The Impacts of Climate Change on Future Hydrometeorological Regimes in the Chao Phraya River Basin, Thailand

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Abstract

The major aim of this study is to investigate the impacts of climate change on hydrometeorological regimes including air temperature, rainfall, potential evapotranspiration and consequently natural runoff. Chao Phraya basin was selected as the case of study area. Rainfall variation and change of the selected irrigation projects in the Chao Phraya basin was also examined. The historic records of air temperature and rainfall were collected from 41 meteorological stations located in and nearby the basin area. Climate change was investigated by using the Generalized Circulation Model (GCM) projection of A1B balance of all source scenario. The study used output data from the United Kingdom Hadley Center's Global Climate Model "HadCM3 (10) (13)" with approximately 180 × 180 km. spatial resolution. Downscaling into the Chao Phraya basin was accomplished using the PRECIS Regional Climate Model with approximately 25 × 25 km. resolution along with the bias correction technique with reference to the mean observed time series. It was found that in the 20-year period during 2017–2036, the average monthly maximum and minimum air temperatures in the Chao Phraya basin trend to increase throughout the normal baseline values during 1981–2010 by 0.5–2.0 degree Celsius. The monthly rainfall under climate change in the Chao Phraya basin over 20-year period during 2017–2036 which is an average of every 5 years, shows significant deviation both higher and lower from the normal baseline values during 1981–2010 in the range of 10 mm per month to 50 mm per month. The monthly average runoff in the Chao Phraya basin over the 20-year period during 2017–2036, average every 5 years across all 4 periods during 2017–2021, 2022–2026, 2027–2031, and 2032–2036 are significantly varied. The highest values during the rainy season were found in the 2027–2031 average period. While the lowest values during the rainy season were observed in the 2022–2026 period. These findings should be useful for water allocation management and appropriate use of water resources under climate change condition in the Chao Phraya basin.

Keywords: Climate change**,** impacts of climate change, Generalized Circulation Model, Chao Phraya basin

1. Introduction

Climate change is the long-term change in weather patterns. They are including namely temperature, rainfall and consequently discharge. It is important to investigate the impacts of climate change on hydrometeorological regimes since their fluctuation will pose the challenges to water management. This is due to the reason that the climate change is altering water patterns causing more frequent and damaging of floods and droughts. With increasing climate change, water users and policy makers are facing with higher resilient. It is therefore needed to prepare for such water-related uncertainties by integrating scientifically sound climate change information to respond to the uncertain water resources.

The early scientific publications to address trends and changes in the hydrometeorological regimes under the impacts of climate change appeared in the 1980's [1–3]. Today, impacts of climate change on streamflow become one of the focuses of scientists from various countries around the world. The impacts of climate change for various scenarios on water resources of individual river basins were in [4–14]. R.I. McDonald et.al. [15] finally concluded that the climate change has profound impacts on stream hydrology, water quantity, water quality and water supply to ecosystems and humans.

In contrast to these research publications, study of the hydrometeorological variation under the influence of climate change in Thailand has not been properly conducted. Two key projects were implemented in the Chao Phraya basin long time ago. It included the Integrated Study on Hydro-Meteorological Prediction and Adaptation to Climate Change in Thailand (IMPAC-T) and the Development of Climate/Disaster Risk Assessment and Application of Risk Information in Development Planning in Thailand (THPRA) [16]. Nevertheless, effort on analysis of the complete hydrometeorological regimes in the country under the latest climate change scenarios is needed.

The future change in relevant hydrometeorological factors affecting to discharge such as air temperature, rainfall amount and potential evapotranspiration under the impacts of climate change will be assessed. Chao

Phraya basin in central Thailand is selected as the case of this study. Rainfall variation and change of the selected irrigation projects in the Chao Phraya basin will also be examined. The future change of river runoff will crucially affect all water users. The results obtained in this study thus are expected to help inform decision making and planning approaches to improve water resources management in the study area.

2. Study Area

Chao Phraya, the principal river basin of Thailand was selected to be the case study of this research. Chao Phraya river basin, the nation's fertile central plain of the country is one of 22 major river basins of Thailand according to the river basin boundary delineation under the Royal Decree on River Basin Designation B.E.2564 (2021) published in the Royal Gazette on February 11, 2021 by the Office of National Water Resources (ONWR). Basin code of the Chao Phraya is 10 as illustrated in **Figure 1**.

The Chao Phraya basin covers an area of 20,441.94 sq.km. The river begins with the Ping – Nan confluence at Nakhon Sawan, 225 km. north of Bangkok. Its tortuous course flows past Chai Nat, Sing Buri, Ang Thong, Nonthaburi, Bangkok to its mouth, the Gulf of Thailand at Samut Prakan as shown in **Figure 2**.

The climate of the Chao Phraya basin is under the influence of the southwest (rainy) and northeast (dry) monsoons. Due to the monsoon winds, rainfall distribution over the basin significantly varies between the rainy (mid-May to mid-October) and dry (mid-October to mid-May) seasons. The mean annual rainfall of the basin is 1,231 mm per annum. The rainfall during the rainy season accounts for about 87% of the mean annual rainfall in the basin area.

The Chao Phraya basin has a mean annual natural flow of 3,550 MCM per annum. The natural flow during the rainy season accounts for about 67% of the mean annual natural flow in the basin. Groundwater storage in the basin area is estimated to be around 14,000 MCM per annum.

