth and duration, which were estimated at every model grid node, was subsequently used as input to a flood loss model for the prediction of economic loss of rice production. The model used in the present study was previously calibrated and validated by Pham *et al.* (2016).

2.2. Prediction of flood induced economic loss of rice production

The flood induced economic loss model for rice production uses the following equation:

$$EL_{(xy)} = A_{(xy)} \times Y \times C \times E_{(Ht)} \times LF \quad (2)$$

$$TEL = \sum_{x=1, y=1}^{m, n} EL \quad (3)$$

Where: $EL_{(xy)}$ is economic loss of rice due to flood in grid xy (VND)

TEL is the total economic loss of rice (VND)

$A_{(xy)}$ is cultivation area of rice in grid xy (m²)

Y is estimated yield of rice per unit area (kg/m²)

C is estimated cost per unit weight of rice product (VND/kg)

$E_{(Ht)}$ is loss coefficient for rice corresponding to depth H and duration t at grid xy (%)

LF is loss factor, taking into account of growing season of rice (%). In the present study, LF is assumed to be 100% as the flood season in the study area (August-November) covers the harvesting season of rice (August-September).

The loss coefficient $E_{(Ht)}$ is calculated based on a stage-loss function. In the present study, we developed three types of function which are exponential function, polynomial function and linear function. Among the three types of function developed, the linear function has the highest coefficient of determination R^2 for all depth levels. It was therefore selected for economic loss calculation. The linear function $E = F(t) = a.t + b$, where E is the loss coefficient in percentage ($E \leq 100\%$), t is the inundation duration (days), a and b are coefficients determined for each water depth level. In the present study, flood depth (H) was divided into three levels: $0.2m < H \leq 0.5m$; $0.5 < H \leq 1.0m$; and $H > 1.0m$. Our assumption is that the flood level shallower than 0.2m caused no economic loss to rice. The loss curves and functions were built from interview survey data with local farmers. 195 farmers in the district whose rice

fields were often inundated by annual flooding were randomly selected for investigation. Figure 3 and Table 1 present loss curves and loss function for rice production.

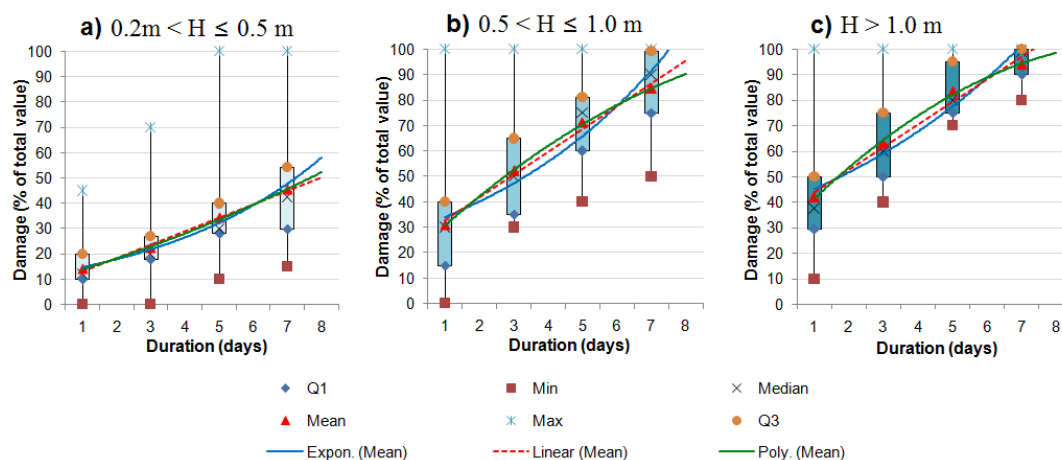


Figure 3 Loss curves for rice production

Table 1 Loss functions for rice production

Depth (m)	Exponential Function	Polynomial Function	Linear Function
$0.2 \leq H \leq 0.5$	$y = 12.14e^{0.196x}$ $R^2 = 0.989$	$y = 0.188x^2 + 3.804x + 10.01$ $R^2 = 0.990$	$y = 5.31x + 7.942$ $R^2 = 0.995$
$0.5 < H \leq 1.0$	$y = 28.80e^{0.166x}$ $R^2 = 0.948$	$y = -0.484x^2 + 12.88x + 18.48$ $R^2 = 0.992$	$y = 9.001x + 23.821$ $R^2 = 0.996$
$H > 1.0$	$y = 39.42e^{0.134x}$ $R^2 = 0.945$	$y = -0.668x^2 + 14.18x + 28.05$ $R^2 = 0.990$	$y = 8.833x + 35.413$ $R^2 = 0.991$

