Impacts of Future Climate Change on Inflow to Pasak Jolasid Dam in Pasak River Basin, Thailand

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Abstract

The impacts of future climate change on inflow to the Pasak Jolasid Dam in the Pasak River Basin was assessed by using the hydrologic modelling system (HEC-HMS) and the bias-corrected climate change projection derived by averaging the outputs of three regional climate models (RCMs) namely: ACCESS, CNRM and MPI. The hydrological response of the Pasak River Basin to future climate projection for the periods 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100) was quantified using the calibrated and validated climate change trends and the HEC-HMS hydrological model which was calibrated and verified using the daily observed data from 1970-2010 and 2007-2015 respectively. The simulation results showed that the future precipitation trend fluctuates and slightly decreases until the end of 21st century by –5.69% and -12.68% under RCP4.5 and RCP8.5 at Lom Sak Station. The projected mean annual maximum and minimum temperatures were found to increase by 4.99% and 6.49% respectively for RCP4.5; by 6.58% and 8.46% respectively for RCP8.5, during twenty-first century. The future inflow to Pasak Jolasid Dam calculated from RCP4.5 and RCP8.5 was found to decrease by -0.61% and -3.39% for 2020s, by -2.82% and -6.15% for 2050s, and by -7.56% and -9.21% for 2080s respectively. However, these long term prediction on the change of future precipitation and temperature is only an estimate. The results can be used as a guideline for long-term sustainable water resources project planning and water resources management as well as in proposing appropriate adaptation strategies for the Pasak River Basin.

Keywords: Climate Change Projection, Hydrological Model, Inflow Change, Pasak Jolasid Dam, Pasak River Basin

1. Introduction

Climate change around the world is caused by natural and by human activity changing. IPCC (2019) [4] reported an increase of 1.5°C to 2°C on average observed temperature at present due to global warming. Climate change has large impact on many natural ecosystems and some of the service. The past trends of duration and frequency of weather conditions and climate extreme events represent fluctuated global warming impacts. It is commonly accepted that climate change leads to significant impact on hydrological cycle and river system (Schulze, 2000; Zhao et al., 2009) [10,17] spatially and temporally from local to global scales (Coulthard et al., 2005; Wang et al., 2012) [3,15]. It is a major challenge to achieve sustainable water resources management. As a consequence, climate related risk and extreme events rely on the global warming, earth's surface position, vulnerability, and alternatives of adaptation and mitigated options (IPCC, 2018) [4]. However, rapid population growth, economy expansion and unplanned urbanization negatively affect land uses and river discharges in many watershed (Wang et al., 2012) [15].

Many previous researches show how future greenhouse gas emission has effect on climate change and its consequences on water cycle and stream discharge (Men et al., 2019; Shrestha et al., 2018) [8,12]. These studies used hydrological modelling to evaluate and investigate surface runoff and base flow considering different representative concentration pathway (RCPs). Shrestha et al., (2018) [12] found that climate change has also impact on water quantity and quality in the Songkhram River Basin, Thailand. Shrestha (2014) [11] evaluated climate change impact to inflow to Ubolratana dam in Northeast of Thailand. The projected maximum and minimum temperatures are increased with the global warming trend. Moreover, increasing rainfall in the future will result in higher vulnerability, exposure, risk in river floodplain areas. Tachikawa et al., (2013) [13] analyzed impact on water resources in the 21st century using a distributed precipitation-runoff modeling with future precipitation and evapotranspiration for the Upper Pasak river basin, Thailand. It was found that over the century from September to July, the annual river flow slightly decreased. The above-mentioned studies clearly indicated that future climate change has a large impact on streamflow and reservoir inflow. The changes in precipitation, temperature and evaporation volumes have significant influence on surface runoff and streamflow discharge. However, Tachikawa et al. (2013) only considered a single regional climate model and a rainfall-runoff model in their study.