Water level in the Chao Phraya main river is greatly influenced by the operations of 2 main reservoirs upstream of the basin area. They are namely Bhumibol dam on the Ping and Sirikit dam on the Nan rivers. Both reservoirs are located at the reaches upstream to the confluence of the Chao Phraya at Nakhon Sawan. The storage capacities of Bhumibol and Sirikit reservoirs are 13,462 and 9,519 MCM, respectively.

The Chao Phraya is the basis of several irrigation projects. Flood plains on both sides of the main river have been for centuries the center of rice cultivation covering an area of around 6 million rais. Most of inhabitants of this river basin earn their living from agricultural productions. But the basin is now in transition from water riches to water scarcity due to the increasing demand and fluctuation of water resources according to the climate change. The basin water resources are therefore limited.

In this critical phase, aware of the impacts of climate change on the hydrometeorological regimes is one of the sound water resources management practices. Better understanding of the water budget stress in the Chao Phraya basin at present and in the future will allow policy makers to make the proper management decision. Decision based sound hydrological aspects will benefit local citizens and sustain the region's water resources. Therefore, the research of impacts on hydrometeorological regimes under climate change is critically needed for strategic and effective water resources planning and management in the basin area

3. Materials and Methods

To understand the future changes in air temperature and rainfall, the historic dataset from 41 meteorological stations in the study area were collected from Thai Meteorological Department (TMD). The list of meteorological stations is summarized in **Table 1**.

Climate change was assessed based on the General Circulation Model (GCM) projection. A1B (balance of all sources) climate change scenario was used to examine how future climate change may affect water resources in the Chao Phraya basin. The output of study was derived by using the data from the United Kingdom Hadley Center's Global Climate Model "HadCM3 (10) (13)" with approximately 180 x 180 km. spatial resolution, which is included in CHIP 5 of AR5. The calculation used IPCC's greenhouse gas emission scenario (SRES) under the A1B scenario, which can be compared to the new RCP6.0 scenario. Subsequently, downscaling was performed to the Chao Phraya basin regional level using the PRECIS Regional Climate Model with approximately 25 × 25 km. resolution and 19 vertical levels, along with the bias correction technique with reference to the mean observed time series.

This part of the research study produced the results for 4 meteorological variables in the Chao Phraya basin area, including monthly average of maximum and minimum temperatures, rainfall amount and potential evapotranspiration for 20-year periods during 2017–2036 averaged every 5 years, namely 2017–2021, 2022–2026, 2027–2031 and 2032–2036. These average values will be compared with those of the 30-year average values during 1981–2010 which is the standard normal period that the World Meteorological Organization (WMO) uses and recommends for worldwide adoption baseline during this research project began.