2.3. The study area

Huong Son ($18^{\circ}16'07''\text{N}$ - $18^{\circ}37'28''\text{N}$; $105^{\circ}06'08''\text{E}$ - $105^{\circ}33'08''\text{E}$) is a rural district located in the North-East of Ha Tinh Province, approximately 350 km South of Ha Noi. The district faces Nghe An Province to the North, Laos PDR to the West, Vu Quang district to the South-East and to Duc Tho District to the East (Figure 4). The district covers an area of approximately 1096.79 km² and is a part of the Ca River Basin (CRB), which stretches on the territory of Laos and Vietnam and is one of the largest river basins in the mainland Southeast Asia. As of 2016, Huong Son has a population of more than 117,200 people. Having a dense river and stream network with Ngan Pho being the main river flowing through the district, Huong Son is threatened by annual river floods. In fact, the North Central Region in general and Huong Son District in particular is well-known as a hotspot of flooding in Vietnam due to high frequency and severity of floods occurring in the region. In Huong Son, rice is grown three crops a year: Winter-Spring crop (early November to mid April), Summer-Autumn crop (early May to late September) and October crop (mid May to mid November) and is a major crop in many downstream communes with a total area of 5,700 ha and a total production of 55,000 tons per year. However, with the main flood season is from early August to late November, the harvesting time of the Summer-Autumn rice and October rice falls into the flood season, the risk of flood damage to rice is therefore very high.

3. RESULTS AND DISCUSSION

3.1. Change in extreme precipitation and flood level

Figure 5 shows daily precipitation in Huong Son district during a period of 56 years from 1960 to 2016. This set of precipitation data was used for the calculation of extreme precipitation using GEV method. Figure 6 presents both the baseline GEV distribution and the 2050s GEV distribution under RCP8.5 projected by the MRI-CGCM3 model for 24-hour extreme precipitation at Pho Chau meteorological station.

