Calculating design flood under the context of climate change - a case study in the south central and central highlands area

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Abstract: Currently, under the impact of climate change (CC), the phenomenon of extreme and against-the-order-of-nature weather appears more and more. Floods often occur suddenly, causing a great deal of damage to people and property. The South Central and Central Highlands have short and steep terrain and are also home to many small and medium reservoirs subjected to direct changes from the flow variation. There have been many studies and reports on the impacts of climate change on heavy rainfall in the area. However, there is some uncertainty between the results due to differences in input models, scenarios and destabilization methods. The paper focuses on assessing and analyzing the change of maximum rainfall in the South Central and Central Highlands under the average climate change scenarios (RCP4.5) and high climate change scenarios (RCP8.5) using different global climate models (GCM). The variation among the models (in percentile 25 to 75 percent) varied from 10 percent to 50 percent, indicating the uncertainty in the rainfall simulation of each GCM. As a result, flood simulation from the rainfall will be different according to the different climate models. The proposed report on the creation of zoning maps of design flood variation under the impact of climate change is based on the "consensus" of trends among GCM models. Based on that, the design floods in the basins in each region will be adjusted accordingly to ensure the safety and economics of the works

Keywords: Design flood, climate change, global climate model, statistical details.

1. Introduction

Design flood estimation has been one of the important tasks of hydrological science from the early days, which is an integral part of the design and assessment of reservoir safety. In recent years, under the impact of climate change, the hydrological regime in many parts of the world has been changing. The phenomenon of extreme and against-the-order-of-nature weather appears more and more. Floods occur frequently and continuously cause great damage to people and property. The South Central and Central Highlands have short and steep terrain and also have many small and medium basins which are subject to direct changes from the flow variation. Although there have been many studies and reports on the impacts of climate change on heavy rainfall in the area, there is some uncertainty among research results due to differences in input models, the use of scenarios and destabilization method, resulting in the variations of simulated flood flows among different climate models (An *et al.*, 2015; Trần Thị Tuyết *et al.*, 2018; Hằng, Dương and Đơn, 2020). The paper focuses on assessing and analyzing the change in maximum daily rainfall for the South Central and Western Highlands according to medium (RCP4.5) and high climate change (RCP8.5) scenarios using different global climate models (GCM). Then, the study proposes a "potential change" in the peak flow map based on the "agreement" of the trends between the outcomes of each model under the different scenarios into 3 groups: "high increasing", "medium increasing" and "no change". Based on that, design floods in the basins in each region will be adjusted accordingly to ensure the safety and economics of the project.

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2. Research methodology

For the South Central Region in particular and Vietnam in general, the cause of floods is mainly due to heavy and prolonged rain. Therefore, precipitation is the most considerable factor to estimate design floods for the South Central region. Criteria of design peak flood estimation for the ungauged basin in Vietnam (depending on the area of the basin) are given below:

- For basins with an area is less than 100 km2: apply the G.A. Alexeyev's formula (Alexeyev, 1967).
- For basins with an area of is in between 100 km2 and 1000 km^2: Using the Sokolovsky's formula (Sokolovsky, 1968).
- For larger basins: Estimated from similar basins by an empirical reduction formula.

Within the scope of the study, the paper carried out design flood calculations with consideration of climate change for small and medium river basins. In this case, the greatest daily rainfall would be the most important input to determine the flow of floods. The simulated rainfall data is derived from 11 global climate models, used by the Intergovernmental Panel on Climate Change (IPCC) in climate change reports (IPCC, 2013) with two climate change scenarios, namely RCP4.5 and RCP8.5. Detailed information of the models is presented in Table 1.

