Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol. 69, No. 4, I_37-I_42, 2013.

RIVER DISCHARGE PROJECTION IN INDOCHINA PENINSULA UNDER A CHANGING CLIMATE USING THE MRI-AGCM3.2S DATASET

Duc Toan DUONG[1], Yasuto TACHIKAWA[2], Michiharu SHIIBA[3], Kazuaki YOROZU[4]

[1]Student Member of JSCE, Dept. of Civil and Earth Resources Eng., Kyoto University (Kyoto 615-8540, Japan)
[2]Member of JSCE, Assoc. Prof., Dept. of Civil and Earth Resources Eng., Kyoto University (Kyoto 615-8540, Japan)
[3]Member of JSCE, Prof., Dept. of Civil and Earth Resources Eng., Kyoto University (Kyoto 615-8540, Japan)
[4]Member of JSCE, Assist. Prof., Dept. of Civil and Earth Resources Eng., Kyoto University (Kyoto 615-8540, Japan)

River discharge in Indochina Peninsula region was projected using a distributed flow routing model (1K-FRM) with kinematic wave flow approximation for three climate experiments: the present climate (1979-2008), the near future climate (2015 - 2044), and the future climate (2075-2104). Topographic data used for the flow routing model is 5-minute spatial resolution data which was processed from scale-free global stream-flow network dataset. The flow routing model 1K-FRM was fed with general circulation model (GCM) generated runoff data for three climate experiments. The GCM dataset used was the latest 20km spatial resolution general circulation model (MRI-AGCM3.2S), which was developed by Meteorological Research Institute, Japan Meteorology Agency. The changes of flow in Indochina Peninsula region under climate change were analyzed by comparing simulated river discharge for the present climate, the near future climate, and the future climate experiment. Analysis results show clearly changes of annual mean discharge, mean of annual maximum discharge and mean of annual minimum discharge with the degree of changes different according to location. The changes, which were detected in the near future climate conditions, become clearer in the future climate conditions. In some locations, the increase of flood and drought risk was found.

Key Words: *Indochina Peninsula, river discharge, 1K-FRM, climate change, general circulation model*

1. INTRODUCTION

Global warming has been having serious impacts on the Earth and its residents. Many researches have shown that even if the emission of greenhouse gases is reduced drastically, climate change will not be reversible in coming centuries. Frequencies and magnitudes of water-related disasters such as floods, droughts and water scarcity are predicted to increase due to changes in precipitation extremes.

To cope with water-related disasters induced by global warming mentioned above, projection of river discharge is necessary. In this regards, hydrological and flow routing models play important roles in transferring the climate model outputs into discharge. Many researchers analyzed changes in future risks of floods and droughts using different scale and spatial resolution hydrological models: global scale with 1-degree spatial resolution runoff model[1)]; regional scale with 2-minute spatial resolution hydrological model[2)]; and basin scale with 1-km spatial resolution runoff model[3)].

In this study, river discharge in the Indochina Peninsula region (Fig. 1) was simulated using a distributed flow routing model (1K-FRM) with kinematic wave flow approximation. The input data for 1K-FRM was the latest 20km spatial resolution general circulation model (MRI-AGCM3.2S), which was developed by Meteorological Research Institute (MRI), Japan Meteorology Agency (JMA), with three climate experiments simulated under the SRES A1B scenario: the present climate (1979-2008), the near future climate (2015 - 2044), and the future climate (2075-2104).

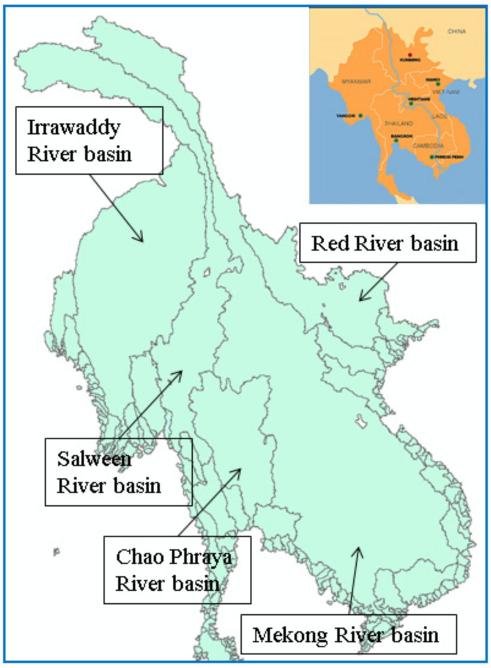


Fig.1 Map of the study area, Indochina Peninsula.

