Projection and Historical Analysis of Hydrological Circulation in Sittaung River Basin, Myanmar

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Abstract: Based on the comparison between several model outputs from CMIP5 (Coupled Model Intercomparison Project Phase-5) and the satellite rainfall mapping data of GSMaP (global satellite mapping of precipitation), This paper selected MIROC4h as a future projection of rainfall in the Sittaung River basin, Myanmar, with the fine spatial resolution of 0.5°. At first, MIROC4h projection towards 2035 was corrected by using the error trend (GSMaP-MIROC4h) for nine years over-lapping of both outputs from 2006 to 2014. Assuming the seasonal autoregressive processes, future error trend at each grid point was estimated by the time series forecast of SARMAP processes using the nine years training data. Then future projection correction was done by MIROC4h output plus error trend at each grid point to obtain the corrected MIROC4h precipitation. As a historical analysis, using the corrected precipitation in the Sittaung River basin and observed river discharge at the outlet of the river, the hydrological model (HSPF (Hydrological Simulation Program Fortran)) calibration was carried out with consideration of the water utilization data for dam/reservoir and irrigation. As a projection analysis, future simulation of hourly discharge at the outlet of Sittaung River from 2015 to 2035 was conducted by using the corrected MIROC4h precipitation. The results of projection analysis show that high risks of flood will appear in 2023 and 2028 and the risks of draught will be expected in 2019~2021.

Key words: Hydrological simulation, HSPF, CMIP5, MIROC4h, TRMM, GSMaP.

1. Introduction

Some researchers have been done in the major rivers of Myanmar, such as Irrewadai, Chindwin and Thanlwin [1, 2]. However, a few reliable researches have been completed in the Sittaung River basin, the fourth largest river in Myanmar. Major topics of past hydrological investigations were on influences of monsoon and historical rainfall patterns on rainfall runoff and river discharges [3]. This study aims at the short-term prediction (30 years) of precipitation and hydrological characteristics in the Shittaung River basin in which the effective water resource management and environmental preservation are in great demand.

For the short term projection of precipitation and atmospheric maximum/minimum temperatures, MIROC4h model outputs are employed in this study.

MIROC4h is a Japan's contribution to the CMIP5 (Coupled Model Intercomparison Project Phase-5) in the AR5 (Fifth Assessment Report) of IPCC (Intergovernmental Panel on Climate Change) [4].

GSMaP (global satellite mapping of precipitation) is used for observation of hourly precipitation that will be necessary for validation and evaluation of MIROC4h model outputs [5]. TRMM (Tropical Rainfall Measurement Mission) satellite observation data, a part of GSMaP [6], is also used for MIROC4h evaluation and historical hydrological simulation.

For the river flow simulation, BASIN-HSPF model is employed for the hydrological simulation in the watershed. BASIN stands for Better Assessment Science Integrating Point and Nonpoint Sources while HSPF stands for Hydrological Simulation Program Fortran. BASIN has been developed by U.S. EPA (United States Environmental Protection Agency) and is widely used for the watershed environment assessment and water quality management. HSPF is

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incorporated in BASIN [7].

The Sittaung River is one of limited cases which have measured river discharge data in Myanmar. This is one reason why this river was selected in this study.

2. Projection of Precipitation

2.1 Correction Methods for Projected Precipitation

The geographical pattern of precipitation is strongly localized, because the climate model was confirmed that it is difficult to predict the precipitation within the next few years. The difference between the precipitation data measured by satellite (GSMaP) and the projection by MIROC4h in the overlapping period of 2006~2014 was used as a learning data of model projection error to create an algorithm for correcting MIROC4h output of predicting future precipitation. Correction method used is summarized below:

(1) using interpolation of GSMaP data (0.1° resolution), convert the daily precipitation distribution of GSMaP to the 0.5° grid system of MIROC4h projection and obtain the difference of data between the two results that can be defined as MIROC4h projection error at each grid point;

(2) determine the time series of MIROC4h projection error for an average monthly rainfall at each grid point in the period of 2006~2014;

(3) assume SARMAP (seasonal auto regressive moving average process) for monthly MIROC4h projection error, estimate the processes and forecast the future error of the monthly rainfall from 2015 to 2035. Fig. 1 shows a sample of evaluated error time series and forecasted error;

(4) although SARMAP corrects the future oscillation processes of the error, it does not correct the mean characteristics. In other words, total amount of rainfall of SARMAP corrected MIROC4h and the GSMaP observation still has a discrepancy as shown in Fig. 2 that depicts the time series of projection, corrected projection and observation of precipitation at the point of Kabul, Afghanistan. Precipitation of MIROC4h in Afghanistan and Nepal tends to have a

three to four times excessive prediction value, but there is also a regional vice versa;

(5) apply the same Procedure (4) to all grid points, the spatial distribution of the under-excessive correction coefficient is shown in Fig. 3 where adjusting factor unity indicates the same predicted value as observed. When adjusting factor is smaller than the unity, it indicates MIROC4h projection is overestimated and larger factor shows the overestimation of MIROC4h projection.