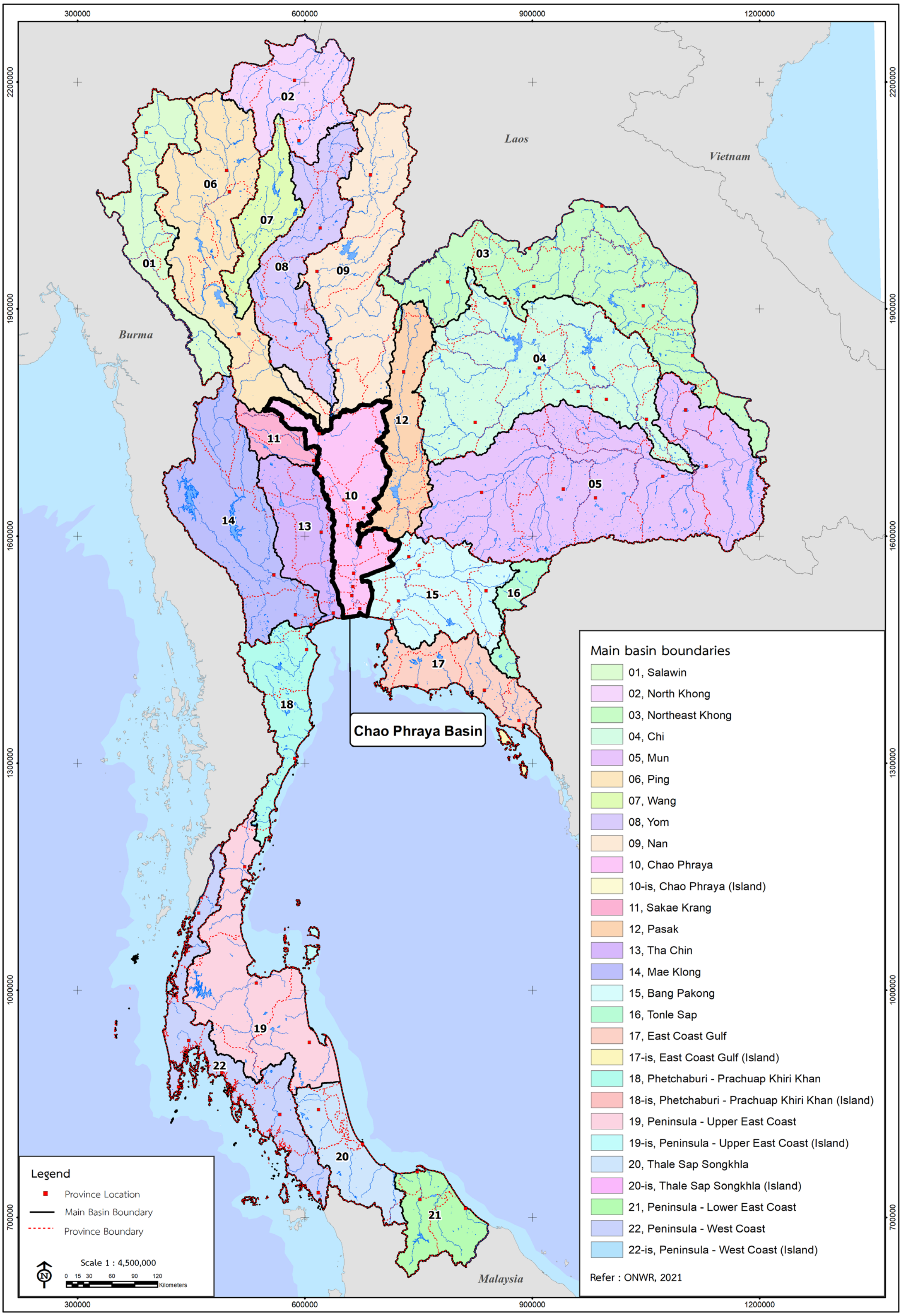

Figure 1 Location of the Chao Phraya basin

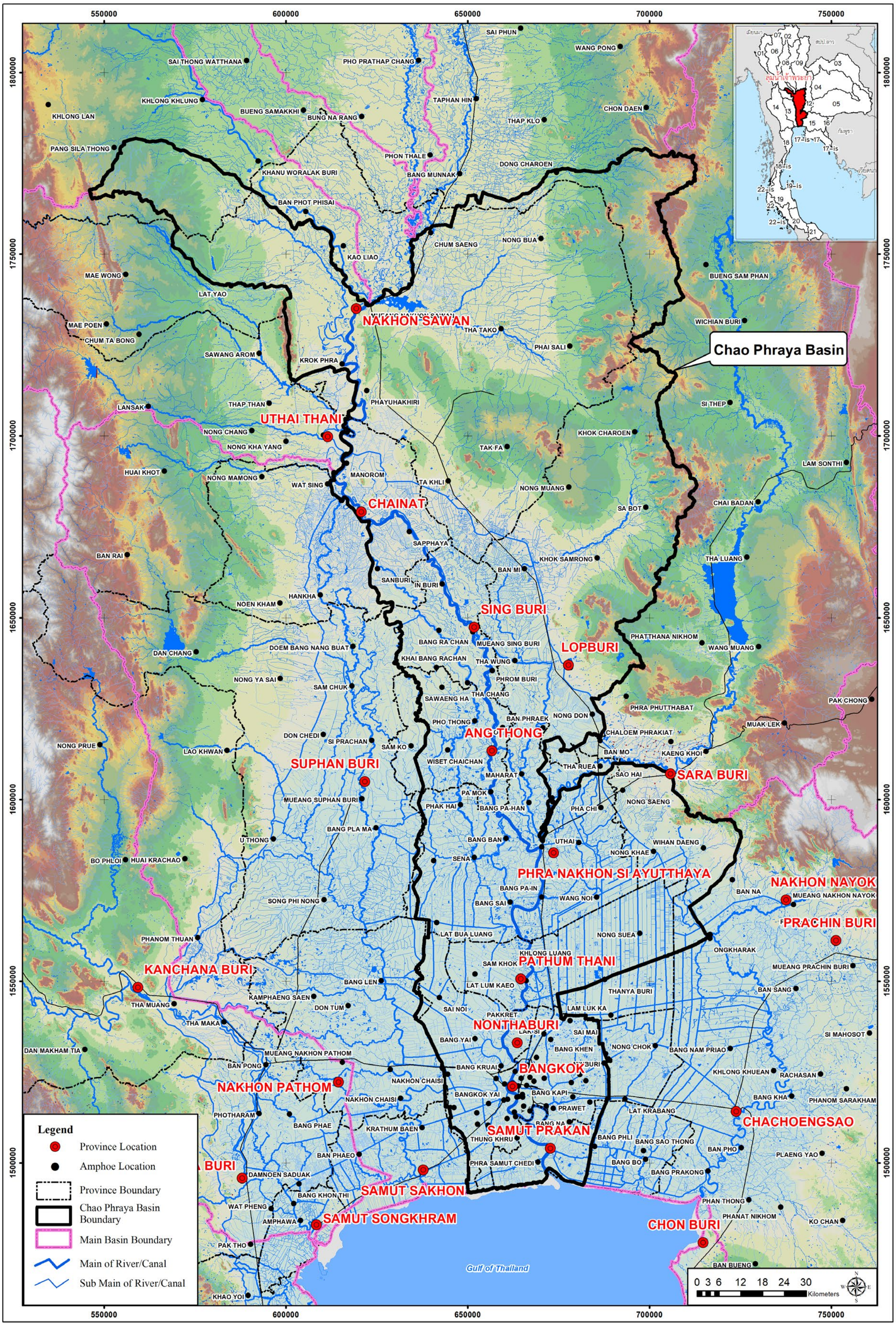

Figure 2 Map of the Chao Phraya basin

This study calculates potential evapotranspiration value using Penman-Monteith method, which incorporates various factors affecting crop water consumption in its calculation, namely solar radiation, wind speed, air temperature and humidity. For calculating the potential evapotranspiration value resulting from the future climate change, this study uses meteorological variable projection data from the result of PRECIS Regional Climate Model.

