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CHANGES IN RIVER DISCHARGE IN THE INDOCHINA PENINSULA REGION PROJECTED USING MRI-AGCM AND MIROC5 DATASETS

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A distributed flow routing model with kinematic wave flow approximation (1K-FRM) was applied to project river discharge in the Indochina Peninsula region. The input data for flow routing model 1K-FRM were the generated-runoff data at 3-hourly time step from the latest versions of the Meteorological Research Institute atmospheric general circulation model (MRI-AGCM3.2S, MRI-AGCM3.2H) and the Model for Interdisciplinary Research on Climate (MIROC5) for three 25-year periods: 1979-2003 (present climate), 2015-2039 (near future climate), and 2075-2099 (future climate). Simulated discharge data for the near future climate and the future climate were compared with those for the present climate to evaluate the changes in flow in the region under a changing climate. The statistical significance of river discharge changes in the Indochina Peninsula region was also analyzed.

Key Words: *Indochina Peninsula, river discharge, climate change, 1K-FRM, MRI-AGCM, MIROC5*

1. INTRODUCTION

In the Fourth Assessment Report (AR4)[1)] published in 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that the anthropogenic increasing of greenhouse gas concentrations is the main cause of the current global warming trend. The global average surface temperature was reported to increase about 0.74 degree Celsius over the last 100 years. Increases in surface temperature are likely to have many impacts on the hydrological cycle and associated extremes such as floods and droughts.

Currently, general circulation models (GCMs) are the most effective tools for simulating present climate and projecting future climate. The outputs of GCMs with various spatial resolutions can be used as inputs to hydrological model simulations to assess the impact of climate change on hydrology and water resources.

In this study, the impact of climate change on river discharge in the Indochina Peninsula region (see Fig.1) and statistical significance of river discharge changes were investigated by conducting distributed hydrological simulations using three different GCM datasets: the MRI-AGCM3.2S[2)], the MRI-AGCM3.2H[2)], and the MIROC5[3)]. Outputs of these GCMs were obtained from the multi-model dataset archive of the Coupled Model Intercomparison Project Phase 5 (CMIP5).

2. METHODS

(1) Hydrological model

River discharge in the Indochina Peninsula region was projected using flow routing model 1K-FRM. 1K-FRM is a distributed hydrological model with kinematic wave flow approximation[4)]. It was developed by Hydrology and Water Resources Research Laboratory of Kyoto University (http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html).

1K-FRM was based on a catchment topography model. The topographic information used for 1K-FRM in this study was generated from processing the scale-free global stream-flow network dataset, which was provided by Masutani *et al.*[5)], with a spatial resolution of 5 arc minutes. The flow direction is defined using 8-direction method, which

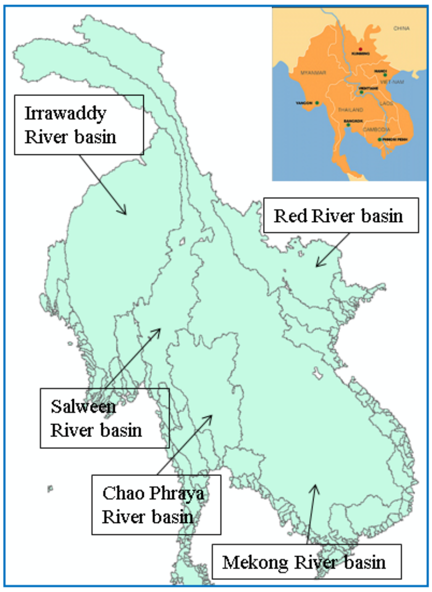


Fig.1 The study area, Indochina Peninsula region.

assigns flow from each grid cell to one of its 8 neighbors, either adjacent or diagonally, in the direction with the steepest downward slope. Each slope element determined by flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. Then the runoff is routed according to the flow direction information by applying the kinematic wave flow model to all slope elements.

(2) General circulation models

The climate models used in this study are MRI-AGCM3.2S, MRI-AGCM3.2H and MIROC5. The MRI-AGCM3.2S (the 20-km model) and MRI-AGCM3.2H (the 60-km model) are the latest atmospheric GCMs based on a model jointly developed by the Japan Meteorological Agency (JMA) and the Meteorological Research Institute (MRI). The MIROC5 (the 140-km model) is an atmospheric-ocean GCM developed jointly by the Atmosphere and Ocean Research Institute (AORI), University of Tokyo, the National Institute for Environmental Studies (NIES), and the Japan Agency for Marine- Earth Science and Technology (JAMSTEC).