Fig. 3 depicts the following characteristics of MIROC4h projection of precipitation in Asia and Oceania:

- overestimation of rainfall in Afghanistan, Nepal, Australia. Its order is 2~3 times (factor: 0.3~0.5);
- underestimation in Indo-China Peninsular, India, Pakistan, northern China. In Pakistan, factor exceeds two (smaller than half rainfall).

Fig. 1 Error defined by the difference of MIROC4h projection and GSMaP observation that is available in the period of 2006~2014 (darker blue line). Error projection computed by SARMAP (light blue line 2015~2035).

Fig. 2 Relation between MIROC4h projection, GSMaP, modified predicted value (corrected MIROC4h), and adjustment of corrected prediction value (adjusted corrected MIROC4h) at the point of Kabul, Afghanistan.

Fig. 3 Spatial distribution of the under-excessive correction coefficient (adjusting factor of mean precipitation between MIROC4h and GSMaP).

2.2 Corrected Precipitation in Asia

Applying the SARMAP correction and multiplying adjusting factor in Fig. 3, monthly precipitation distribution in Asia was obtained from 2015 to 2035. Fig. 4 shows the monthly precipitation distribution in August 2028, the heaviest rainfall year in Myanmar. Fig. 4a shows original MIROC4h projection, the center shows SARMAP correction of MIROC4h projection, and the bottom shows mean value adjusted SARMAP correction of MIROC4h.

For the hydrological simulation, the accuracy of precipitation information is inevitable. However, the model projection provides only unreliable output of rainfall distribution. The correction procedure conducted in this study should be discussed and improved its methodology.

2.3 Corrected Precipitation Projection in Sittaung River Basin

The projection of annual precipitation was corrected in the Sittaung River basin as shown in Fig. 5. In the figure, Yangon is the city located in southern part of the basin, OkeTwin is located in the central part, the capital city Naypyaw is in the northern part of the basin. Average annual precipitation in Yangon is over 3,000 mm, and annual precipitation in the central and northern parts are around 2,000 mm. In 2015, rain fall in Yangon is high, rainfall in central and northern will be heavy in 2016,

Fig. 4 Monthly precipitation distribution observed by GSMaP and reproduced by MIROC4h in August, 2014: (a) MIROC4h projection; (b) SARMAP correction of MIROC4h; (c) adjusted SARMAP correction of MIROC4h.

Fig. 5 Annual precipitation in Sittaung River basin estimated by the corrected MIROC4h output.

2017, 2023, 2025, 2028 and 2031. The heaviest rain is expected in 2028 in Sittaung River basin and shortage of rainfall is expected in 2018~2022.

3. Hydrological Simulation in Sittaung River

3.1 Computational Conditions

Sittaung River (also spelled as Sittang or Sittoung) generates originally at the edge of the Shan Plateau, southeast of Mandalay Region ($20^{\circ}31'N$ and $96^{\circ}18'E$) and then flows southward through Bago Region until it enters into the Gulf of Martaban. The total river length is 420 km. It flows through flat areas between the forested Bago Mountains on the west and the steep Shan Plateau on the east. The river is contributed by 22 major streams and the total watershed area is $330,350 \text{ km}^2$. Fig. 6 shows land use and DEM (digital elevation model), watershed and the river network of study area.

Fourteen meteorological points with length interval of 0.5° were used to cover the whole watershed evenly. The 3B42 rainfall estimates products of TRMM (Tropical Rainfall Measurement Mission) were used for historical simulation [8]. Fig. 7 shows the river basin boundary and annual average rainfall distributions for eight years from 2006 to 2013. The daily maximum and minimum temperature data of NCEP-CFSR (National Centers for Environmental Prediction-climate forecast system reanalysis) were used for the evapotranspiration computation.