Table 1. Global climate models used in the study

No	Models	Institutions	Countries	Resolution
1	ACCESS 1.3	Bureau of Meteorology	Australia	$1{,}875^o \times 1{,}25^o$
2	CanESM2	Climate Modeling and Analysis Center	Canada	$2{,}81^o \times 2{,}79^o$
3	CMCC-CMS	Mediterranean Center for Climate Change	Italy	$1{,}875^o \times 1{,}865^o$
4	CNRM-CM5	National Center for Meteorological Research	France	$1{,}40^o \times 1{,}40^o$
5	CSIRO-MK3.6	Federal Institute for Science and Industry	Australia	$1{,}875^o \times 1{,}865^o$
6	FGOALS-g2	Institute of Atmospheric Physics, Institute of Science	China	$2{,}81^o \times 2{,}79^o$
7	GFDL-ESM2G	Laboratories of geophysical dynamics	America	$2{,}50^o \times 2{,}00^o$
8	HadGEM2-CC	Met Office Hadley Center	England	$1{,}875^o \times 1{,}25^o$
9	IPSL-CM5A-MR	Institute of Pierre Simon Laplace	France	$2{,}50^o \times 1{,}268^o$
10	MIROC5	Institute of Atmospheric and Oceanic Studies	Japan	$1{,}40^o \times 1{,}40^o$
11	MPI-ESM	Max Planck Institute of Meteorology	Germance	$1{,}875^o \times 1{,}865^o$

Observed rainfall data of 93 stations located in the South Central and Central Highlands are used to describe the precipitation condition in local. The data series are taken from the beginning of observation in each station until 2005 (the end of the historical simulation of the climate models), which is also considered as the baseline period for evaluating the variations of climate in the future. The missing and abnormal data of each station is analyzed to evaluate and adjust accordingly. The station network used in the study is depicted in Figure 1.

Observed precipitation at 93 stations in the area was used to correct the bias of GCM models. The method for bias correction is to find a function h in which, when plotting the simulated variable P_m, its new distribution function corresponds to the distribution of the observed variable P_o (where P_m and P_o are the simulated rainfall and observed rainfall). This transforming function can be represented by the formula:

$$Po = h(Pm) \qquad (1)$$

Statistical transforming functions are an application of the inverse integral of the probability distribution, and if the distribution of the variables is known, the transforming function is defined by Ines and Hansen, (2006) and Piani et al, (2010):

$$P_o = F_o^{-1}(F_m(P_m)) \qquad (2)$$

Where F_m is the cumulative probability distribution of P_m and F_o^{-1} is the cumulative inverse function corresponding to P_o.

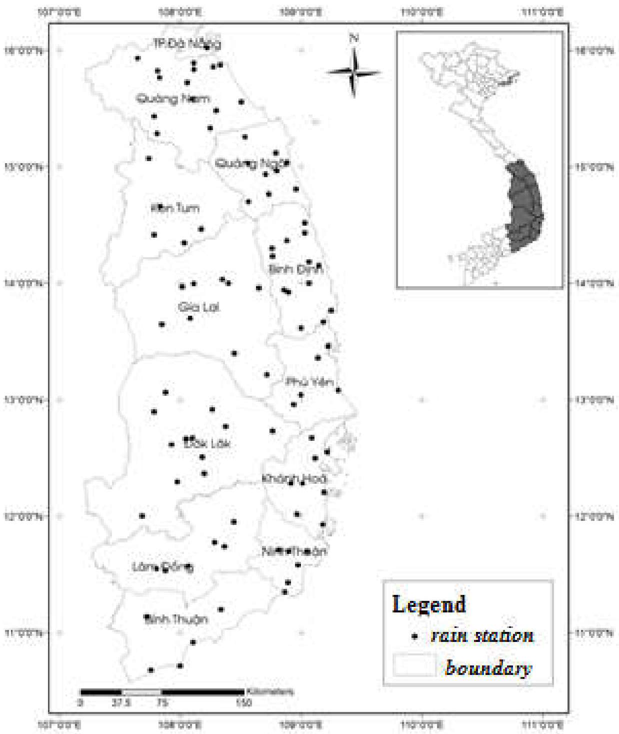

Figure 1. Map of the areas and stations used in the study

The results of the daily precipitation simulated from the 11 global climate models will be corrected the bias by applying the formula (1) for each station in the area. According to the Alexeyev and Xokolopski formulas, the design peak discharge taking into account climate change depends on the changing of the maximum daily precipitation in the future. From these two calculations, it can be seen that the rate of change of future design peak discharge will be equal to the change in the maximum daily precipitation with the assumption of other features of the basin and the relationship between short-term precipitation and unchanged daytime rainfall.