Table 1 List of meteorological stations

CODE	NAME	LAT.	LONG.
424301	Ratchaburi	13.4897	99.7922
455301	Bang Na Agromet.	13.6666	100.6166
429601	Suvarnabhumi Airport	13.6863	100.7675
455203	Bangkok Port (Khlong Toei)	13.7069	100.5680
455201	Bangkok Metropolis	13.7263	100.5600
455601	Don Muang Airport	13.9191	100.6050
451301	Nakhon Pathom	14.0166	99.9666
450201	Kanchana Buri	14.0225	99.5358
419301	Pathum Thani	14.1000	100.6166
425301	U Thong Agromet.	14.3036	99.8647
425201	Suphan Buri	14.4744	100.1388
415301	Ayutthaya	14.5333	100.7166
431301	Pak Chong Agromet.	14.6438	101.3208
450401	Thong Phaphum	14.7422	98.6363
426201	Lop Buri	14.8000	100.6166
402301	Chai Nat Agromet.	15.1500	100.1833
426401	Bua Chum	15.2647	101.1908
400301	Tak Fa Agromet.	15.3500	100.5000
379402	Wichian Buri	15.6569	101.1083
400201	Nakhon Sawan	15.8000	100.1666
376401	Um Phang	16.0247	98.8644
379201	Phetchabun	16.4333	101.1500
386301	Phichit Agromet.	16.4380	100.2925
380201	Kamphaeng Phet	16.4833	99.5333
379401	Lom Sak	16.7736	101.2494
378201	Phitsanulok	16.7833	100.2666
376201	Tak	16.8783	99.1433
373201	Sukhothai	17.1061	99.8000
373301	Si Sam Rong Agromet.	17.1666	99.8666
376203	Bhumibol Dam	17.2333	99.0500
351201	Uttaradit	17.6166	100.1000
328202	Thoen	17.6350	99.2347
330201	Phrae	18.1666	100.1666
328201	Lampang	18.2833	99.5166
328301	Lampang Agromet.	18.3166	99.2833
329201	Lamphun	18.5666	99.0333
331201	Nan	18.7797	100.7777
327501	Chiang Mai	18.7900	98.9769
331301	Nan Agromet.	18.8666	100.7500
331401	Tha Wang Pa	19.1105	100.8025
331402	Thung Chang	19.4119	100.8852

4. Research Results

Combined graphs of the average monthly hydrometeorological time series under climate change over 20 years during 2017–2036 averaged every 5 years during 2017–2021, 2022–2026, 2027–2031, and 2032–2036 were plotted in comparison with the normal baseline during 1981–2010. The aim is to determine the variation and trend of the change. The results of climate change impacts on future hydrometeorological regimes in the study area, Chao Phraya basin is presented as follows:

4.1 **Calibration, Validation and Bias Correction**

For calibration, validation and bias correction in this study, the information was divided into 3 datasets across 2 time periods. They are namely measurement data and RCM output data from the same time in the calibration period and RCM output from the validation period. However, since the different starting time of observed meteorological variables from various stations in the study area, different calibration and validation periods were established. For air temperature and rainfall, the calibration period was between 1971–1990 and the validation period was between 1996–2010. For other meteorological variables, the calibration period was between 1981–1995 and the validation period was between 1996–2010. Although RCM is an effective tool for explain regional climate conditions, there are still significant system errors. Due to limitations in processing GCM that lacks consideration of appropriate physical processes in atmospheric layers and difference of land conditions, directly apply the results obtained from the RCM may cause significant errors in future predictions. This problem can be solved by using the bias correction technique. Bias correction is aimed to achieve the results that most closely match the values obtained from the actual measurement before using in further study.

The bias correction technique used in this research involves modifying the data based on difference between the values of RCM and that of the observation. Shown in **Figure 3** is the sample of the results obtained. It shows the comparison of observed daily maximum air temperature, the RCM output and the results after bias correction at Suphan Buri meteorological station during January to March in 2010. It is clearly seen that the bias corrected data variate similarly to that obtained from measurement.

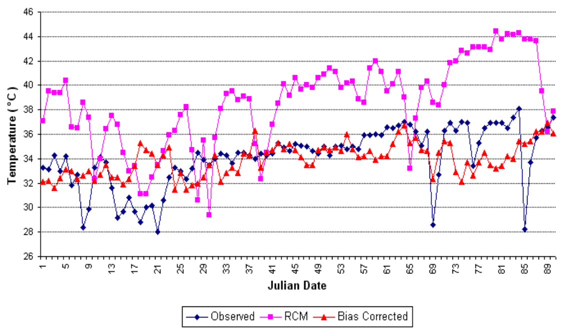

Figure 3 Comparison of observed daily maximum air temperature, RCM output and the result after bias correction at Suphan Buri meteorological station during January–March, 2010.

4.2 Impacts of Climate Change on Future Maximum Air Temperature in the Chao Phraya Basin

The average monthly maximum air temperature in the Chao Phraya basin for the 20-year period, averaged every 5 years during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 were compared with the average of normal baseline values during 1981–2010 as illustrated in **Figure 4.**

It shows the values for all 4 periods during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 that are clearly 0.5–2.0 degree Celsius higher than the 30-year average values during 1981–2010. Particularly, during the period of 2032–2036, the average monthly maximum air temperature is higher than other periods.

In summary, it can be concluded that in the 20-year period during 2017–2036, the average monthly maximum air temperature in the Chao Phraya basin for all 4 periods (during 2017–2021, 2022–2026, 2027–2031 and 2032–2036) tends to increase throughout the normal baseline values by 0.5–2.0 degree Celsius.

4.3 Impacts of Climate Change on Future Minimum Air Temperature in the Chao Phraya Basin

The average monthly minimum air temperature in the Chao Phraya basin for the 20-year period, averaged every 5 years as shown in **Figure 5**, shows the values during the winter season (between mid-October to mid-February) for all 4 periods during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 that are similar and clearly 0.5–2.0 degree Celsius higher than the 30-year average values during 1981–2010. Particularly, during the period of 2032–2036, the average monthly minimum air temperature is higher than other periods. For the other season across all 4 periods, the average monthly minimum air temperature remains higher than the normal baseline average during 1981–2010 throughout the year by approximately 0.5–2.0 degree Celsius as well.