The main objective of this study is to predict the annual inflow discharge to Pasak Jolasid reservoir using three climate projections under two representative concentration pathways (RCP4.5 and 8.5). The sub-objectives of this study are; (i) investigative downscaling climate prediction in the 21st century using linear bias correction process with past weather data; (ii) calibration and verification of hydrologic model (HEC-HMS) on stream flow and discharges; (iii) evaluative inflow of Pasak Jolasid reservoir with the predicted precipitation and temperature from the average of three regional climate models.

2. Study Area and Data Collection

2.1 Description of Study Area

The Pasak River Basin (PRB) is a sub-watershed of the greater Chao Phraya River located between north and middle regions of Thailand, originated from Loei-Phetchabun ranges (Tachikawa et al., 2013) [13]. Its watershed covers 15,625 square kilometers and the river length is over 400 kilometer long in north-south direction that pass through 7 provinces, namely Loei, Phetchabun, Chaiyaphum, Saraburi, Lopburi, Nakhon Ratchasima and Phra Nakhon Si Ayutthaya. Its watershed topography is approximately 70% undulating, 20% steep slope and 10% hill slope areas, respectively. Pasak River lies in tropical climate zone. The minimum and maximum annual temperatures are 17.3-36.6 °C and the average annual precipitation is 1,122.6 mm. The Pasak Jolasid Dam is located at 14° 39′N, 101° 04′E, after the confluence point of Pasak River and Lom Santi channel (Manee et al., 2015) [7]. There are large agricultural land and household area that help to absorb flood volume and reduce flood problems in the middle part of the greater Chao Phraya River Basin during rainy season. A small hydropower plant was installed at the Dam for hydropower generation. This study focuses on the upstream part of the Pasak Jolasid Dam which covers 7 sub-basins as shown in figure 1.

2.2 Data Collection

The data were collected from various organizations such as Royal irrigation Department and Thai Meteorological Department at the stations in the river basin and nearby. The data on physical characteristics and parameters of watershed are elevation, soil and land cover, etc. The meteo-hydrological data such as rainfall, temperatures and streamflow were used for climate bias correction and hydrological modelling. For main inputs for climate change projection, the ACCESS-CSRO-CCAM, CNRM-CM5-CSIRO-CCAM, MPI-ESM-CSIRO-CCAM with resolution 0.50 degree under RCP4.5 and 8.5 were downscaled to predict atmospheric parameters such as precipitation, air maximum and minimum temperatures. All of those parameters were on daily units only.

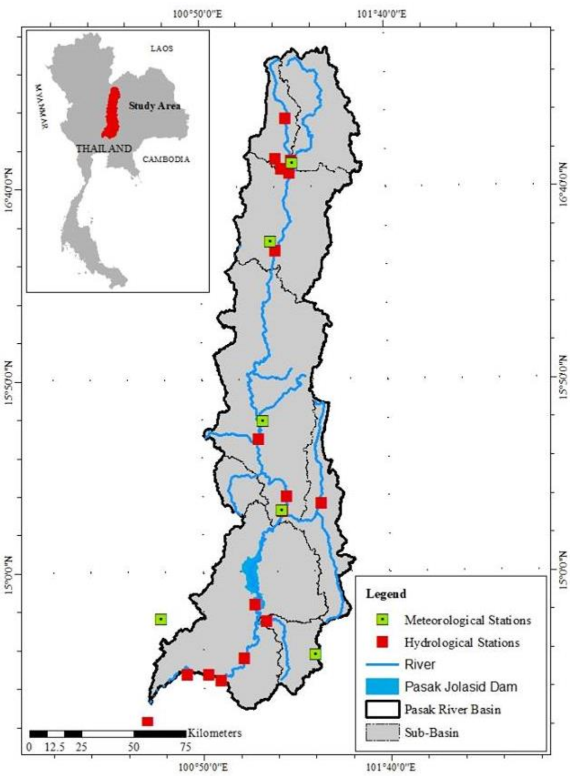


Fig. 1 Location of study area in the Pasak River Basin (PRB)