3. Results and discussion

3.1. Bias correction evaluation

Figure 2 shows the mean error (a) and the standard deviation error (b) between the results of the simulation of the maximum daily precipitation of the 11 models and measured results in the study area. For each model, the white box on the left represents the error between the unbias value and the measured one, and the blue box on the right represents the error after the bias correction process. The boxes represent the variable ranges corresponding from 25% to 75%. Dashes between boxes show average values.

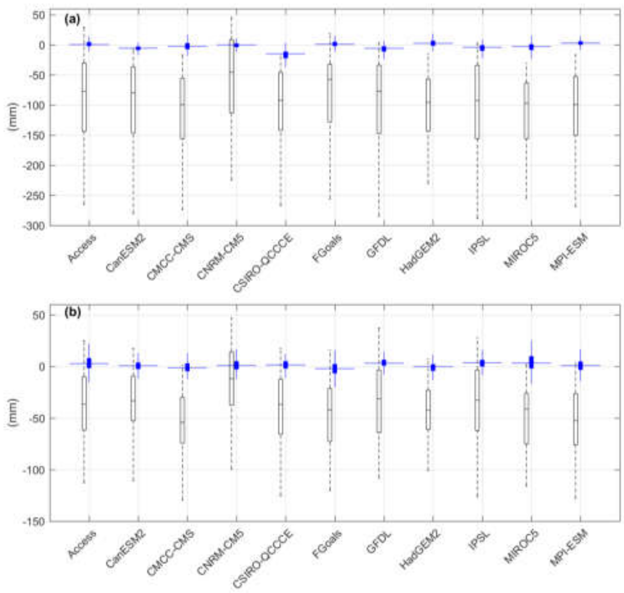

Figure 2. The average (a) and standard deviation (b) of the difference between the maximum daily precipitation of 11 GCM models with observed data at 93 rainfall stations in the study area

The results show that the precipitation in the past was simulated with a remarkably consistent local condition after bias correction. Before the correction, the difference between the mean and standard deviation of the maximum daily rainfall of the model was very large. The maximum daily rainfall is generally smaller than the observations from 50mm to 150mm, especially in cases of variation of up to 250mm as in CSIRO-QCCCE, CMCC-CMS, IPSL models.

After the bias correction, the average maximum daily rainfall (on the average of 93 stations) of the models was approximately equal to the actual measurement (within ± 5 mm). Similarly, mean standard deviation values have also been improved from -10 mm to -70 mm difference to ± 5 mm (in percentile 25 to 75 percent). The CMCC-CMS, CNRM-CM5, FGoals, HadGEM2 models exhibit a good fit at both the mean and standard deviation of the maximum daily rainfall series. The CSIRO-QCCCE model shows the worst results when both the mean error and the standard deviation error are still significantly lower than the real ones after correcting the error.

3.2. The development of the changing maximum daily precipitation map of the study area

The calculation results of the maximum daily precipitation from the 11 global climate models for the two phases of 2040-2069 and 2070-2099 are used to develop the maximum daily precipitation map in the South Central Region by two scenarios RCP4.5 and RCP8.5.