In summary, it can be concluded that for both winter and other seasons in the 20-year period during 2017–2036, the average monthly minimum air temperature in the Chao Phraya basin for all 4 periods (during 2017–2021, 2022–2026, 2027–2031 and 2032–2036) tends to increase throughout the year of the normal baseline average values during 1981–2010 by 0.5–2.0 degree Celsius.

4.4 Impacts of Climate Change on Future Rainfall in the Chao Phraya Basin

The average monthly rainfall in the Chao Phraya basin for the 20-year period, averaged every 5 years during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 are compared with the normal baseline average values during 1981–2010 as illustrated in **Figure 6**.

It shows the values during the rainy season (during mid-May to mid-October) for all 4 periods during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 that clearly vary both higher and lower than the 30-year average values during 1981–2010. The values above average range from 10 mm per month to 50 mm per month. The values below average also range from 10 mm per month to 50 mm per month. The highest values are found during 2027–2031. While the lowest values are found during 2022–2026.

For the other seasons across all 4 average periods, the average monthly rainfall shows slight variations both above and below the 30-year average values during 1981–2010.

In summary, it is revealed that the average monthly rainfall in the Chao Phraya basin for the 20-year period during 2017–2036, averaged every 5 years has similar pattern to those of 30-year average values during 1981–2010. But it shows clear constant variations both above and below the normal baseline values.

The rainfall patterns for the 20-year period, averaged every 5 years, show that all 4 periods have the distinct rainfall starting from February through November. Therefore, it can be concluded that the rainfall pattern in the Chao Phraya basin lasts for 10 months starting in February, which is the period of early summer.

4.5 Impacts of Climate Change on Future Potential Evapotranspiration in the Chao Phraya Basin

The monthly potential evapotranspiration (PET) in the Chao Phraya basin for the 20-year period averaged every 5 years compared with the 30-year average monthly rainfall during 1981–2010 are plotted in **Figure 7**. When compared with the 30-year average monthly rainfall, it is found that during summer season (mid-February to mid-May), rainy season (mid-May to mid-October) and winter season (mid-October to mid-February), PET varies respectively at the range of 120–170, 120–150 and 100–120 mm per month.

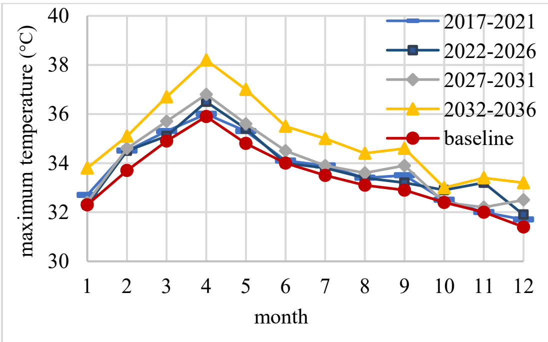

Figure 4 Comparison of average monthly maximum air temperature under climate change over 20 years (2017–2036), averaged every 5 years during 2017–2021, 2022–2026, 2027–2031, and 2032–2036 with the normal baseline 1981–2010 of the Chao Phraya basin

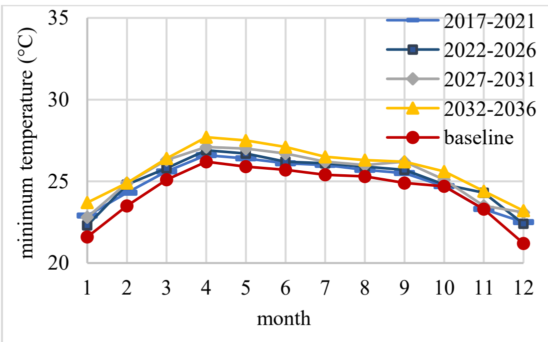

Figure 5 Comparison of average monthly minimum air temperature under climate change over 20 years (2017–2036), averaged every 5 years during 2017–2021, 2022–2026, 2027–2031, and 2032–2036 with the normal baseline 1981–2010 of the Chao Phraya basin

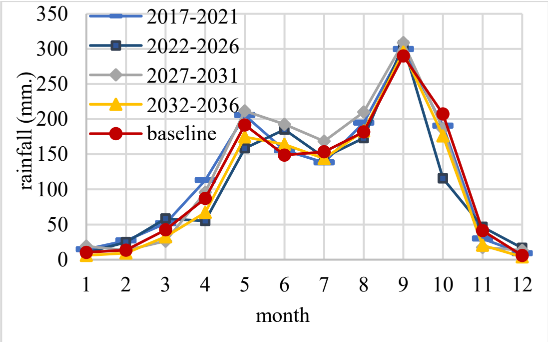

Figure 6 Comparison of average monthly rainfall under climate change over 20 years (2017–2036), averaged every 5 years during 2017–2021, 2022–2026, 2027–2031, and 2032–2036 with the normal baseline 1981–2010 of the Chao Phraya basin