3. Research Methodology

The study can be described in three steps as shown in Figure 2 as following: Step 1) downscaling climate parameters of RCMs, Step 2) calibration and validation of rainfall-runoff modelling and Step 3) projection of future inflow discharge to the Pasak reservoir. The first step is the simulation of climate characteristics from three different RCMs in the same scale resolution including ACCESS-CSRO-CCAM, CNRM-CM5-CSIRO-CCAM, MPI-ESM-CSIRO-CCAM. All computed precipitation, maximum and minimum temperatures from the selected RCMs for the period 1970-2010 were used for comparison and correction with the base data at each weather station using linear bias correction model (Buytaert, 2010) [11]. With climate projection, the three RCPs generated the average future climate trend under the expected future greenhouse gas emission, especially RCP4.5 and 8.5. In the second step, HEC-HMS was calibrated and validated using input rainfall in computing inflow to the Pasak Jolasid reservoir for the period 2007 until 2017. The model performance was evaluated using statistical indices namely Nash-Sutcliffe coefficient (NSE), the coefficient of determination (R^2), Root Mean Square Error (RMSE) and Percent Bias (PBIAS). The third (last) step was to investigate all results from steps 1 and 2 to predict the inflow to Pasak Jolasid reservoir in the 21st century. The results were presented by the comparison of the past observed data and the inflow projection in three different time periods during 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100) respectively.

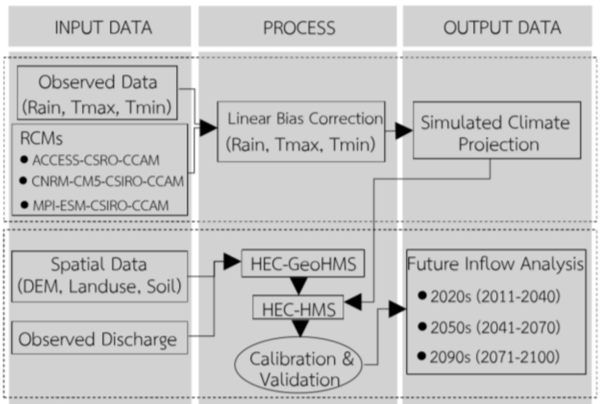


Fig. 2 Overall Methodology in the study

3.1 Downscaling methods

Linear scaling (LS) is the perfect matching month average of corrected values and observed measurement data (Babur et al., 2016; Lee et al., 2016; Manee et al., 2015; Nyunt et al., 2017; Shrestha et al., 2018) [1,6,7,9,12]. RCMs include climate characteristics with finer resolutions for several regional intersections. The Pasak river basin covers approximately 19 intersects which are insufficient and inaccurate. To increase the precision, all climate characteristics from multi RCMs per each grid were corrected using bias correction process and checked with described sensitivity parameters including standard deviation (SD) and mean to check dispersion and central tendency of data. The corrected historical and simulated temperatures from each RCMs were applied with equations 1 and 2, respectively to investigate both maximum and minimum daily temperatures. Additional, equations 3 and 4 were used for correction of historical and projected average daily precipitation (Shrestha, 2018) [12].

Temperature correction equations:

$$T'_{his,d} = T_{his,d} + [\mu_m \cdot T_{obs,d} - \mu_m \cdot T_{his,d}] \quad (1)$$

$$T'_{sim,d} = T_{sim,d} + [\mu_m \cdot T_{obs,d} - \mu_m \cdot T_{his,d}] \quad (2)$$

Precipitation correction equations:

$$P'_{his,d} = P_{his,d} \left[\frac{\mu_m \cdot P_{obs,d}}{\mu_m \cdot P_{his,d}}\right] \quad (3)$$

$$P'_{sim,d} = P_{sim,d} \left[\frac{\mu_m \cdot P_{obs,d}}{\mu_m \cdot P_{his,d}}\right] \quad (4)$$

Where, P is precipitation, T is temperature, d is daily unit, μ_m is long term monthly unit, obs is observed data, his and sim are historical and simulated RCMs data and ' is corrected value.

3.2 Hydrological Modelling

HEC-HMS (US Army Corps of Engineering, 2017) [14] simulated hydrologic process from precipitation to river runoff for watershed that has six components related watershed and meteorological data, i.e., meteorological, water losses, direct runoff, base flow, flow routing and reservoir models. It can also analyze river sediment transport and water quality. The study used HEC-HMS version 4.2.1 to transform rainfall to runoff discharge.