The generated-runoff data at 3-hourly time step from three GCMs mentioned above were used as input for flow routing model for three 25-year periods: 1979-2003 (present climate), 2015-2039 (near future climate), and 2075-2099 (future climate). The data used for future projection were based on the Special Report on Emissions Scenarios (SRES) A1B scenario (MRI-AGCM3.2S, MRI-AGCM3.2H) and the Representative Concentration Pathway 6 (RCP6) scenario (MIROC5). The SRES A1B scenario and the RCP6 scenario are more or less equivalent in term of CO_2 concentration.

(3) Relative change in river discharge

The ratio of annual mean discharge, mean of annual maximum daily discharge, and mean of annual minimum daily discharge of the near future climate and the future climate to the one of the present climate were calculated and analyzed to examine the change in river discharge in the Indochina Peninsula region under climate change.

(4) Statistical significance

The statistical significance of river discharge change in the Indochina Peninsula region was assessed by comparing annual mean values of projected river discharge data in the near future climate and the future climate with those in the present climate. It is to evaluate whether the changes in river discharge are statistically significant or just occur by chance.

The null hypothesis H_0 for the statistical significance testing of river discharge change was defined as follows: there is no significant difference between annual mean discharge/mean of annual maximum daily discharge/mean of annual minimum daily discharge of the near future climate/the future climate and the present climate.

The approach for comparing those statistics is chosen based on the distribution of projected river discharge data. If the data are normally distributed, a parametric approach can be employed to determine whether the difference in the means is statistically significant or not. In cases where the data are not normally distributed, non-parametric approaches can be used. Non-parametric tests are generally less powerful than parametric tests because they are based on fewer assumptions.

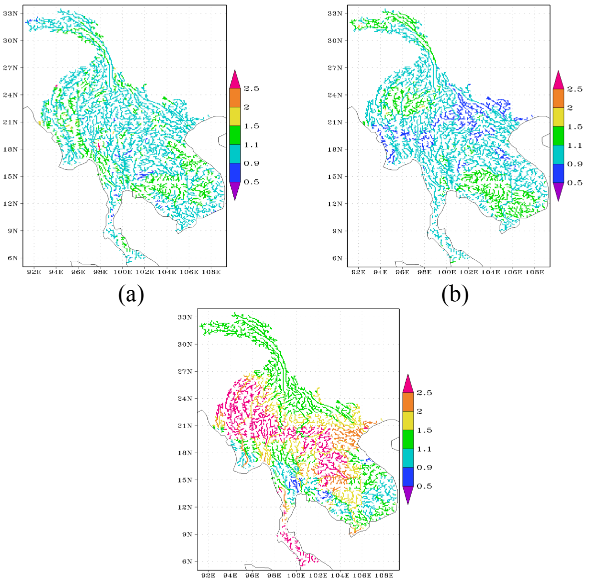
In this study, the Shapiro-Wilk W test[6] was applied to test for normality of the projected data at each model grid cell. The parametric Welch correction t-test[7] was performed to test for statistical significance of normally distributed river discharge data. And the non-parametric Mann-Whitney U test[6] was applied for the data which have a non-normal distribution. A significance level of 5% (or confidence level of 95%) was selected.

The map of statistical significance of river discharge change in the Indochina Peninsula was made by combining the results from statistical tests mentioned above.

3. RESULTS

(1) Changes in annual mean discharge

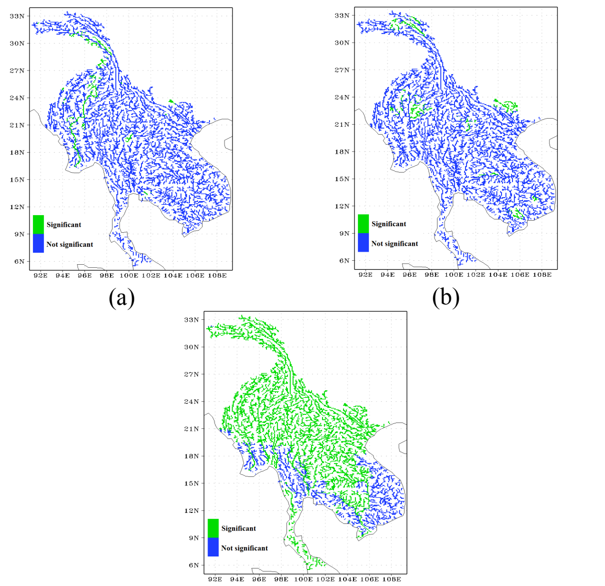
The relative change and statistical significance differences between annual mean discharge of the near future climate and the present climate are illustrated in Fig.2 and Fig.3.