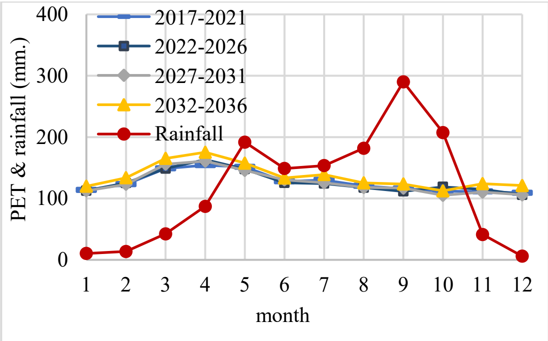

Figure 7 Comparison of average monthly potential evapotranspiration under climate change over 20 years (2017–2036), averaged every 5 years: 2017–2021, 2022–2026, 2027–2031, and 2032–2036 with the 30-year average monthly rainfall during 1981–2010 of the Chao Phraya basin

4.6 Impacts of Climate Change on Future Natural Runoff in the Chao Phraya Basin

Hydrologic cycle in the Chao Phraya basin is a complex process. It is affected by local climate, topography, soil, vegetation cover and human activities. The runoff in the basin study area is not natural flow, but rather managed flow through regulator, water gate, irrigation and drainage systems including all relevant water control structures throughout the irrigation projects in the basin area. As a result, runoff monitoring stations in the study area is the regulated regime. Therefore, it is not appropriate to calculate the runoff at each consideration point using natural flow analysis methods commonly used in hydrological engineering study. This is due to the runoff in the irrigation projects of the Chao Phraya basin is the allocated runoff through the Chao Phraya and Pasak River water management systems and rainfall into the basin area. However, the natural river runoff in the study area is largely influenced by rainfall.

Thus, in this research study, natural runoff in the Chao Phraya basin was evaluated using the rainfall – runoff relation derived from the historical records of rainfall and runoff from the technical report of Royal Irrigation Department [17] as shown in Eq. (1).

$$Rc = (0.0675 \times R) - 64.166 \quad (1)$$

Where R_c is runoff coefficient (%)
R is rainfall amount (mm.)

Calculation of the runoff coefficient can be done by substituting the rainfall amount into the equation of the relationship between the runoff coefficient and rainfall. Then the runoff can be calculated by multiplying the rainfall amount with the obtained runoff coefficient. Runoff data for the 20 years during 2017–2036 was then synthesized using the obtained rainfall – runoff parameters along with the analysis of the rainfall under climate change for 20-year period during 2017–2036. The runoff obtained for 20 years during the same period is therefore the regimes under climate change. The analysis was conducted for monthly values average every 5 years during 2017–2021, 2022–2026, 2027–2031 and 2032–2036.

The findings showed that the monthly average runoff in the Chao Phraya basin over the 20-year period, averaged every 5 years across all 4 periods during 2017–2021, 2022–2026, 2027–2031 and 2032–2036 significantly varied. As shown in **Figure 8**, the highest values during the rainy season were found in the 2027–2031 average period. While the lowest values during the rainy season were observed in the 2022–2026 period.

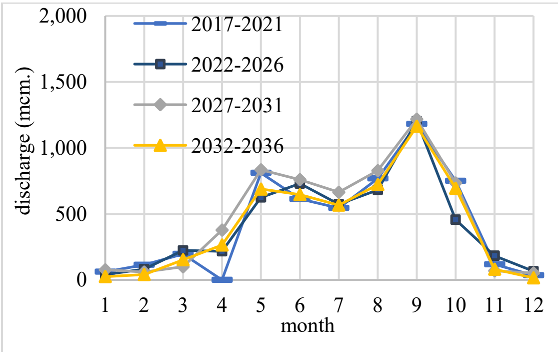

Figure 8 Monthly runoff under climate change in the Chao Phraya basin for 20-year period during 2017–2036), averaged every 5 years: 2017–2021, 2022–2026, 2027–2031, and 2032–2036

4.7 Historical Rainfall Variation and Changes at the Irrigation Projects in the Chao Phraya Basin

Irrigation projects in the Chao Phraya basin which were selected as the case for this study are Nakhon Luang, Lower Pasak and Khlong Priao – Sao Hai operation and maintenance projects in Saraburi and Ayutthaya provinces. The location of these three irrigation projects is shown in **Figure 9**.

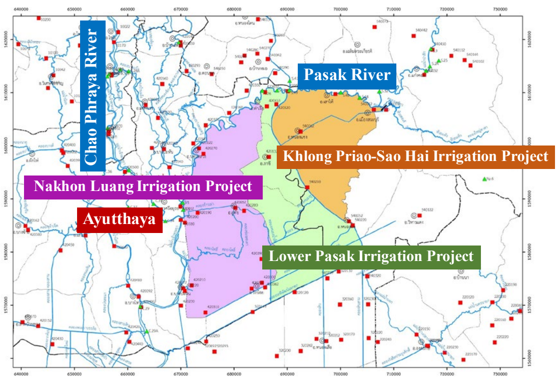

Figure 9 Location of Nakhon Luang, Lower Pasak and Khlong Priao – Sao Hai irrigation Projects in the Chao Phraya basin

Details of water management of each project are collected from Royal Irrigation Department (RID). They are summarized as follows:

1. Nakhon Luang Irrigation Project: Nakhon Luang main irrigation canal branching from the right side of Rabhi Bhat canal at km.4+112 was constructed in 1960. Total main canal length is approximately 60 km. The conveyance capacity of the canal is 34 m^3/s. Subsequently, the lateral and sub-lateral canals were constructed along with the relevant control structures. The project was completed in 1964.

2. Lower Pasak Irrigation Project: The project is first Thailand's regulator, built across the Pasak River at Tha Luang subdistrict, Tha Rua district, Ayutthaya province during the Reign of King Rama VI. The regulator therefore was named Rama VI Dam during its inauguration on December 1, 1924. Since Tha Luang subdistrict is at lower elevation than Saraburi province, the irrigation project area can also receive water allocation from the Chao Phraya River when the water volume in the Pasak River is insufficient.