3.2.1 Model Setup

HEC-GeoHMS is the extension of HEC-HMS modeling to delineate hydrological element including sub-basin, river network, sink and diversion which used digital elevation model (DEM) with ArcGIS program. The result from HEC-GeoHMS is input into HEC-HMS which is the base model. In infiltration loss method, land cover and land soil type are considered in selecting SCS curve number and impervious area percentage. A simple canopy equation is used considering water surface detention in each sub-basin. For surface runoff analysis, Clark unit hydrograph formula is used for simulation of surface runoff given time of concentration and storage coefficient. Constant monthly base flow is applied to determine river base flow for every month. For the input precipitation, the weights per sub-basin were generated from Thiessen polygon modification method to find gages weights at each weather station. The HEC-HMS model computed results were compared with daily historical runoff data to check the model accuracy. This process is known calibration and validation. The model was calibrated and validated from 2007 until 2017. The model performance in calibration and validation was evaluated by using standard statistical performance indices and in some cases model parameter adjustment to improve its performance is required to meet the required accuracy. After validation, the HEC-HMS model was used to predict future inflow discharge to the Pasak Jolasid reservoir under climate change conditions. These conditions were given in terms of daily precipitation, maximum and minimum temperatures created from the average of three RCMs under RCP4.5 and 8.5.

4. Result and Discussion

4.1 Downscaling and Climate Change Projection

Future climate was analyzed on two climate characteristics, especially, temperatures (Tmax and Tmin) and precipitation from three regional climate models (ACCESS-CSRO-CCAM, CNRM-CM5-CSIRO-CCAM, MPI-ESM-CSIRO-CCAM); with two recent emission scenarios (RCP 4.5 and 8.5). Those characteristics during 1970-2010 were compared with baseline data from 6 meteorological stations, namely 327202, 379201, 379401, 426201, 426401 and 431301 as shown in Figure 1. This is to correct and evaluate for future climate prediction in the 21st century using linear bias correction method. The results were calculated in terms of absolute percentage change for the three periods (2020s, 2050s and 2080s). Therefore, the standard deviation (SD) and mean were calculated to correct the bias data against the historical data as shown Table 1. The table presented the model performance of the previous three decades using linear bias correction method.

All three corrected RCMs data be equal to baseline trend for six weather station in PRB. In statistical, the whole average precipitations were quietly equaled on three RCMs that means rainfall data nearby central tendency values. Standard deviation was selected to measure data dispersion. The SD volume of precipitation and maximum temperature from raw, ACCESS, CNRM and MPI close to historical data. Except, the double SD volume of minimum temperatures on ACCESS, CNRM and MPI for total stations comparing with raw data.

Table 1 Performance of climate downscaling method (analysis only for ACCESS-CSRO-CCAM, CNRM-CM5-CSIRO-CCAM, MPI-ESM-CSIRO-CCAM).

Station ID	Precipitation		Maximum Temperature		Minimum Temperature	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
327202						
Historical	3.13	9.65	32.06	7.36	21.45	5.63
ACCESS	3.38	8.68	31.88	8.12	21.27	8.01
CNRM	3.54	8.24	31.89	8.14	21.27	8.01
MPI	3.33	7.46	31.89	8.13	21.27	8.03
379201						
Historical	2.94	8.70	32.75	5.33	21.63	4.52
ACCESS	3.26	8.90	32.57	8.18	21.45	8.08
CNRM	3.18	8.78	32.57	8.19	21.45	8.07
MPI	3.22	7.66	32.57	8.18	21.45	8.09
379401						
Historical	2.81	8.44	32.46	5.01	21.43	4.33
ACCESS	3.29	10.54	32.28	8.14	21.25	8.06
CNRM	3.25	9.78	32.28	8.15	21.25	8.05
MPI	3.02	10.61	32.46	8.08	21.43	7.94
426201						
Historical	3.03	9.56	32.87	5.61	22.81	5.10
ACCESS	3.24	9.29	32.69	8.15	22.63	7.75
CNRM	3.29	6.55	32.70	8.16	22.63	7.76
MPI	3.14	7.81	32.70	8.16	22.63	7.77
426401						
Historical	2.95	9.54	31.97	7.80	21.72	4.61
ACCESS	3.25	9.53	31.80	8.17	21.54	8.00
CNRM	3.27	7.66	31.80	8.18	21.54	8.00
MPI	3.17	9.83	31.80	8.18	21.54	8.01
431301						
Historical	2.94	8.72	30.50	5.74	19.77	4.48
ACCESS	3.09	10.86	30.32	8.08	19.60	8.03
CNRM	3.25	9.89	30.32	8.09	19.60	8.04
MPI	2.92	8.03	30.32	8.08	19.60	8.05