Not only for the agricultural and urban utilization but also for hydro-power generation, 15 dams were established within the Sittaung River basin, and two more dams are under construction processes. Among 15 dams, 12 dams are for irrigations and urban utilization purposes while the rest three are for hydro-power generations. Fig. 8 shows the monthly water utilization of dams for four-year period (2010~2013) which is observed by Ministry of Agriculture and Irrigation, Myanmar. The observed discharge is not available at the river mouth but available at Madauk Town, which is relatively close

to river mouth.

4. Historical Analysis of River Discharge

The discharge of river mouth observation gauge at

Fig. 6 Land use and DEM data in the Sittaung River basin.

Fig. 7 Sittaung River basin and its annual rainfall intensity (mm/yr) (2006~2013 average of TRMM data).

Fig. 8 Monthly water utilization of dams for four-year period (2010~2013).

Madauk Station was used for validating the result of HSPF model together with the monthly dam utilization data for four years (2010~2013). HSPF's key parameters were adjusted to reflect the characteristics of watershed of study area. Although the reservoir characteristics could include in calibrating the HSPF model, monthly water utilization of reservoirs/dams were applied only after simulating the river flow.

Fig. 9 shows the graphical comparison between daily river discharges simulated (using TRMM rain data) and observed at Madauk Station. Table 1 shows the annual river discharge and percentage errors between the simulation and observation.

The flow patterns and distributions between observation and simulation are relatively corresponding and the coefficient of determination value R^2 is 0.8422 that shows the high correlativity between simulation and observation. The average

percentage error of simulation is 5.05 and it is acceptable compared to the criteria error range of HSPF model, $\pm 10\%$. By examining these results, it can be assumed that the model calibration was good enough and the adjustments of key parameters were working well by reflecting the watershed characteristics.

To check the correlation between two simulations of TRMM satellite rainfall case and MIROC4h projection rainfall case, the historical simulations of TRMM and MIROC4h were carried out from 2006 to 2013 without dam utilization data (Fig. 10). The results show that there is high correlation between two simulation results because the coefficient of determination R^2 is 0.7742.

5. Projection of River Discharge

As HSPF hydrological model calibration performed well by reflecting the characteristics of watershed, and

Fig. 9 Daily river discharge comparison between simulation (using TRMM rain) and observation.

Table 1 Total flow volume comparison and percentage error between simulation and observation.

Year	Total flow volume(km ² -mm)		Percent error (%)
	Observed flow	Simulated flow	
2010	34,589,981.11	27,528,376.52	20.42
2011	45,716,275.94	50,160,214.97	-9.72
2012	44,828,645.14	40,977,465.67	8.59
2013	37,875,061.48	36,115,917.79	4.64
Total	163,009,963.7	154,781,976.2	5.05

Fig. 10 Daily discharge comparison between simulations using TRMM (observation) rain and MIROC4h (simulation) rain.

Fig. 11 Hourly precipitation estimated by MIROC4h projection and computed river discharge at Sittaung River from 2014 to 2035.

the adjustment of MIROC4h projection rainfall estimates showed high correlativity with TRMM satellite rainfall estimates. It can be concluded that the future river flow of study area could be simulated, with high estimation, by using the adjusted model parameters and adjusted MIROC4h projection rainfall estimates. Therefore, the daily future flows at Madauk discharge station were simulated for 22 years, from 2014 to 2035. Fig. 11 shows the hourly precipitation (inch/hr) estimated by MIROC4h projection and computed river discharge (m^3/s) at Sittaung River. The following facts were concluded according to the results of future flow simulation at river outlet discharge station in Sittaung River basin:

(1) In June of 2016–2018, the moderate floods will be expected to occur. In June of 2023 and 2028, the storm will be expected and devastating floods will hit the Sittaung River basin. In 2019–2021, 2027 and 2029, the river discharge decreases in rainy season;

(2) The river flow may not change distinctly in summer season (February, March, April and May), and it will increase in rainy season (June, July, August and September), obviously in June. The river discharge may increase slightly in winter season (October, November, December and January).

6. Conclusions

After comparing between several model outputs

from CMIP5 and the rainfall observation of GSMap, the authors selected MIROC4h as a future projection of rainfall in the Sittaung River basin. A historical analysis was conducted by using the precipitation of TRMM and observed river discharge at the outlet of Sittaung River to calibrate hydrological model (HSPF). For future simulation, the corrected precipitation from MIROC4h was used. From the future simulation of hourly discharge in the Sittaung River basin, period of 2015~2035, it was pointed out that high risks of flood may appear in 2023 and 2028 and the risks of water shortage will be expected in 2019~2021.

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