(a) (b)

(c)

Fig.2 Ratio of annual mean discharge of the near future climate to the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).



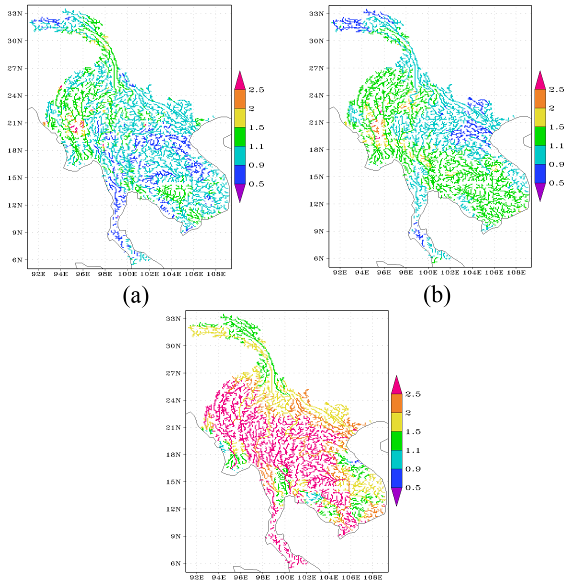
(a) (b)

(c)

Fig.3 Statistical significant differences between annual mean discharge of the near future climate and the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).

The increase of annual mean discharge is commonly found in the middle part of the Irrawaddy River basin and lower part of the Mekong River basin. Only the simulation using MRI-AGCM3.2H dataset shows a decreasing trend at the upper part of the Red River basin (see Fig.2b). However, except the simulation using MIROC5 dataset, the changes in annual mean discharge in the near future were not statistically significant.

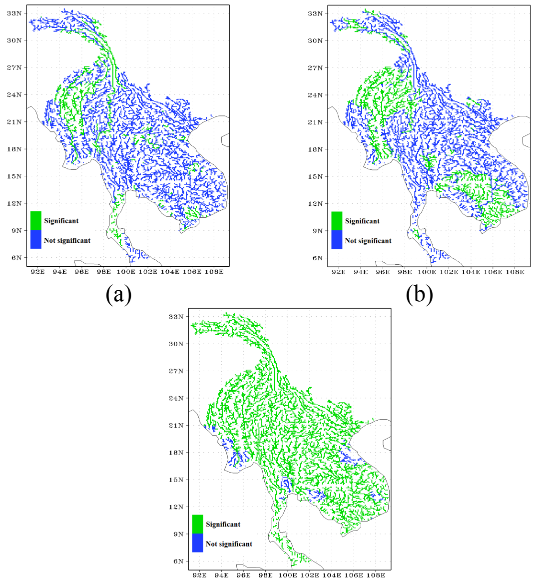
For the future climate, the changes of annual mean discharge and statistical significance are



(a) (b)

(c)

Fig.4 Same as Fig.2, but for the future climate.



(a) (b)

(c)

Fig.5 Same as Fig.3, but for the future climate.

represented in Fig.4 and Fig.5. The pattern of river discharge changes in the future climate was similar to the one in the near future climate but with larger area and higher ratio. The increase of annual mean discharge in the future was statistically significant at the Irrawaddy River basin and lower most part of the Mekong River basin in all three simulations. The simulation using MIROC5 dataset showed a significant increase in annual mean discharge in almost all over the study area.