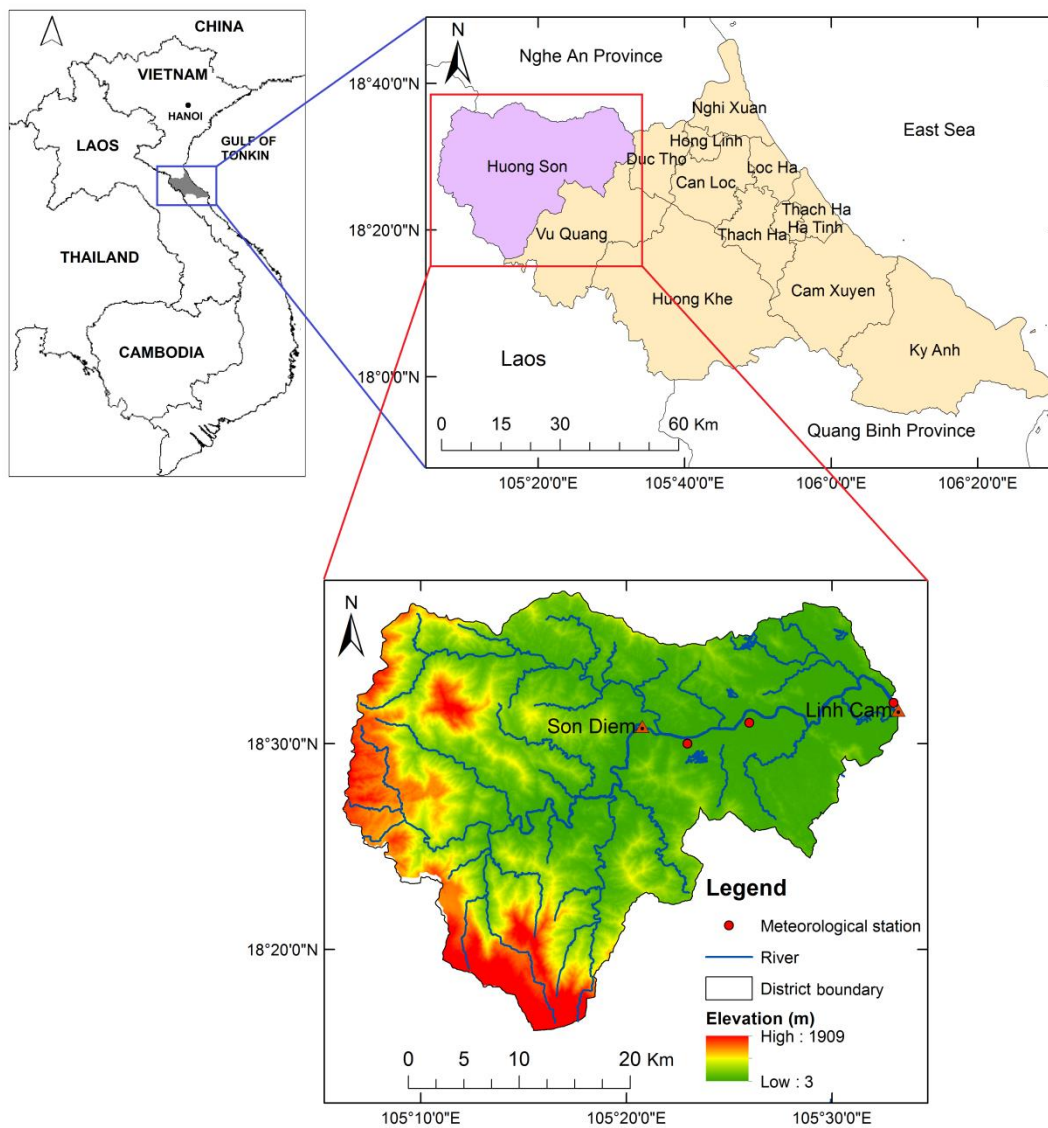


Figure 4 Map of the study area

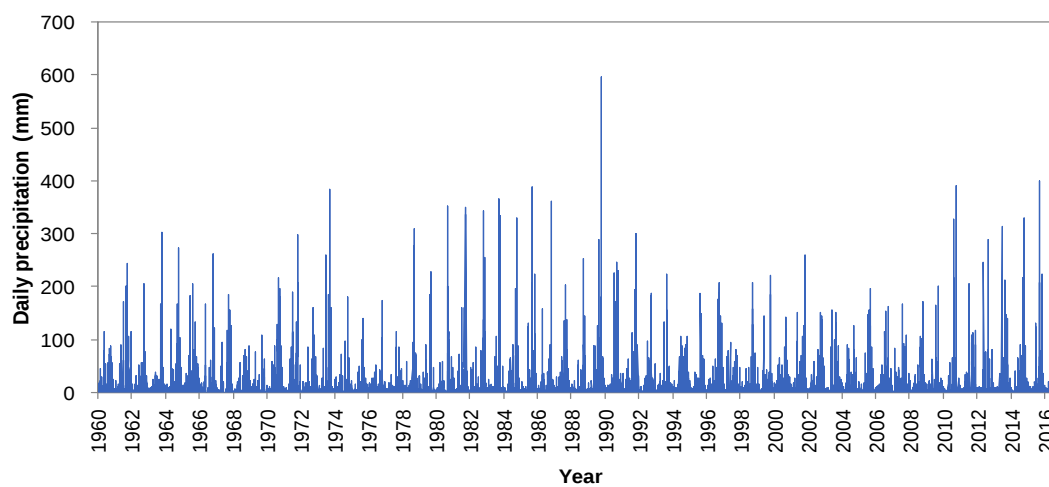


Figure 5 Daily precipitation at Pho Chau during 1960-2016

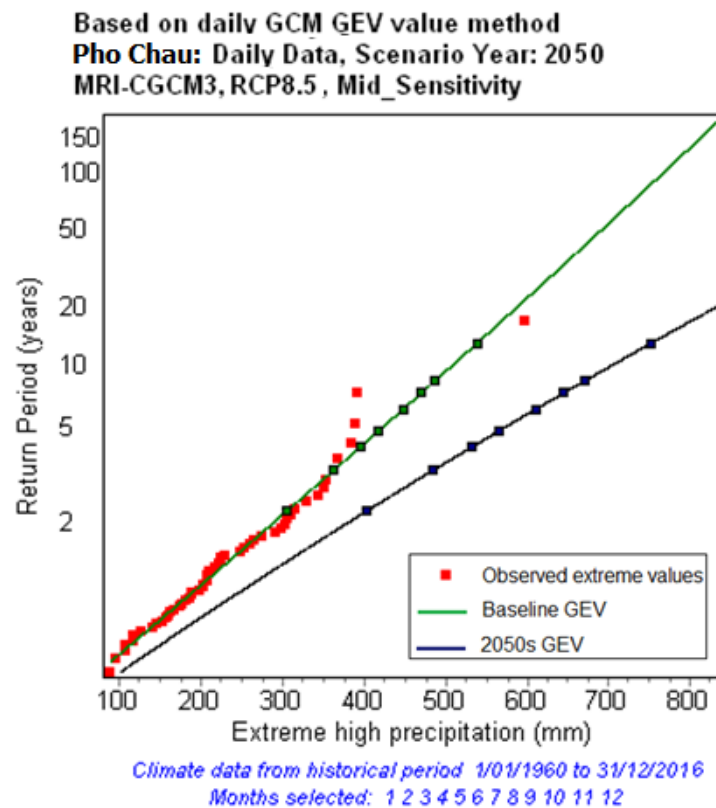


Figure 6 Extreme precipitation under the baseline period and 2050s

Figure 6 obviously shows that in 2050s under climate change impact, extreme precipitation at all level will become more intensified or more frequent compared to the baseline period. The line of GCM projected GEV becomes increasingly farther apart from the line of observed GEV towards the upper tail of the distribution indicates stronger climate change effects causing more extreme precipitation events. This pattern of precipitation change was previously discussed in Ye and Li (2011), which also applied GEV distribution and Pattern Scaling method for extreme precipitation prediction.