The original version of 1K-FRM was based on 1km spatial resolution topographic data which was extracted from USGS HydroSHEDS 30 arc-second Digital Elevation Models (DEM). With that high resolution, the requirement for computational resources is also high, and it takes a long computational time. For a balance of spatial resolution, computational resources, and application of hydrological models, 1K-FRM has been modified to use with scale-free global stream-flow network dataset which was provided by Masutani et al[4]. Among the scale-free stream-flow network dataset, DEM data with spatial resolution of 5-minute was processed to use for this research.

The purpose of this research is to analyze the simulated river discharge from flow routing model 1K-FRM to locate possible hotspot river catchments in the Indochina Peninsula region, where significant changes related to floods, droughts and water resources could occur under climate change.

The model implementation and parameter setting for this study are described in section 2 and section 3. In section 4, some statistical comparisons between simulated discharge and observed discharge at some specific location are presented. The changes of river discharge in Indochina Peninsula under climate change are shown in section 5. Finally, conclusion is given in section 6.

2. MODEL DESCRIPTION

(1) Watershed model

The topography of the catchment is modeled using the 8-direction method which assumes the flow direction one-dimensionally to the steepest gradient direction. Each slope element determined by the flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. The watershed model is developed using Digital Elevation Models. Catchment topography is represented by a set of slope units. For each slope unit, its area, length and gradient used for a flow model are easily calculated. Schematic drawing of a watershed model using the eight direction method is shown in Fig. 2.

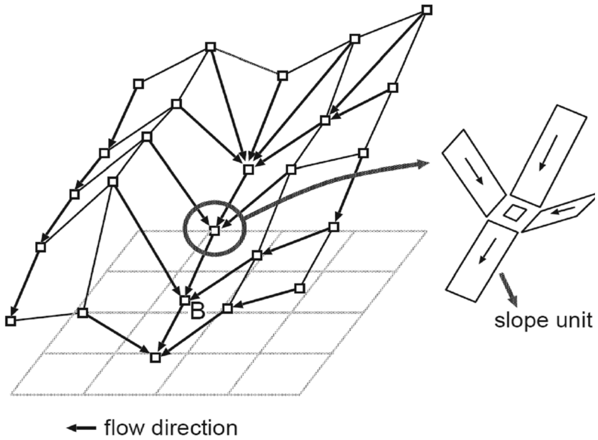


Fig.2 Schematic drawing of a watershed model using the 8-direction method.

The topographic information used for flow routing model 1K-FRM in this study is generated by processing 5-minute spatial resolution DEM in the scale-free global stream-flow network dataset.

(2) Flow model

1K-FRM is a distributed flow routing model based on kinematic wave theory. The kinematic wave model is applied to all slope units and runoff is routed according to the flow direction information. The basic form of the kinematic wave flow equation is:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_L(x,t) \quad (1)$$

$$Q=\alpha A^m, \quad \alpha=\frac{\sqrt{i_0}}{n}\left(\frac{1}{B}\right)^{m-1}, \quad m=\frac{5}{3} \quad (2)$$

where, $A(x, t)$ is the flow cross-sectional area, $Q(x, t)$ is the flow discharge, $q_L(x, t)$ is the lateral inflow per unit length, i_0 is the slope, n is the Manning roughness coefficient, and B is the width of the flow.

Eq. (1) is the continuity equation. It is derived from the principle of mass conservation within a control volume. Eq. (2) is derived from Manning's laws which are flow resistance laws of open channel uniform flow.