(2) Changes in mean of annual maximum daily discharge

For the mean of annual maximum discharge, the near future increase of annual maximum daily discharge appeared at the upper part of Irrawaddy

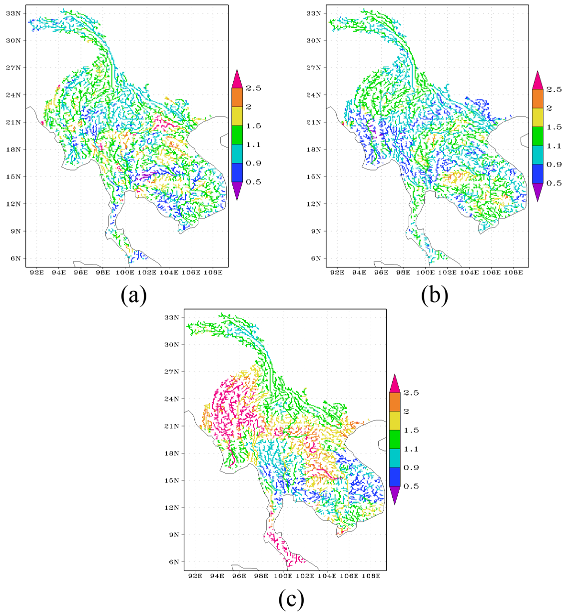


Fig.6 Ratio of mean of annual maximum daily discharge of the near future climate to the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).

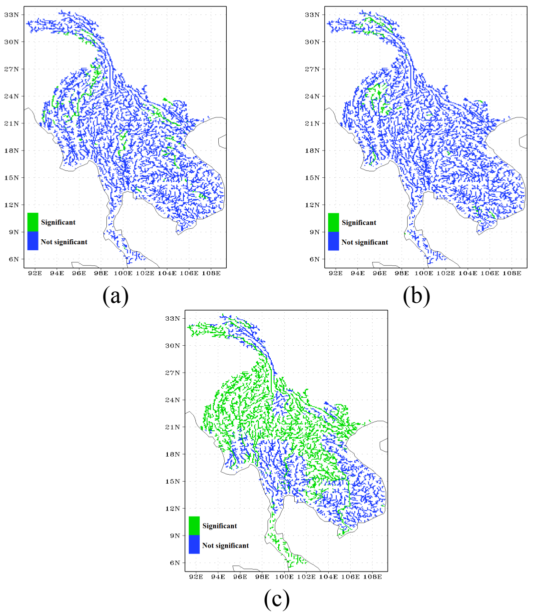


Fig.7 Statistical significant differences between mean of annual maximum daily discharge of the near future climate and the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).

River basin and lower part of Mekong River basin in all three simulations, although the statistically significant area was small (see Fig.6 and Fig.7). In addition, both MRI-AGCM3.2S and MIROC5 simulations showed the statistical significance in the increasing of annual maximum daily discharge at the lower tributary of the Red River.

From Fig.8, it can be seen that the increasing trend of annual maximum daily discharge in the Irrawaddy River basin and the Red River basin,

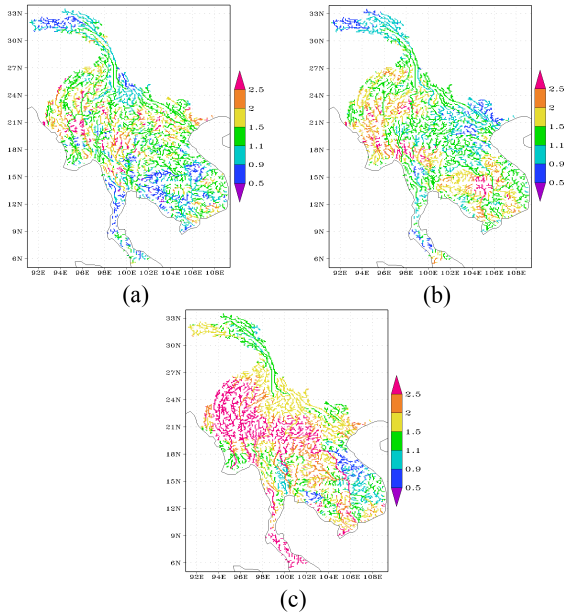


Fig.8 Same as Fig.6, but for the future climate.

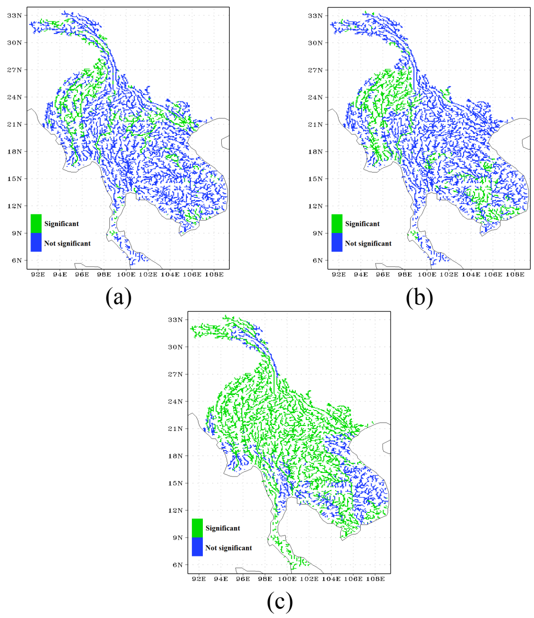


Fig.9 Same as Fig.7, but for the future climate.