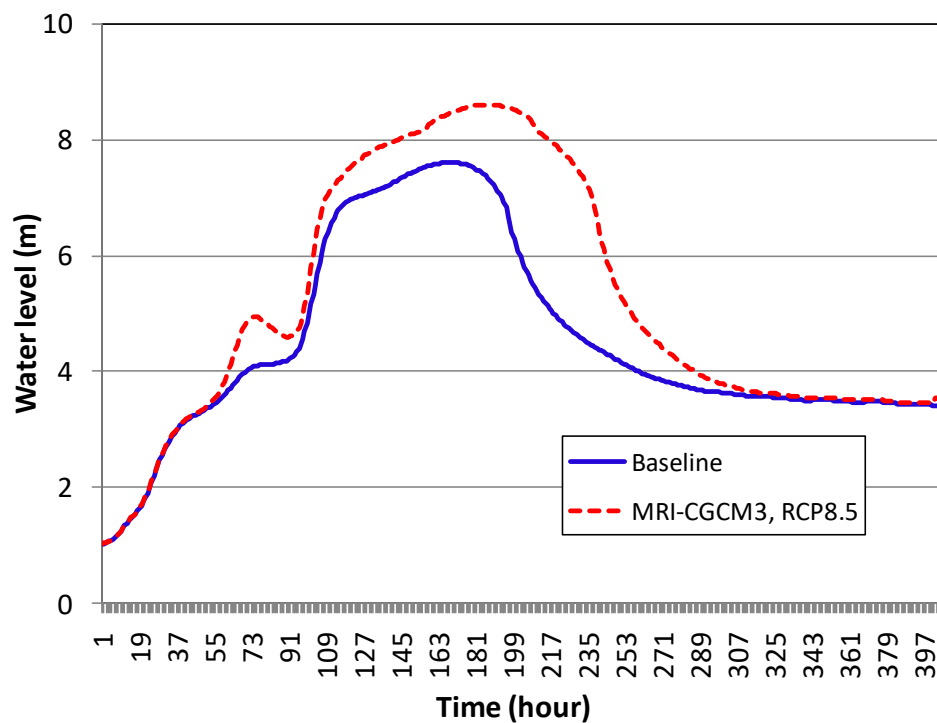


Figure 7 Comparison of water level in the baseline period and in 2050s

Our analysis of historical rainfall and flood data shows that in Huong Son district, the number of days from it starts raining till floods reach the reach peak level on average is 5 days. This study therefore calculated the change of five-day extreme precipitation. The result show that for an average extreme precipitation (EP) level, the baseline intensity of the 20 year-return period EP was 786.1 mm and changed to 1172.4 mm under RCP8.5 projection scenarios, which represents a potential range of intensity increase of 49.14%. The frequency of the 20 year-EP level of baseline changed to 4.2 years, which are significant frequency increases nearly 5 times.

Figure 7 shows the change in flood water level at Son Diem, the main hydrological station in Huong Son District. The water level in 2050s projected by MRI-CGCM3 model under RCP8.5 presents a significant increase compared with the baseline period. The peak water level was predicted to rise nearly 1 meter, from 7.62m in the baseline period to 8.59m in 2050s. Future flood events would also last longer under the impact of climate change as the distance between MRI-CGCM curve and the baseline curve increasingly enlarges with time during the peak flood period. A similar pattern of climate change induced raise in flood water level was previously found and discussed in Pham and Tran (2018).

3.2. Economic loss of rice production

Results from MIKE FLOOD model provided depth and duration of the flood at each mesh grid of the model. These data were then used for the generation of maps of depth and duration using spatial interpolation method. The maps are shown in Figure 8 - Figure 11. Calculation results from inundation maps show that the flooded area in the baseline period was 7,106.65 ha, accounting for 6.5% of the total natural area of the district. Most upstream communes with high terrain are not flooded, but downstream communes are flooded with large areas. Under climate change reinforcement, flooded area would increase to 7,534.64 ha (an increase of 427.09 ha) in 2050s under the MRI-CGCM3, RCP8.5 scenario. In addition to a significant increase in flooded area, the maps also show an increase in flood depth and inundation time. The increase in area of flood inundation due to climate change reinforcement was a common prediction among the scientific community and was reported by recent studies (Pham and Tran, 2018; Yue *et al.*, 2019). The area of rice cultivation inundated was identified by overlaying the inundation map and land use map. The loss of rice production was calculated using the stage-loss function (which is previously presented in Table 1) for every map grid and is shown in Figure 12.