3. Khlong Priao – Sao Hai Irrigation Project: The construction began in 1952 and was completed in 1970. The water resources of the project are Khlong Priao reservoir and Pasak River at downstream of Pasak reservoir. The maximum storage volume and active storage of Khlong Priao reservoir is respectively 7.20 and 5.76 MCM. The active storage capacity of Pasak reservoir is 960 MCM. There are 2 pumping stations drawing water from the Pasak River at downstream of Pasak reservoir. They are Khlong Priao and Sao Hai pumping stations. Both pumping stations are located at Pak Priao subdistrict, Muang Saraburi district, Saraburi province. Khlong Priao pumping station was constructed with 5 pumps installed each with the pumping rate of 2 m^3/s. Sao Hai pumping station construction began in 1969 and was completed in 1975 with 8 pumps installed each with the pumping rate of 1 m^3/s.

The study of historic 30-year records of rainfall changes in the selected irrigation projects, Nakhon Luang, Lower Pasak and Khlong Priao – Sao Hai was conducted using the areal average rainfall of the project areas. Thiessen Polygon Method (TPM) was used to analyze the Equivalent Uniform Depth (EUD) of the rainfall in the selected irrigation project areas. TPM is a commonly used method for weighting observation from meteorological stations according to the area. This method is also called the weighted mean method and is considered one of the most practical in hydrological engineering. TPM does not account for topographical aspects. Because the Chao Phraya basin is the plain and lacks significant elevation differences, therefore, TPM is appropriate to calculate the areal average rainfall in the area.

The study of historical rainfall change was conducted to examine the deviations from normal or average rainfall over a 30-year period during 1994–2023. The analysis considered monthly rainfall averaged every 5 years across 6 periods over the past 30 years. They are including 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, 2019–2023. This is expected to examine whether these data showed trends of increase, decrease or no change. The 5-year average monthly rainfall of the Nakhon Luang, Lower Pasak, and Khlong Priao - Sao Hai irrigation projects across the 6 periods of 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, and 2019–2023) were compared with the 30-year average monthly rainfall during 1994–2023 and the normal baseline during 1981–2010 as shown in **Figure 10–12**.

The findings can be summarized as follows:

1. Nakhon Luang Irrigation Project: The rainfall for all six 5-year average periods of 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, 2019–2023 showed clear variations both above and below the 30-year average values during 1994–2023. The 5-year average for September during 2009-2013 shows the highest deviation above the 30-year average rainfall during 1994–2023 at 92.2 mm per month (42.6%). The 5-year average for September during 1999–2003 shows the largest deviation below the 30-year average values during 1994–2023 at 75.0 mm per month (34.7%).

2. Lower Pasak Irrigation Project: The rainfallfor all six 5-year average periods of 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, 2019–2023 also showed obvious variations both above and below the 30-year average rainfall during 1994–2023. The 5-year average for October during 2014–2018 shows the highest deviation above the 30-year average values during 1994–2023 at 65.9 mm month (57.1%). The 5-year average for September during 1999–2003 shows the largest deviation below the 30-year average values during 1994–2023 at 64.5 mm per month (29.9%).

3. Khlong Priao – Sao Hai Irrigation Project: The rainfall for all six 5-year average periods of 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, 2019–2023 also showed clear variations both above and below the 30-year average values during 1994–2023. The 5-year average for September during 2004–2008 shows the highest deviation above the 30-year average rainfall during 1994–2023 at 74.3 mm per month (32.3%). The 5-year average for September during 1999–2003 shows the largest deviation below the 30-year average rainfall during 1994–2023 at 41.8 mm per month (18.2%).

The rainfall during the dry season from mid-October to mid-May for all six 5-year average periods of all 3 irrigation project areas showed slight variations both above and below the 30-year average ones during 1994–2023.

In summary, it can be concluded that the average monthly rainfall during the dry season in these three irrigation project areas over all six 5-year average periods of 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, 2019–2023 was close to the past dry season of 30-year average values during 1994–2023.

However, the comparison of predicted monthly average rainfall for the 5-year period of 2017–2021 under climate change in the Chao Phraya basin with observed values from the whole area of Nakhon Luang, Lower Pasak and Khlong Priao - Sao Hai Irrigation Projects showed significant differences especially during the rainy season as illustrated in **Figure 13**. Hence, it should be aware that climate change in the future is based on specified scenarios. It may not be the outcome that will occur in the future. Applying this kind of numerical results require precaution of significant knowledge and understanding of atmospheric sciences. Otherwise, it will mislead the understanding and affect the policy making.

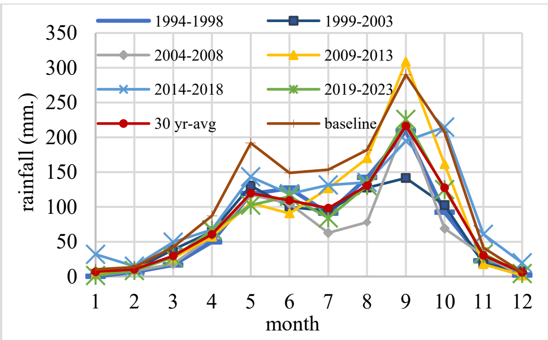

Figure 10 Comparison of 5-year average monthly rainfall across 6 periods: 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, and 2019–2023 with the 30-year average monthly rainfall during 1994–2023 and the normal baseline during 1981–2010 of the Nakhon Luang Irrigation Project