which was detected in the near future, become more visible in the future. The relative change of discharge was higher than in the near future climate; and the area with statistically significant change in discharge was also larger (see Fig.9).

In the future climate, the increase of annual maximum daily discharge was also found statistical significance at lower most part of the Mekong River basin from the results of all three simulations (see Fig.9).

(3) Changes in annual minimum daily discharge

For the annual minimum daily discharge, Fig.10 and Fig.11 show opposite results from three simulations. While simulation using MIROC5

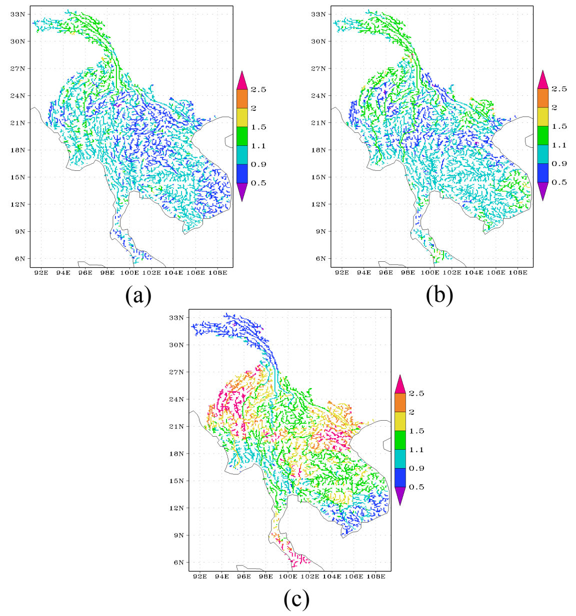


Fig.10 Ratio of mean of annual minimum daily discharge of the near future climate to the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).

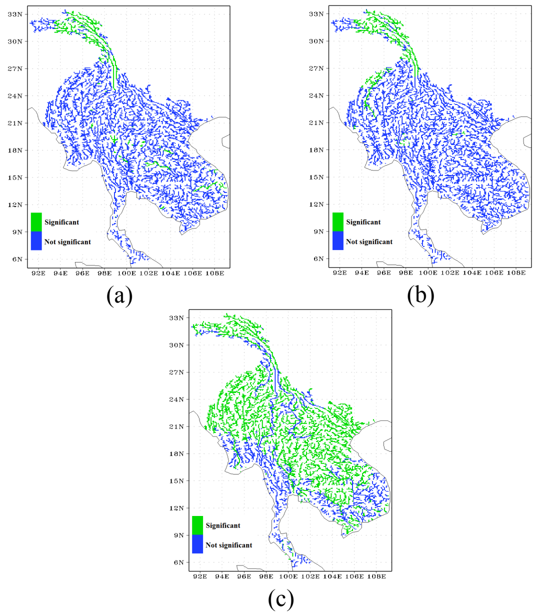


Fig.11 Statistical significant differences between mean of annual minimum daily discharge of the near future and the present climate simulated using MRI-AGCM3.2S (a), MRI-AGCM3.2H (b), and MIROC5 (c).

dataset demonstrated a statistically significant decreasing trend at the upper most parts of the Salween River basin and the Mekong River basin, the others illustrated an increase of river discharge with statistical significance in the near future climate.

In other parts of the Indochina Peninsula region, except the result from MIROC5 simulation, the changes in annual minimum daily discharge were not statistically significant.