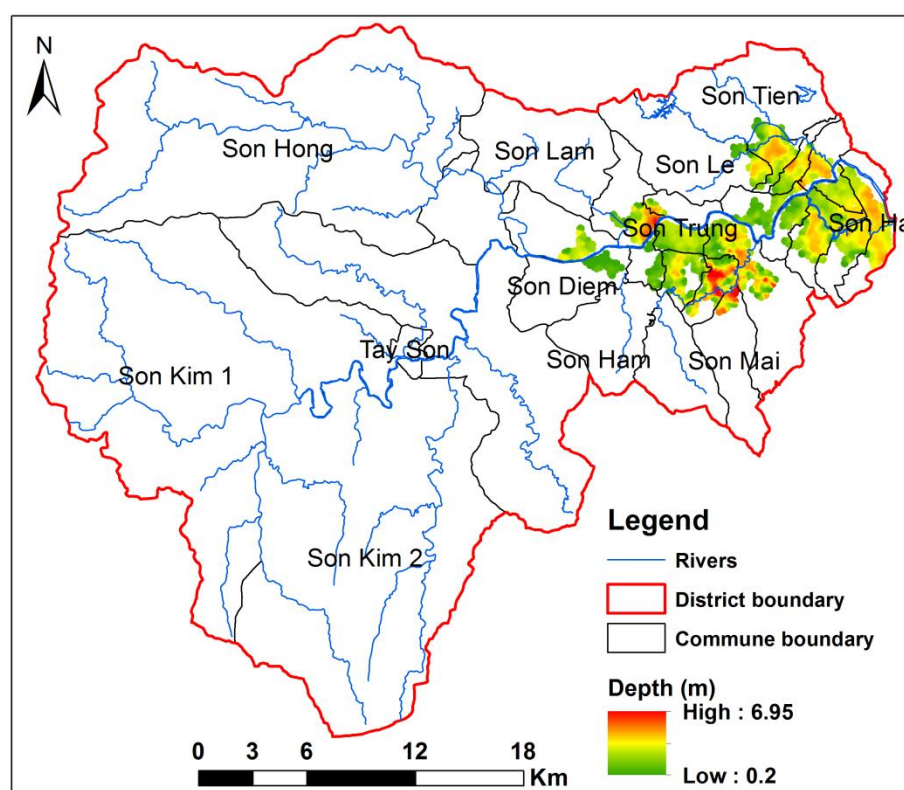


Figure 8 The area of inundation in Huong Son district in the baseline period

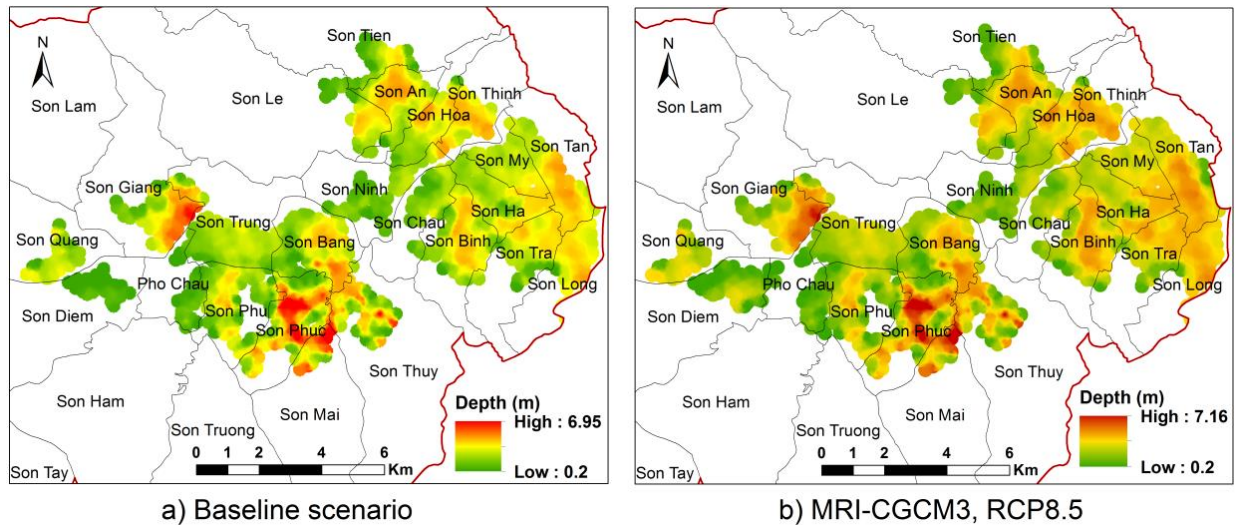


Figure 9 Inundation depth under baseline and MRI-CGCM3, RCP8.5 scenarios

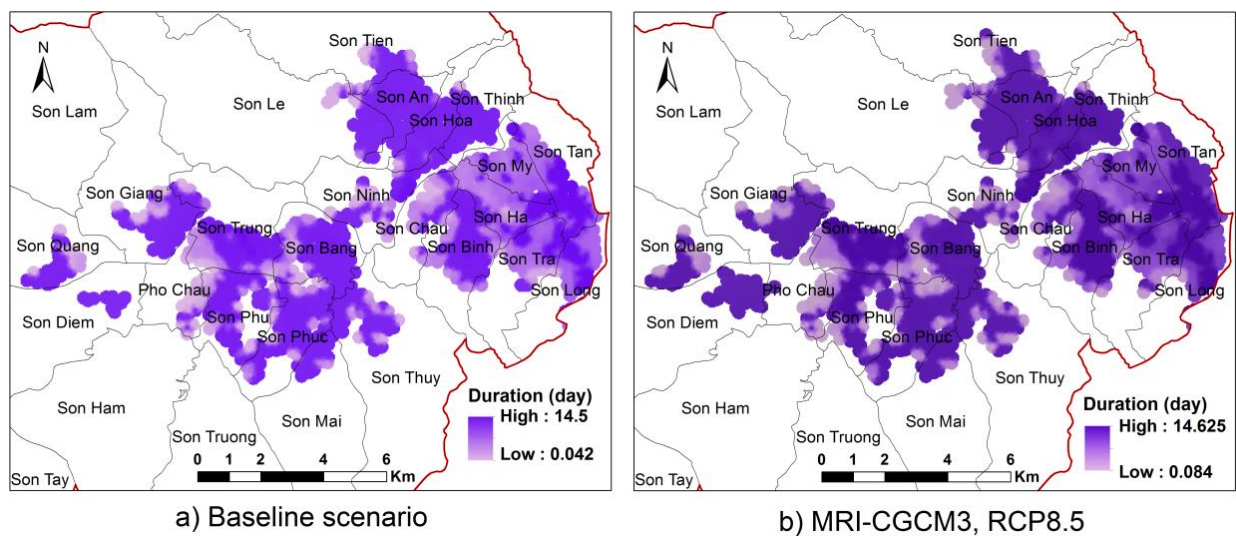