(3) Forcing data

The input data for flow routing model 1K-FRM were provided by the latest 20 km spatial resolution general circulation model MRI-AGCM3.2S which has been developed by the MRI, JMA. MRI-AGCM3.2S provides various atmospheric and hydrologic variables for the present climate experiment (1979-2008), the near future climate experiment (2015 - 2044), and the future climate experiment (2075-2104). River discharge in Indochina Peninsula was projected by feeding daily surface runoff generation and daily subsurface runoff generation data, which were simulated by a land-surface process model (SiB model) embedded in MRI-AGCM3.2S, into 1K-FRM.

(4) Parameter settings

The model parameters of 1K-FRM are the width of the flow B and Manning roughness coefficient n. The value of B is determined using the regression relationship $B = aS^c$, where S is the catchment area at the calculated points, and a=1.06 and c=0.69 are constant parameters. The value of n is determined to be $0.03m^{-1/3}s$ for channel when catchment area at the calculated point is larger than $500km^2$ and $11.0m^{-1/3}s$ for slope when catchment area is smaller than $500km^2$. All these values were chosen in reference to other applications by Tachikawa et al[5]. Because the purpose of the research is to locate possible hotspot river catchments, the use of parameters mentioned above with some tuning based on DEM spatial resolution is acceptable.

3. COMPARISON OF SIMULATED DISCHARGE AND OBSERVATIONS

Simulated river discharge for the present climate experiment was compared with available observed data at some locations. Fig. 3 shows the comparison of monthly average river discharge at several hydrological stations such as Monywa in Irrawaddy River basin; C2 in Chao Phraya River basin; Pakse in Mekong River basin; and Hanoi in Red River basin. The drainage areas of these hydrological stations are about $115{,}000km^2$; $110{,}000km^2$; $545{,}000km^2$ and $145{,}000km^2$ respectively.

Without any bias correction of GCM data, the simulated river discharge data might not be so realistic. In addition, the model parameters of flow routing model 1K-FRM were not tuned for each river catchment in the study area. However, the comparison of simulated discharge with observations has a certain meaning for seeing the discharge time series characteristics such as mean value, standard deviation and tendencies of change in river discharge.

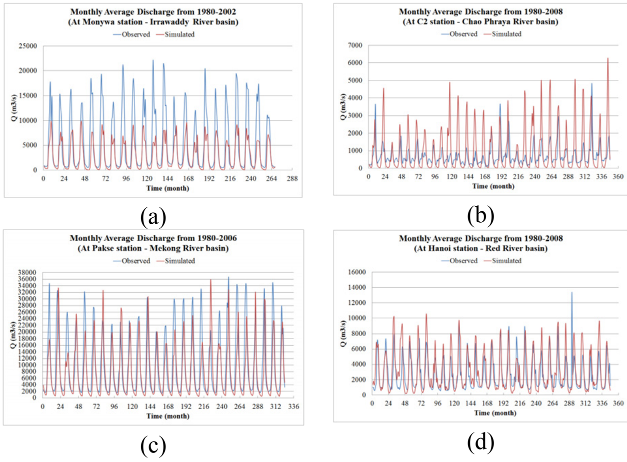


Fig.3 Comparison of simulated river discharge with observations at Monywa station (a), C2 station (b), Pakse station (c), and Hanoi station (d).

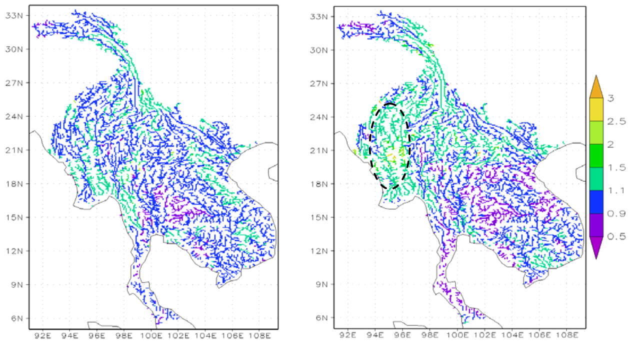
As can be seen in Fig. 3, simulated river discharge from flow routing model 1K-FRM for the present climate experiment shows a quite good agreement with observed data at locations with large catchments size such as Pakse and Hanoi station. At Monywa station, the simulated flow was underestimated. However, the hydrograph showed a similarity in pattern. There were also some disparities between simulated discharge and observation at C2 station. It can be explained by the uncertainties in GCM data and the impacts of well-regulated dams and reservoirs in the upstream part of observed points. In Chao Phraya River basin, the two largest dams in the upstream part of C2 station are Bhumibol and Sirikit dams with live storage capacity of 9.7 billion m^3 and 6 billion m^3, which control the runoff from 22 percent of the entire basin area.