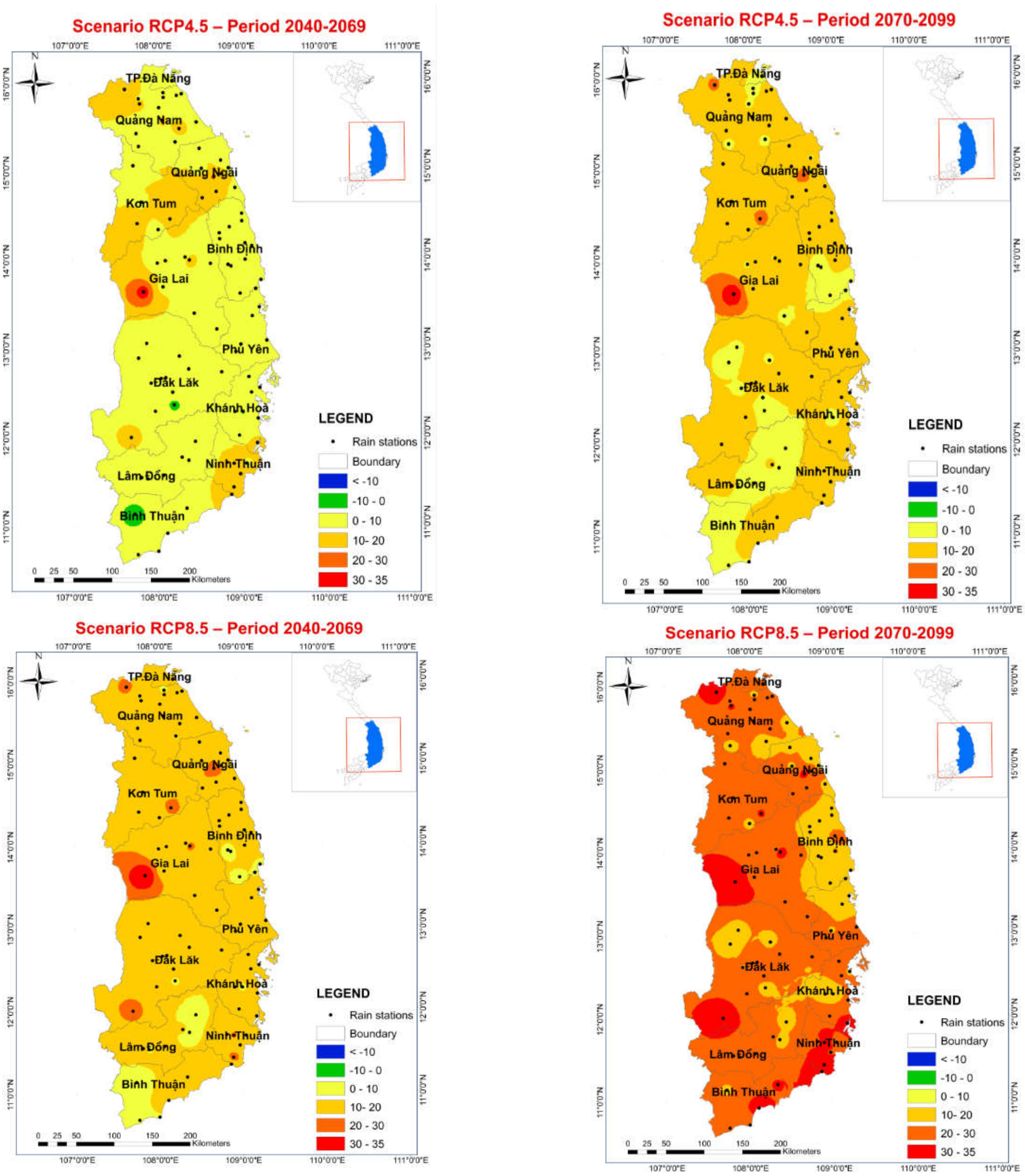

Figure 3. Map of the largest daily change in rainfall (%) according to scenarios

From the results of the maximum daily precipitation (Figure 3), it can be seen that in the scenario RCP4.5 phase 1 (2040-2069), most of the models show an increasing trend of rainfall compared to the base period, with an increase by from 0% to 20%. Results of the average rainfall calculation compared with the baseline from 11 models, generally in the South Central area, have an upward trend with a common increase from 0-10%. In the second period (2060 - 2099) for RCP4.5 scenarios, the average rainfall is likely to increase compared to the first period, with the typical increase of 20-30% except for Chu Prong station in Gia Lai. Scenario RCP8.5 in both phases tends to have similar trends to RCP4.5 with an average increase of 10-20% in period 1 and 20-30% in period 2.