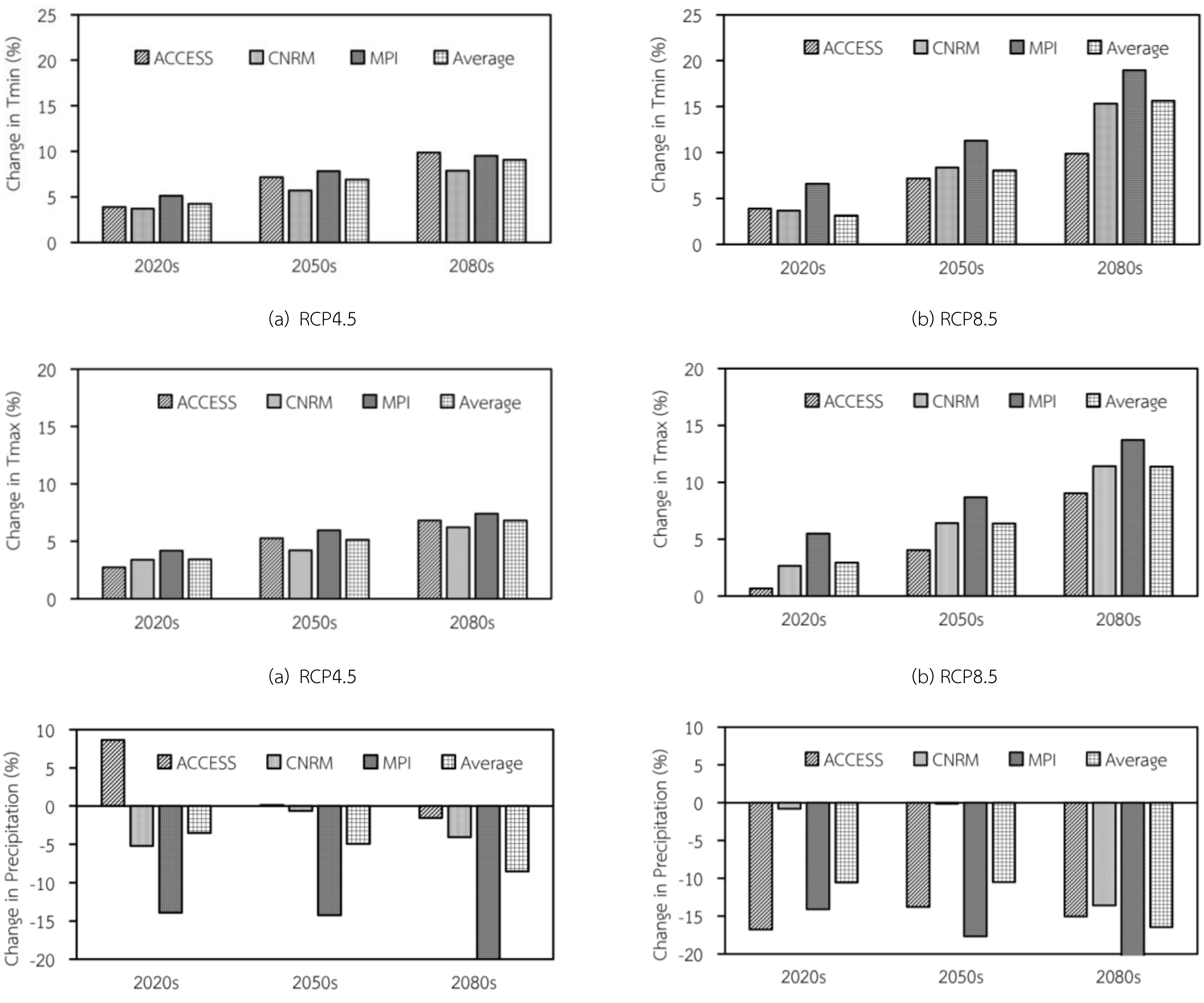
The MPI RCP has highest accuracy and precision over both RCMs (ACCESS and CNRM), especially, mean and SD of 431301 station equivalent previous data. Additional, some ACCESS and MPI precipitation standard deviation volumes including station 379401 and 401301 were higher than baseline. The study was used average from three future bias corrected rainfall, maximum and minimum temperature to be major input for rainfall-runoff model. Wherefore, this will increase data accuracy and average variances of all RCMs sources.