4. CHANGES OF RIVER DISCHARGE IN INDOCHINA PENINSULA UNDER CLIMATE CHANGE

In this study, river discharge projection in Indochina Peninsula region was carried out for three climate experiments: the present climate (1979-2008), the near future climate (2015-2044), and the future climate (2075-2104). Daily mean discharge, max hourly discharge in day data is stored in 5-minute spatial resolution. The simulated river discharge was analyzed to locate possible hotspot basins with significant changes of floods, droughts and water resources under climate change.

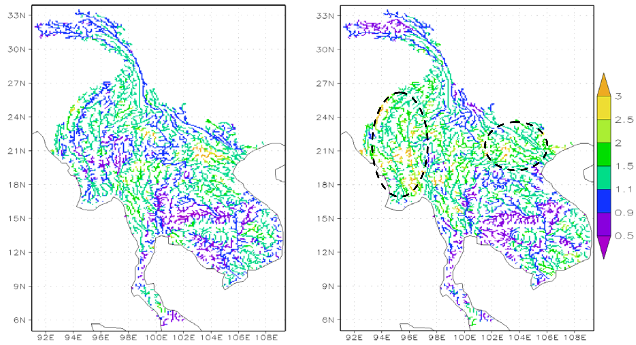
(1) Change of water resources

Annual mean simulated river discharge for three climate experiments was calculated and used to analyze changes in water resources in Indochina Peninsula region.



(a) (b)

Fig.4 Ratio of annual mean discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).



(a) (b)

Fig.5 Ratio of mean of annual maximum daily discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

Fig. 4 shows the change ratio of annual mean discharge for the near future climate and the future climate to the present climate experiment. From Fig. 4a, it can be seen that there are not so much changes in annual mean discharge in the near future. The increases in annual mean discharge with the ratio smaller than 1.5 can be detected at the most upper parts of Salween and Mekong River basin, the lower part of Irrawaddy River basin, and western part of Vietnam. Only eastern part of Chao Phraya River basin shows a trend of decreasing in annual mean river flow with the ratio is between 0.5 and 0.9.

Fig. 4b shows a similar trend with higher intensity in the future climate experiment. We can see that the area with changes in annual mean discharge and ratio range become larger, especially at the middle and lower part of Irrawaddy River basin, and eastern part of Chao Phraya River basin. However, the annual mean flow in the future climate tended to decrease in the central part of Vietnam. The change ratio is lower than 0.9.

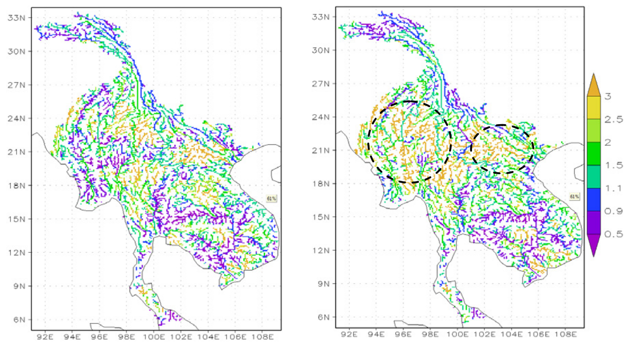
(2) Change of flood risk

Annual maximum daily discharge data for three climate experiments were compiled and were analyzed.

The change ratio of mean of annual maximum daily discharge for the near future climate and the future climate with respect to the present climate experiment are shown in Fig. 5.

For the near future climate experiment, the mean of annual maximum daily discharge has significant changes at the upper and lower part of Salween River basin, north-western part of Vietnam, and eastern part of Chao Phraya River basin.