To clarify the changes, the study focuses on analyzing the maximum daily precipitation changes of some major areas compared to the baseline including the whole zone, Vu Gia Thu Bon (VGTB), Tra Khuc (TK), Cai River (Cai), Ba River, Kone, Sesan and Srepok. Accordingly, the average daily rainfall variation in each basin is represented by a box representing 25 to 75 percent of the 11 models. The dashes in each box correspond to 50%, while the diamonds correspond to the mean. The stripes are extended to a range of 1.5 times the spacing between the top and bottom of the box. The external (+) signs represent exceptional values. The results show that the maximum daily precipitation variations in the areas are as follows: Except for scenario RCP 4.5 simulating the first period for the maximum daily precipitation in which there is a large difference in rainfall from the baseline, most models generally show a significant increase in rainfall in the basins despite remarkable differences between models. The variation between the models (in the 25 to 75 percent range) fluctuates from 10% to 50% (especially in the Srepok River Basin), which demonstrates uncertainty in the rainfall simulation of each GCM model. On the other hand, many models show the greatest reduction in average daily rainfall in the Ba, Kone, Srepok and Cai basins, although the rainfall in these basins increases on average (Figure 4).

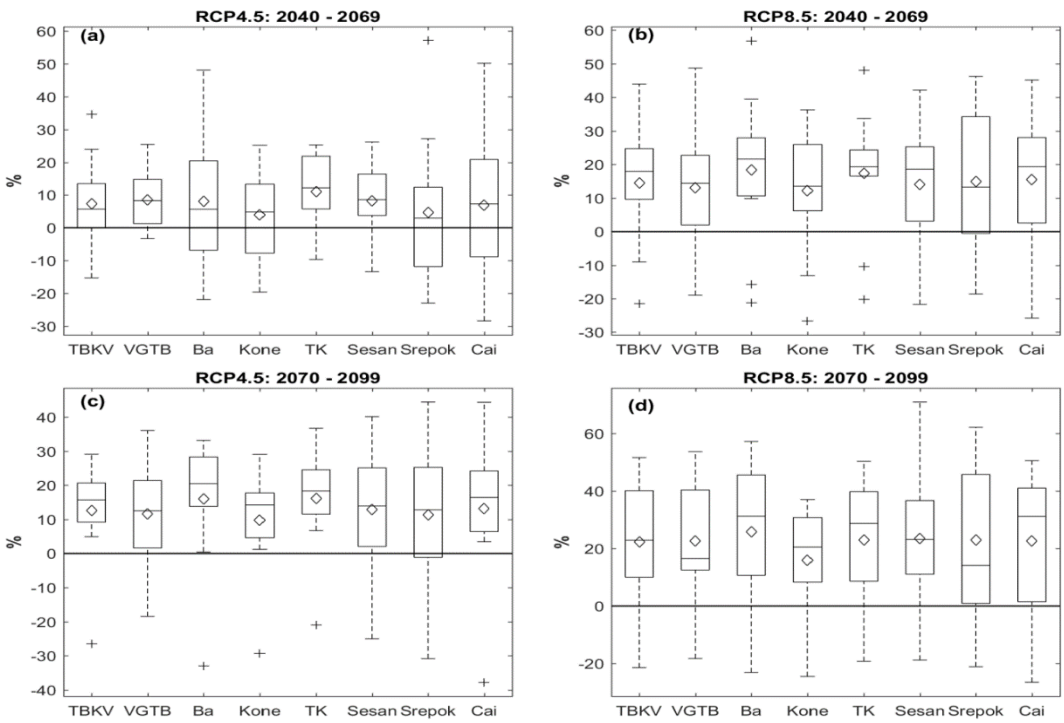

Figure 4. Average variations of largest one-day rainfall in some major river basins compared to the baseline

3.3. Develop a risk map of increasing design peak discharge for small and medium basin

From the results of calculating the maximum daily precipitation under the climate change scenarios, it can be seen that future flood flows will also have the same change when using the Xokolopski and Alecxayep. Fluctuations in peak discharge also indicate that there is a difference between GCMs and even contradictory increases or decreases in intensity. To simplify the selection of the design, the study recommends the criteria for the classification of "potential change" for the peak of flow as shown in Table 2. The general criteria for zoning are based on the maximum daily precipitation variability of each model and the average of all 11 models, and also consider the number of models "agreeing" with such "general" variation.