Figure 10 Inundation duration under baseline and MRI-CGCM3, RCP8.5 scenarios

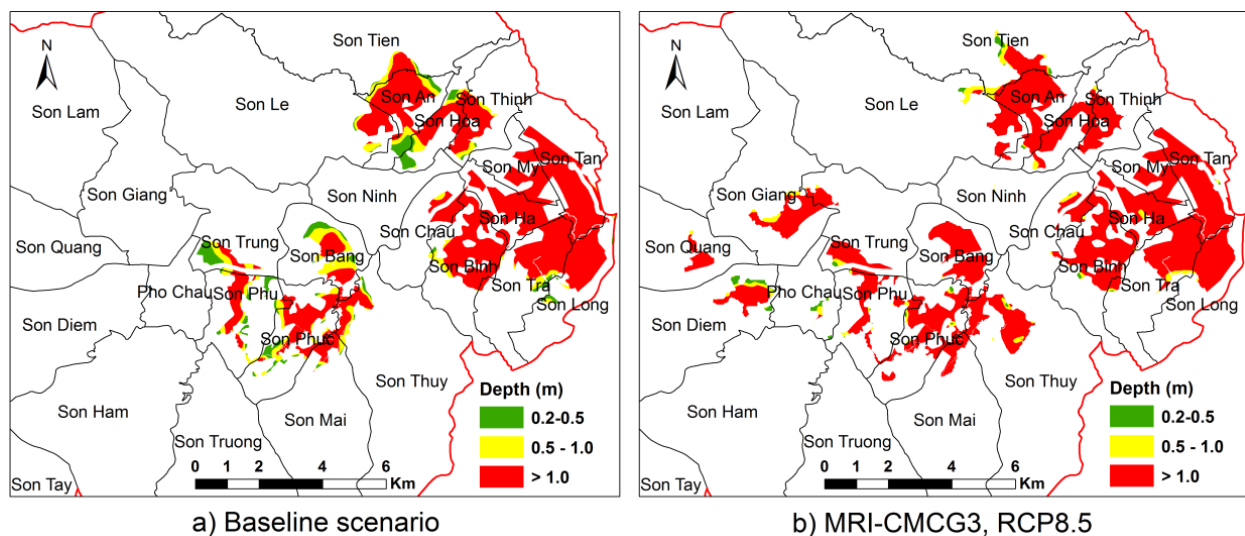


Figure 11 Map of classified inundation depth upon rice cultivation area

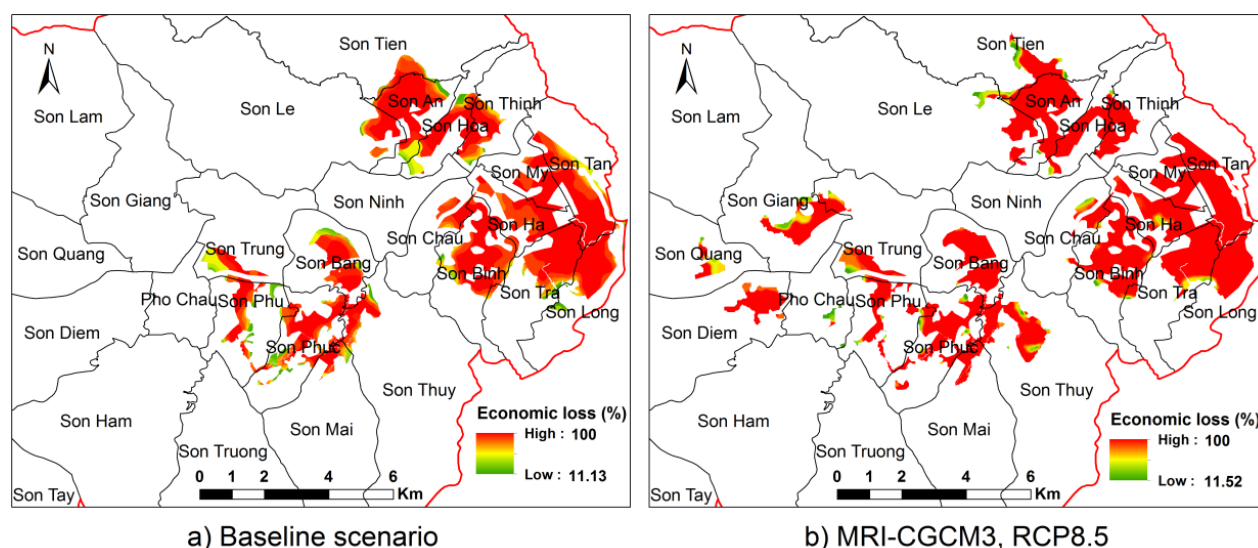


Figure 12 Loss of rice in percentage due to flooding under baseline and MRI-CGCM3, RCP8.5 scenarios