Future climate projection was analyzed until the 21st century which is separated into three periods namely, 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100) referring to near, middle and far future. The baseline average precipitation, Tmax and Tmin at station 379401 (Lom Sak, Phetchabun province) is 1,168 mm, 32.45°C and 21.43°C, respectively. The climate projection result showed that temperature will slightly increase approximate 2°C and precipitation rate will gradually reduce to 0.5 mm per year. Future maximum and minimum temperature trends from the average three RCMs were increased from 32.45 to 34.67°C and 21.43 to 23.37°C (RCP4.5), from 32.45 to 36.15°C and from 21.43 to 24.77°C (RCP8.5). The average precipitation was reduced from 1,168 to 1068.16 and 975.70 mm under RCP4.5 and RCP8.5 respectively.

Percentage of change for Tmin, Tmax and precipitation tend to increase in every period of time. Maximum and minimum temperatures of MPI and ACCESS are highest and lowest over mean for three periods. Its changes in 2080s are about 10 and 15 % for RCP 4.5 and 8.5 as shown in Figure 3. Whereas, future average annual precipitation was dropped close to -10 and -15 % (RCP4.5 and 8.5) during the 21st century. Lowest rainfall changing for both RCPs is CNRM RCM. Moreover, the ACCESS RCM precipitation from 2011 to 2040 for RCP4.5 was increased more than 8% that is different with other RCMs.

4.2 Calibration and Validation of Hydrological Model

The HEC-HMS modeling was calibrated and validated for daily streamflow discharge at hydrological station S.39 (Chai Badan district, Lop Buri province) located near to the inlet point of Pasak Jolasid reservoir. The described performance parameters include 5 indicators namely, root mean square error (RMSE), coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), Percent Bias



(a) RCP4.5 (b) RCP8.5

(a) RCP4.5 (b) RCP8.5

(a) RCP4.5 (b) RCP8.5

Fig. 3 Absolute change in minimum temperature (top), minimum temperature (middle) and precipitation (bottom) at station 379401

(PBIAS) and Volume ratio (Vr) for both calibration and validation periods (2007-2008 and 2012-2015, respectively) to check and improve accuracy of the model. Those indicators were selected following previous studies (Shrestha, 2018; Babur, 2016) [3, 4] that are very suitable for rainfall-runoff model (HEC-HMS).

In Table 2, the statistical results shown that the agreement between observed and simulated daily inflow discharge are: R^2 = 0.79, RMSE = 14.17, NSE = 0.78, PBIAS = 34.09, Vr = 0.99 for calibration and R^2 = 0.83, RMSE = 11.05, NSE = 0.81, PBIAS = 34.70, Vr = 0.99, for validation respectively. The model performance is high in accuracy with low dispersion and high data central tendency. To consider acceptable modeling, the volume ration is very strong (value closed to 1) that means summation of the predicted is the same as the observed volume. R^2 shown less variance for both durations that confirmed the reliability of this model for future prediction with different global greenhouse gas emission scenarios.

Table 2 Performance of hydrological modelling (HEC-HMS).