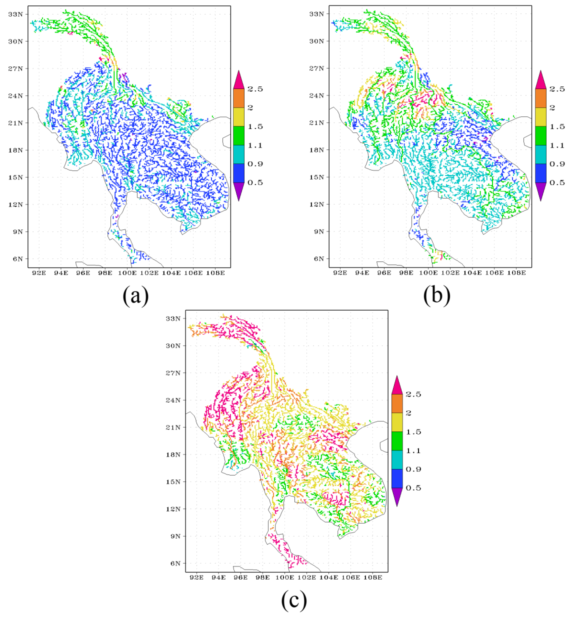


Fig.12 Same as Fig.10, but for future climate.

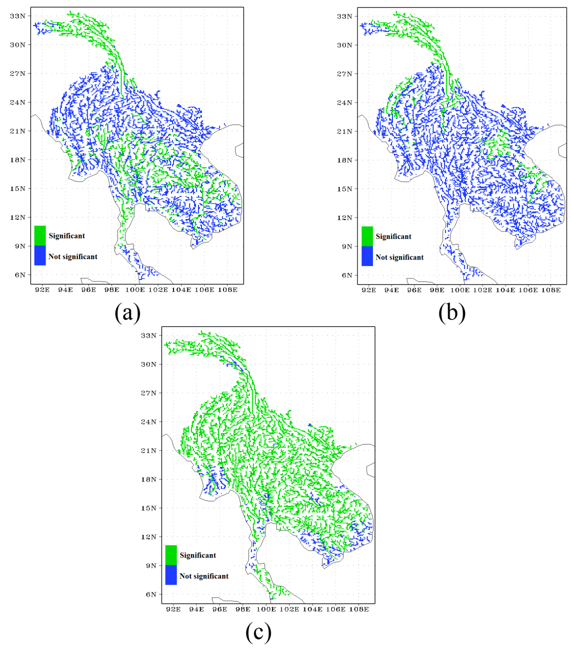


Fig.13 Same as Fig.11, but for future climate.

In the future climate, all three simulations showed an increase in annual minimum daily discharge at the upper most part of the Salween and the Mekong River basin. This increase is also statistically significant (see Fig.12 and Fig.13).

In the central part of Vietnam, a decreasing trend of annual minimum daily discharge in the future climate was found statistically significant from simulations using MRI-AGCM3.2S and MRI-AGCM3.2H datasets. However, the simulation using MIROC5 dataset displayed an opposite trend (see Fig.12c, Fig.13c). This opposition also occurs at the Chao Phraya River basin and middle part of the Mekong River basin.

4. DISCUSSIONS

From the simulation results presented above, there are discrepancies on the ratio of river discharge change and area of statistically significant increase or decrease among three simulations using different GCMs datasets. These discrepancies may come from the differences in GCMs structures, parameterization, and spatial resolution.

According to Giorgi *et al.*[8], regional topographic forcing due to orography, land-sea contrasts and vegetation characteristics will be described more precise with fine spatial resolution. Consequently, processes such as orographic precipitation and monsoon circulations, which strongly forced by topography, improve at increased resolution. And the generated-runoff data used as input for flow routing model are strongly related to projected precipitation data. Therefore, we can see that the ratio of river discharge change and area of statistically significant increase with the decrease of spatial resolution, especially in the simulation using MIROC5 dataset.

Factors other than spatial resolution may be contributors to the simulation biases of river discharge. It needs more future further work to investigate.

However, the results from those three simulations also showed a consistent statistically significant increase in river discharge in the Irrawaddy River basin, especially the annual maximum daily discharge in the future climate. It means that flooding risk in this area could increase in the future.

5. CONCLUSIONS

This study investigated the change in river discharge in the Indochina Peninsula region under a changing climate using the distributed flow routing model 1K-FRM and three different GCMs datasets (MRI-AGCM3.2S, MRI-AGCM3.2H, and MIROC5). Statistical analysis was also carried out to examine the statistical significance of river discharge changes in the region. A clear change of river discharge was detected and found statistically significant in the Irrawaddy River basin, especially the annual maximum daily discharge in the future.

For future further work, more GCMs' data will be used to evaluate the uncertainty in climate projection and to investigate the factors contributed to the simulation biases of river discharge.

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