Figure 13 shows the area of rice inundated, the corresponding rice production affected, and the consequent economic loss of rice production. The area of rice inundated at the baseline period is 2752.32 hectares, increasing to 3099.38 hectares (up 12.61%) in the 2050s period according to MRI-CGCM3, RCP8.5 scenario. With an average rice yield of 5 tons/ha, rice price is 6.5 million VND/ton according to statistics of Huong Son District Statistical Office in 2018, rice production affected by flooding increased from 13761.58 tons to 15496.91 tons; the value of damage increased from VND 78.94 billion to VND 95.54 billion (up 21.02%). The above results show that the increasing trend of inundation time and depth of flooding has made the value of damage to rice production increased under the MRI-CGCM3, RCP8.5 scenario.

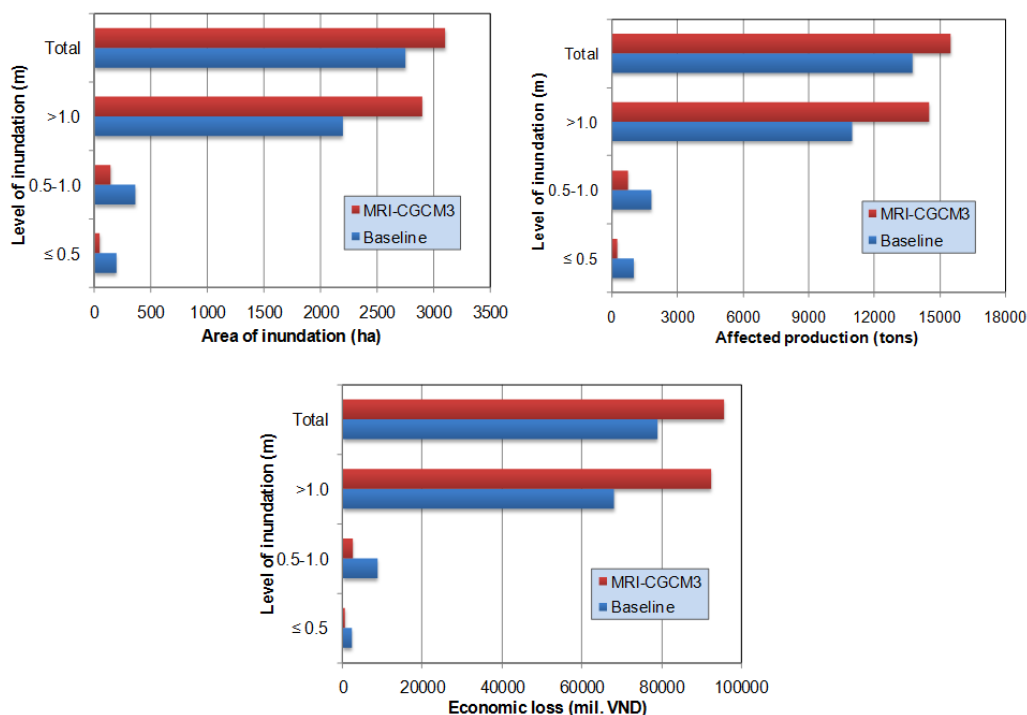


Figure 13 (a) Inundated area, (b) production affected and (c) economic loss of rice production under the baseline period and in 2050s.

The study found that the increase in the economic loss of rice production was not proportionate to the increase in the inundation area due to additional effect by the increase in inundation duration. It is widely agreed besides main factors including flood season, depth and duration, flood induced economic loss also depends on many other factors such as flood flow velocity,

contamination of flood water, sediment concentration, flood forecast, and the response of government and people in a flood situation. These factors, however, are very heterogeneous in space and time, difficult to predict, and there is limited information on their effects, they are therefore often neglected in economic loss calculation. Although some quantitative hints about the influence of several of the above factors was recommended (Thieken *et al.*, 2005), there is still no comprehensive approach for including all of such factors in economic loss evaluation. This is also the limitation of this study and more investigation on the effect of those factors is recommended for further research.

4. CONCLUSION AND RECOMMENDATION

Due to its geographic location and socio-economic conditions, Vietnam is among the countries most affected by floods and most vulnerable to climate change. In Vietnam, flood induced economic loss of rice production is a serious concern since rice is a major product for export and livelihood of large populations depends on rice production. This study predicted the economic loss of rice production due to flood inundation under climate change impacts using a modeling approach with a case study of Huong Son District, Ha Tinh Province, Vietnam. Extreme precipitation and its return periods were identified by GEV distribution method using historical daily observations and output of MRI-CGCM3 climate model. The predicted extreme precipitation data was then employed as an input of hydrological models for flood modeling. Finally, a complex approach taking into account depth and duration of inundation and crop calendar was used for the prediction of potential economic loss of rice production. Result of the study shows that the seriousness of floods would increase under climate change impacts as they become more intensified, deeper and longer, and consequently the economic loss of rice production would increase significantly. This finding is useful for long-term agricultural and infrastructural planning in order to tackle with potential flooding threats under climate change impacts.