Period	Duration	R^2	RMSE	NSE	PBIAS	V_r
Calibration	2007-2008	0.79	14.17	0.78	34.09	0.99
Validation	2012-2015	0.83	11.05	0.81	34.70	0.99

The graphs of the historical and simulated water discharges from HEC-HMS are shown in figure 4. Calibration was analyzed for two years from 2007 to 2008 and validation for four years from 2012 to 2015. The predicted trend was similar to that of the baseline for all peak and low discharge durations. Especially, the observed and simulated peak flow discharges in 2007 and 2013 are 806.00, 779.100 and 356.25, 323.04 CMS, respectively. In drought season (February- May), the observed and computed base flows are both less than 10 CMS. For example, in 2012 the difference between the observed and computed base flows during dry season is only 4.49 %.

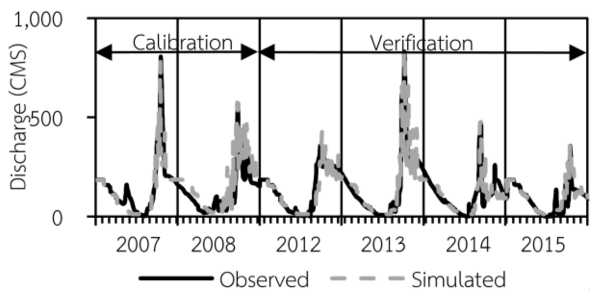


Fig. 4 Calibration and validation of Inflow discharge results at hydrological station (S.39) from HEC-HMS model

4.3 Runoff Simulation Results under Future Climate Projection

Future climate change has impacts on change in precipitation rate and average temperatures and hence inflow discharge to Pasak Jolasid reservoir. The simulated inflows were estimated in three time periods (2020s, 2050s and 2080s) with medium and high greenhouse gas emission, namely RCP4.5 and RCP8.5. Reduction in future precipitation mainly reduces stream discharge. Increasing average temperature lead to higher evaporation rate from water surface. Figure 5 shown annual inflow discharge of baseline and future which can be separated into two scenarios. In both scenarios, the predicted inflows were gradually decreased until the 21st century. In 2020, the expected annual inflow discharges is 1,644.38 and 1,361.09 MCM for RCP4.5 and 8.5. This implies that high greenhouse gas emission results in lower inflow discharge. The peak inflows in 2052, 2065 (RCP4.5) and 2026 (RCP8.5) have over 17,000 MCM per year. In 2090 and 2095, the inflows are expected to be even lower, i.e., 1079.31 and 1,117.73 MCM respectively. Both trends were decreasing with time, despite their visible fluctuations.

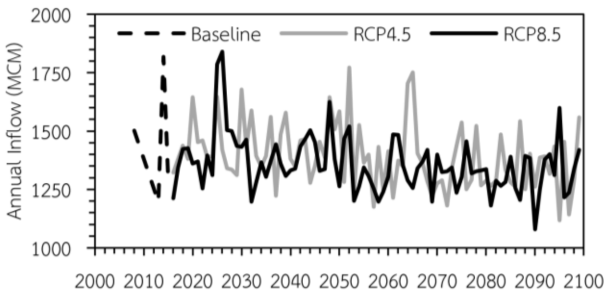


Fig. 5 The trend of past and future annual inflow discharges to Pasak Jolasid Dam

Comparisons of the average predicted inflow with the baseline were assessed under two global greenhouse emissions. The future projected period was delineated to 2020s, 2050s and 2080s to represent average inflow of every 30 years as in Table 3. The annual mean inflow discharge of RCP4.5 is 1,441 MCM in 2020s; 1,409 MCM in 2050s and 1,340 MCM in 2080s respectively. Approximately this is an annual reduction of about 1 MCM per year. For RCP8.5, the mean annual inflow discharge is 1,401 MCM in 2020s, 1361 MCM in 2050s and 1316 MCM in 2080s respectively or annually a reduction of about 0.94 MCM per year. For the period from 2020s to 2080s (a duration of 90 years), the inflow volumes for RCP8.5 during rainy and winter seasons are lower than in the past decade by -1.12 and -0.41 MCM per year whereas in summer seasons, the inflow volume is higher by 0.59 MCM per year. These results confirm that streamflow will increase in summer seasons and reduce in both rainy and winter seasons. The overall annual discharge will slightly reduce in future depending on global greenhouse gas emission.