The changes, which were detected in the near future climate experiment, become more visible in the future climate experiment. Irrawaddy River basin and Red River basin showed a noticeable increasing of mean of annual maximum daily discharge in the future climate experiment. The ratio at some areas are larger than 2.5. It means that the risk of flooding at those areas will increase.



(a) (b)

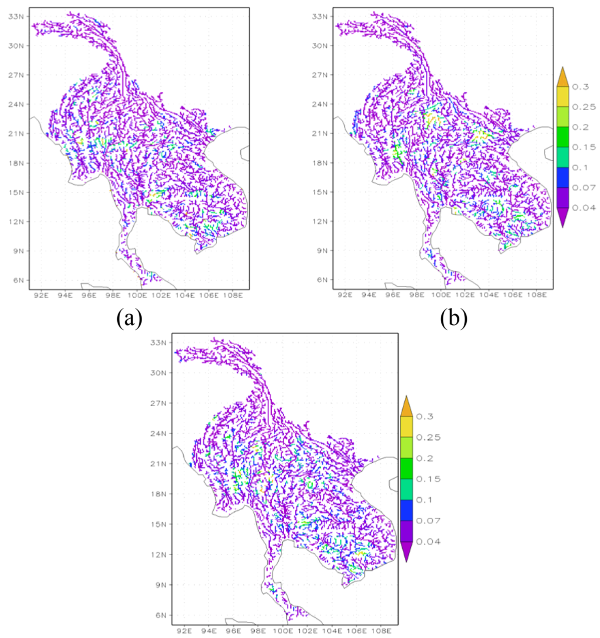
Fig.6 Ratio of standard deviation of annual maximum daily discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

The ratio of the standard deviation of the annual maximum daily discharge for the near future climate and the future climate to the present climate experiment were also calculated and analyzed.

The standard deviation also showed a similar trend to the changes of mean of annual maximum daily discharge. The increases of standard deviation of annual maximum daily discharge can be found in Irrawaddy River basin, Salween River basin, and Red River basin (see Fig. 6).

In addition, the Generalized Extreme Value (GEV) distribution was fitted to the annual maximum daily discharge for each climate experiment. The standard least-square criterion (SLSC)[6] was used to evaluate the goodness-of-fit of the distribution. Then, the 10-year return period discharge for each climate experiment was obtained.

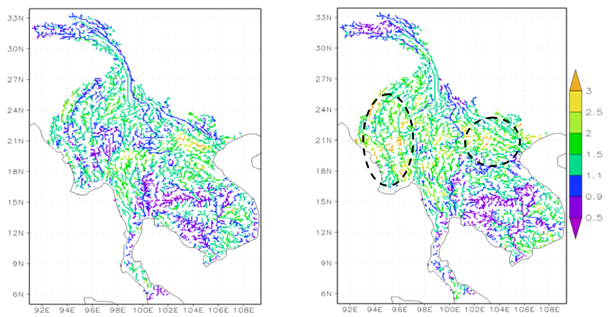
According to Takara and others[6], the critical value of SLSC is 0.04. And, with a sample size of hydrological data smaller than 30, SLSC < 0.07 is acceptable to river discharge frequency analysis[7].



(a) (b)

(c)

Fig.7 SLSC values for fitting the GEV distribution to the annual maximum daily discharge for the present climate (a), the near future climate (b), and the future climate (c).



(a) (b)

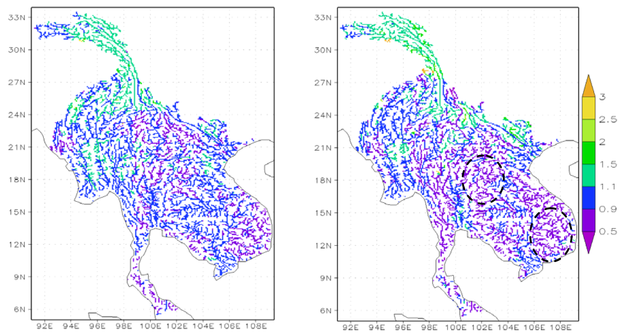
Fig.8 Ratio of the 10-year return period maximum daily discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

Fig. 7 shows that the SLSC values for each climate experiment in the Indochina Peninsula region are acceptable.