Table 2. Criteria for Classification of "potential change" in peak of flow

Groups	Number of models for increased peak discharge	Qmax change of average GCM models	The change of average coefficient of variation
3 (High Increasing)	> 2/3	>10%	>=0
2 (LowIncreasing)	> 2/3	>10%	<0
	> 1/2	>0	>=0
1 (No change)	< 1/2		

Based on the criteria in Table 2, the study establishes "changing of the peak of flow" based on the maximum daily precipitation change for two periods: 2040–2069 and 2070 – 2099 (Figure 5). To apply this map when calculating design floods for basins within the scope of the map, it is important to depend on the area of the basin and the importance of the constructions for making reasonable choices. For example, if the basins for calculation are small and located in the areas corresponding to the design flood peak which is likely to increase more than the base period, after calculating the design flood flow according to the mentioned methods, this design flood flow can be added a safety factor of 10%. Likewise, for areas where the increased design flood flows are little, a safety factor of 5% may be obtained. With the "No change" area, the calculation results are kept.

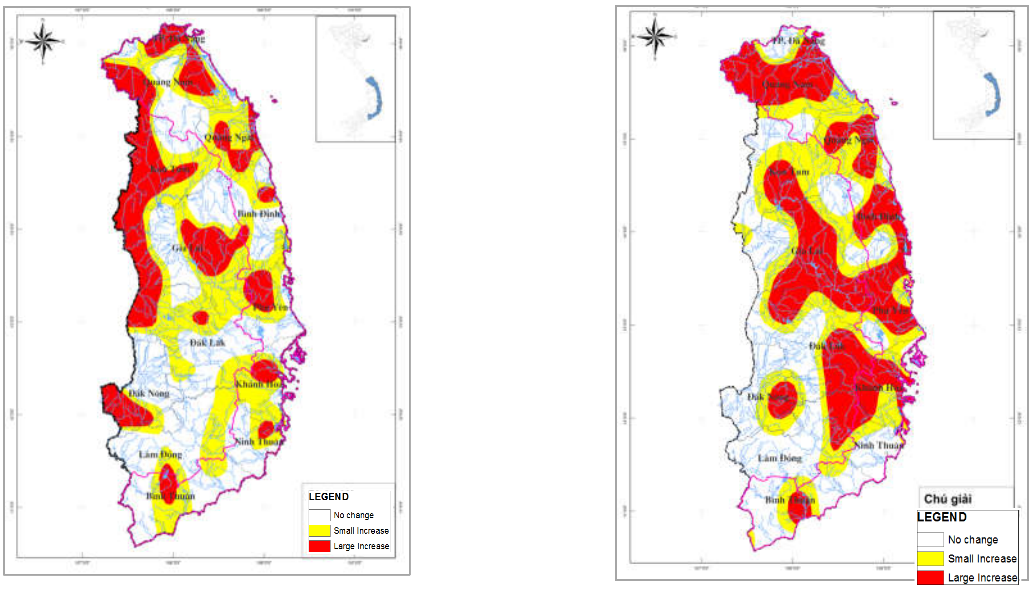

Figure 5. Zoning map of design flood flow fluctuations in 2040 - 2069 period (left) and 2070 - 2099 period (right)

4. Conclusions

The study used data from 93 regional rainfall stations and simulation results of 11 global climate models. The report has been bias-corrected between simulation results from the GCM model and measured data in stations in the base period using the empirical quantile mapping method. The results showed that the bias correcting step reduced the errors in the simulation of the model.

From the correcting of simulation results of the future rainfall according to the 11 models, the inverse distance weight interpolation method is used to describe the precipitation to generate maps of the maximum daily rainfall variations in the future for the entire study area. The output results of the average rainfall compared to the baseline from the 11 models of the first period (2040-2069) show that in general, the South Central region witnessed an upward trend with a common increase of 10-20%, and 20-30% in the second period (2070-2099) under both scenarios RCP4.5 and RCP8.5.

The study compiled the criteria for the classification of "potential change" in peak discharge based on the changes in the maximum daily precipitation of each model and the average of 11 models. Then a risk map for flood variation taking into account climate change is generated for small and medium basins. Based on the maps, the future design flood estimation should be considered.

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