Table 3 Average annual inflow discharge with different greenhouse gas emission scenarios at inlet to Pasak Jolasid reservoir.

Season	Average Annual Inflow under Climate Scenarios					
	2020s		2050s		2080s	
RCP	4.5	8.5	4.5	8.5	4.5	8.5
Annual	1,441	1,401	1,409	1,361	1,340	1,316
Summer	182	200	227	206	218	253
Rainy	651	619	600	599	556	519
Winter	608	582	582	556	567	545

Figure 6 shows change in inflow discharge for annual, summer, rainy and winter seasons for the three time periods (2020s, 2050s and 2080s). The annual inflow tends to decrease from -0.61 in 2020s to -7.56% in 2080s for RCP4.5; and -3.39 to -9.21 (RCP8.5) respectively. The inflow decrease in winter season in 2020s, 2050s and 2080s is about -9.52, -13.28, -15.65% for RCP4.5; and -13.36, -17.21, -18.91% for RCP8.5.

5. Conclusion and Recommendation

This study quantifies future global climate impact on inflow discharge to Pasak Jolasid Dam. Future climate changes were simulated using linear bias correction method from different regional climate models under two greenhouse gas emission scenarios (RCP4.5 and RCP8.5). Inflow discharge assessment wascalculated by using hydrological model (HEC-HMS) to simulate transformation of rainfall to stream flow discharge. However, statistical performant of HEC-HMS is high acceptable and accuracy. In future streamflow prediction were investigate from corrected future precipitation, maximum and minimum temperatures to be major input to HEC-HMS model.

Climate change analysis shown that future average temperatures tend to increase approximately 2°C in the 21st century. Future precipitation significantly decreases by -8.55% (RCP4.5) when compared with the baseline and by -16.46% (RCP8.5). These trends lead to significant impacts to future flow with a decrease in volume of about 1 MCM per year in rainy season over the century, 0.46 MCM per year in winter and an increase of about 0.4 MCM per year in summer. The future average annual inflow discharge to the Pasak Jolasid Dam in the 21st century will slightly decrease approximately 1.12 MCM per year for RCP4.5 and 0.94 MCM per year for RCP8.5 or an average of 1.03 MCM per year for both RCPs. The result of this study can be used as a guideline for future planning and management of sustainable water resources and water balance to reduce water shortage and climate change impacts in the Pasak River Basin.

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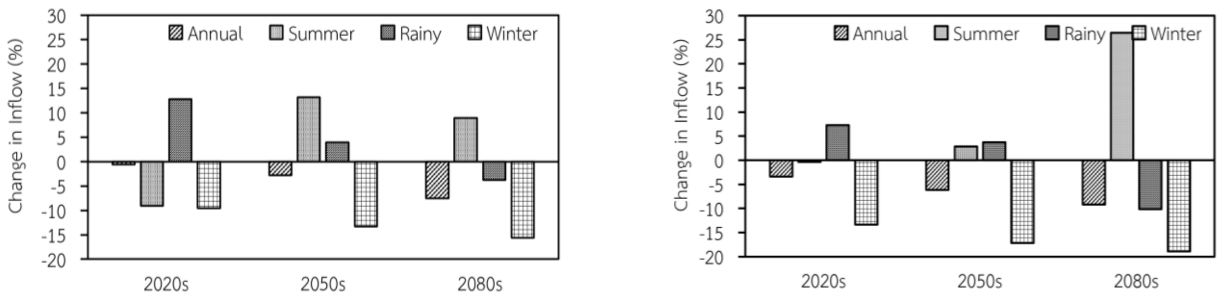

(a) RCP4.5 (b) RCP8.5

Fig. 6 Percentage changing in inflow discharge to Pasak Jolasid Dam on 2020s, 2050s and 2080s

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