The change ratio of 10-year return period maximum daily discharge for the near future climate and the future climate with respect to the present climate are showed in Fig. 8. The spatial pattern of the change ratio of 10-year return period discharge showed a similarity to the change ratio of the mean of annual maximum daily discharge with significant changes in Irrawaddy River basin, Red River basin and lower part of Mekong River basin.

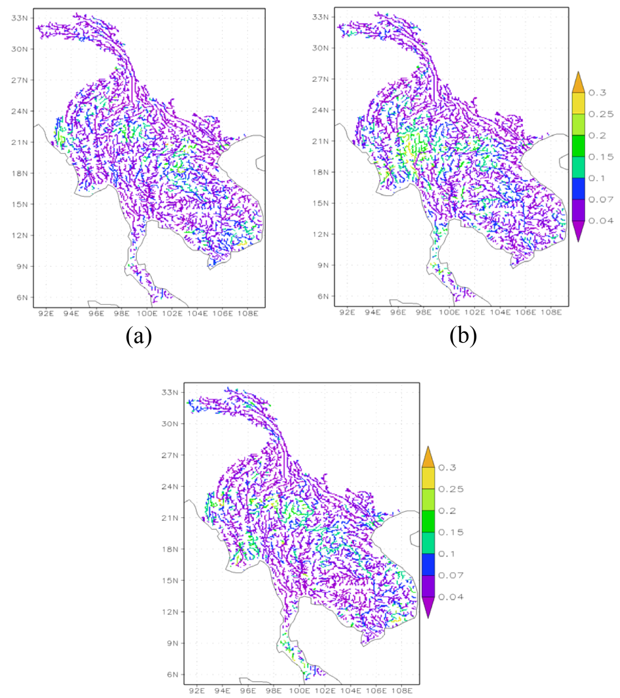
(3) Change of drought risk

The change of drought risk in Indochina Peninsula region was also analyzed by comparing the mean of annual minimum daily discharge in the near future climate and the future climate experiment with those values in the present climate.



(a) (b)

Fig.9 Ratio of mean of annual minimum daily discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).



(a) (b)

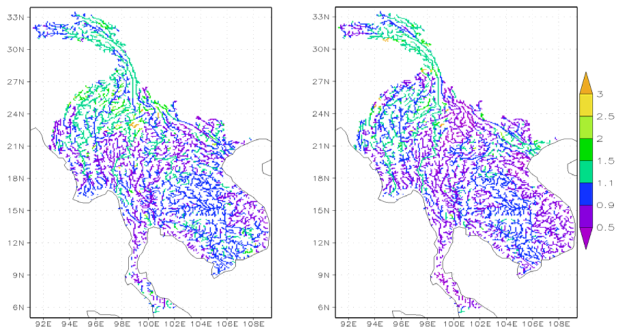
(c)

Fig.10 SLSC values for fitting the Weibull distribution to the annual minimum daily discharge for the present climate (a), the near future climate (b), and the future climate (c)

From Fig. 9, it can be seen that there is a decrease trend at the middle part of Mekong River basin in the territory of Lao PDR, western part of Chao Phraya River basin, and the south-eastern part of Indochina Peninsula, especially the southern part of Vietnam. And this trend becomes clearer in the future climate experiment.

The SLSC values and change ratio of the 10-year return period discharge for annual minimum daily discharge in each climate experiment was also calculated using the Weibull distribution.

The SLSC values for fitting the Weibull distribution showed higher values than critical value in some locations with small catchment size (see Fig. 10). However, the values in most of large river basins were less than 0.07, the SLSC critical value.



(a) (b)

Fig.11 Ratio of the 10-year return period minimum daily discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

Fig. 11 shows a similar pattern to the change ratio of mean of annual minimum daily discharge. For 10-year return period minimum discharge, the decrease of minimum discharge in Chao Phraya River basin and south-central part of Vietnam became more visible.