Acknowledgement

This paper presents results of the key research project number T2018-04-08TD of Vietnam National University of Agriculture. The author wishes to thank the agencies and institutions of the Government of Vietnam for providing the data necessary for this study.

REFERENCE

1. Banerjee L. Effects of Flood on Agricultural Productivity in Bangladesh. Oxford Development Studies 2010; 38: 339–356.
2. Daniell J, Friedemann W, Schaefer A. The economic costs of natural disasters globally from 1900-2015: historical and normalised floods, storms, earthquakes, volcanoes, bushfires, drought and other disasters. Geophysical Research Abstracts 2016; 18: EGU2016-1899.
3. Huong Son Statistics Office. Statistics year book of 2018. Huong Son, Ha Tinh, Vietnam. 2018.
4. Dutta D, Herath S, Musiak K. A mathematical model for flood loss estimation. Journal of Hydrology 2003; 277: 24–49.
5. EMDAT (2019): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium
6. Intergovernmental Panel on Climate Change (IPCC). Climate change 2014: Synthesis Report. Contribution of Working Group I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. 2014.
7. Landwehr J, Matalas N, Wallis J. Probability weighted moments compared with some traditional techniques in estimating gumbel parameters and quantiles. Water resources research 1979; 15:1055–1064.
8. Messner F, Penning-Rowsell E, Green C, Meyer V, Tunstall S, Veen AVD. Evaluating flood damages: guidance and recommendations on principles and methods (Report No. T09-06-01). Centre of Environmental Research, Dresden Flood Research Center, Germany. 2007.
9. Penning-Rowsell E, Yanyan W, Watkinson AR, Jiang J, Thorne C. Socioeconomic scenarios and flood damage assessment methodologies for the Taihu Basin, China. Journal of Flood Risk Management 2013; 6: 23–32.
10. Pham QG, Toshiki K, Kunikane S, and Sakata M. Integrated water resources management in Vietnam under the challenges of climate change. Environment and Natural Resources Journal 2012; 10: 28 - 41.
11. Pham QG, Toshiki K, Sakata M, Kunikane S, Tran QV. Modelling Climate Change Impacts on the Seasonality of Water Resources in the Upper Ca River Watershed in Southeast Asia. The Scientific World Journal 2014; <http://dx.doi.org/10.1155/2014/279135>.
12. Pham QG, Kurisu K, Hanaki K. Assessing the accuracy of flood inundation simulation in a watershed scale using different correlation based and non-correlation based statistics. Proceedings of the 5th Annual International Conference on Sustainable Energy and Environmental Sciences (SEES 2016). Singapore, February 22nd- 23rd, 2016.
13. Pham QG and Tran TP. Evaluation of Loss of Rice Production due to Climate Change Reinforced Flood in Vietnam Using Hydrological Model and GIS. Environment Asia, Volume 11, pages 65-78, 2018
14. Standard and Poor's. Climate Change Is A Global Mega-Trend For Sovereign Risk. Standard and Poor's, New York,

- USA. 2014.
15. Thieken AH, Muller M, Kreibich H, Merz B. Flood damage and influencing factors: New insights from the August 2002 flood in Germany, *Water Resource Research* 2005; 41(12): W12430.
 16. United Nation Office for Disaster Risk Reduction (UNISDR). *Global Assessment Report on Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction (UNISDR) Geneva, Switzerland. 2009.*
 17. Vozinaki AEK, Kourgialas NN, Karatzas GP. Estimation of Agricultural Flood Loss in the Koiliaris River Basin in Crete, Greece. *European Water* 2012, 39: 53-63.
 18. Weyant J, Azar C, Kainuma M, Kejun J, Nakicenovic N, Shukla PR, Rovere EL, Yohe G. Report of 2.6 Versus 2.9 Watts/m² RCPP Evaluation Panel. *IPCC Secretariat, Geneva, Switzerland. 2009.*
 19. Ye W and Li Y. A method of applying daily GCM outputs in assessing climate change impact on multiple day extreme precipitation for Brisbane River Catchment. 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011.
 20. Yue Z, Ying W, Yu C, Fengguo L, Heping L. Assessment of future flash flood inundations in coastal regions under climate change scenarios-A case study of Hadahe River basin in northeastern China. *Science of the Total Environment* 2019; 693, 133550.
 21. Yukimoto, S., et al., 2011: Meteorological Research Institute-Earth System Model v1(MRI-ESM1)—Model Description. Technical Report of MRI. Ibaraki, Japan, 88 pp.
 22. Yukimoto S, Adachi Y, Hosaka M, Sakami T, Yoshimura H, Hirabara M, Tanaka T, Shindo E, Tsujino H, Deushi M, Mizuta R, Yabu S, Obata A, Nakano H, Koshiro T, Ose T, Kitoh A. A new global climate model of the Meteorological Research Institute: MRI-CGCM3—Model description and basic performance. *Journal of the Meteorological Society of Japan* 2012; 90A: 23–64.