5. CONCLUSION

The impacts of climate change on river flow in Indochina Peninsula region were analyzed using distributed flow routing model 1K-FRM and runoff generation data which were generated by the latest 20km resolution general circulation model MRI-AGCM3.2S. River discharge was projected with the kinematic wave flow model with 5-minute spatial resolution DEM data for three climate experiments: the present climate (1979-2008), the near future climate (2015-2044), and the future climate (2075-2104).

In the Irrawaddy River basin (Myanmar), the annual mean discharge and mean of annual maximum daily discharge tended to increase in the near future climate experiment. The increases were much clearer in the future climate experiment. A same trend can be detected at Red River basin (Vietnam). Hence, flood risk is expected to increase in those river catchments. They would be hotspot basins on flood risk under climate change.

Drought risk was also found in the middle part of Mekong River basin and southern part of Vietnam. The mean of annual minimum daily discharge at locations mentioned above showed a decrease in the near future climate experiment. And the areas with decreasing in discharge were expanded in the future climate experiment.

In conclusion, a clear change of river flow in the Indochina Peninsula region was detected with the degree of change differs from location to location. It became clearer in the future climate experiment. The increase of flood risk was found in the Irrawaddy River basin (Myanmar) and Red River basin (Vietnam). The risk of droughts tended to increase in the middle part of Mekong River basin (Lao PDR) and southern part of Vietnam.

For further works, rainfall data will be analyzed to investigate the effects on the changes of river discharge in the Indochina Peninsula region. A detailed distributed hydrological model will be developed for hotspot river basins in the region with significant changes in river discharge. Dam operation function will be set in the detailed distributed hydrological model for hotspot basins to analyze the change of water resources under climate change.

ACKNOWLEDGMENT: We acknowledge Meteorology Research Institute, Japan Meteorology Agency for providing GCM data, and Dr. Jun Magome (University of Yamanashi) for providing scale-free global stream-flow networks datasets.

REFERENCES

1) Hirabayashi, Y., Kanae, S., Emori, S., Oki, T., Kimoto, M.: Global projections of changing risks of floods and droughts in a changing climate, *Hydrological Sciences Journal,* 53 (4), 754 – 772, 2008.

2) Kiem, A. S., Ishidaira, H., Hapuarachchi, H. P., Zhou, M. C., Hirabayashi, Y., Takeuchi, K.: Future hydro-climatology of the Mekong river basin simulated using the high-resolution Japan Meteorological Agency (JMA) AGCM, *Hydrological Processes,* 22, 1382 – 1394, 2008.

3) Hunukumbura, P. B., Tachikawa, Y.: River discharge projection under climate change in the Chao Phraya river basin, Thailand, using the MRI-GCM3.1S dataset, *Journal of the Meteorological Society of Japan,* 90A, 137 – 150, 2012.

4) Masutani, K., Akai, K., Magome, J.: A new scaling algorithm of gridded river networks, *Japan Society of Hydrology and Water Resources,* 19 (2), 139 – 150, 2006 (in Japanese).

5) Tachikawa, Y., Takino, S., Fujioka, Y., Yorozu, K., Kim, S., Shiiba, M.: Projection of river discharge of Japanese river basins under a climate change scenario, *Journal of Japan Society of Civil Engineers, B1 (Hydraulic Engineering),* 67(1), 1–15, 2011 (in Japanese).

6) Takara, K., Stedinger, J. R.: Recent Japanese contribution to frequency analysis and quantile lower bound estimator, *Stochastic and Statistical Methods in Hydrology and Environmental Engineering, Hipel K.W. (ed.), Kluwer Academic Publishers,* 1, 217-234, 1994.

7) Hayashi, H., Tachikawa, Y., Shiiba, M., Yorozu, K., Kim, S.: Introducing a statistical hypothesis testing into SLSC goodness-of-fit evaluation for hydrological frequency analysis models, *Journal of Japan Society of Civil Engineers, B1 (Hydraulic Engineering),* 68(4), I1381–I1386, 2012 (in Japanese).

(Received September 30, 2012)