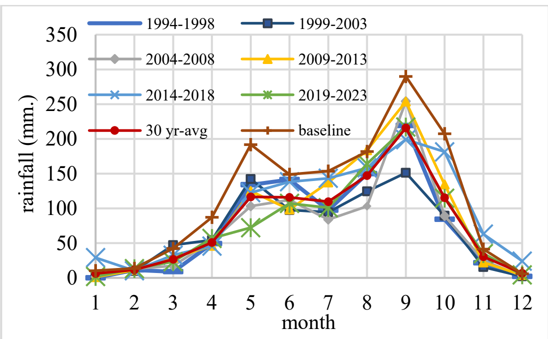

Figure 11 Comparison of 5-year average monthly rainfall across 6 periods: 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, and 2019–2023 with the 30-year average monthly rainfall during 1994–2023 and the normal baseline during 1981–2010 of the Lower Pasak Irrigation Project

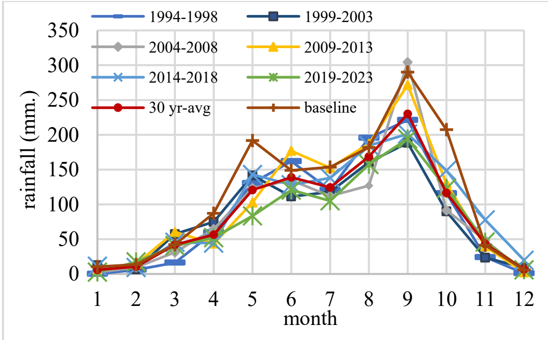

Figure 12 Comparison of 5-year average monthly rainfall across 6 periods: 1994–1998, 1999–2003, 2004–2008, 2009–2013, 2014–2018, and 2019–2023 with the 30-year average monthly rainfall during 1994–2023 and the normal baseline during 1981–2010 of the Khlong Prai – Sao Hai Irrigation Project

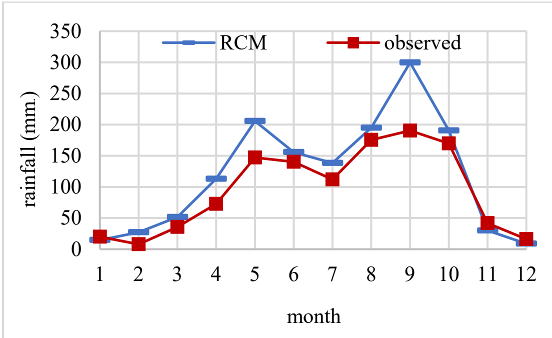

Figure 13 Comparison of predicted average monthly rainfall for the 5-year period of 2017–2021 under climate change in the Chao Phraya basin with observed values from the whole area of Nakhon Luang, Lower Pasak and Khlong Priao - Sao Hai Irrigation Projects

5. Discussion and Conclusion

Most of the early summer rainfall in the Chao Phraya basin is caused by high pressure systems of cold and dry air masses from China moving into upper region of Thailand. These air masses are colliding with warm and humid air masses moving from the southeastern coast into the country. These two air masses with different characteristics and temperatures cause mixing, turbulence and strong air uplift resulting in thunderstorms and strong gusts in the collision areas. However, these conditions occur shortly within small areas. This phenomenon is called summer storm. The greater the temperature difference between the two air masses, the higher severe the storm explodes. Therefore, during this period, caution must be taken regarding large billboards, unstable buildings and houses, and large trees with many branches that may collapse and cause damage to property and endanger lives. Relevant government agencies and the public must be cautious of these potential hazards.

Following this period is the rainy season starting from mid-May with possible tropical cyclones moving from the South China Sea into the upper region of Thailand during August to October. This results in significantly increased scattered rainfall covering the Chao Phraya basin area.

Afterward is the transition period from rainy season to winter season. Some rainfall still occurs but less than that during the rainy season. This is due to high pressure system of cold and dry air masses from China moving into the upper region of the country. These air masses are colliding with residual moisture from the recent rainy season in the upper part of the country causing rainfall to end in November.

Therefore, in planning future activities such as agricultural, industry or commercial in the Chao Phraya basin, both in irrigation zones and rainfed areas, it is essential for responsible parties to carefully and thoroughly consider the rainfall pattern, rainfall distribution and the amount of rainfall under climate change to maximize benefits and minimize potential losses as much as possible.

According to the rainfall pattern, it is obvious that in summer, there is no remaining water in the soil. This is due to the amount of water loss exceeds the amount of rainfall. Throughout the rainy season, water loss is much less than the rainfall received. But at the beginning of the rainy season, water loss is significantly lower than rainfall received. This causes the soil moisture increase. It may lead to flooding, particularly during August to October. In winter, similar in summer, there is not much water in the soil. It is due to water loss exceeds rainfall received, resulting in clear drought conditions.

In conclusion, for the 20-year period during 2017–2036, in the Chao Phraya basin, drought condition may occur for approximately 6 months from November to April of the following year. And wet condition may occur for approximately 6 months from May to October. Therefore, any activities requiring water use in the basin area should be carefully planned and aligned with these natural patterns.

As the results of study, it was found that the climatic impacts on the hydrometeorological regimes in the future of the Chao Phraya basin are significantly variated. The average monthly rainfall under climate change over the 20 years period during 2017–2036 shows similar trend but vary seasonally with notably high during the rainy season (mid-May to mid-October) and low during the dry season (mid-October to mid-May) for each period of average values.

The average runoff in the Chao Phraya basin over the 20 years period during 2017–2036 also shows obvious variation between rainy season and dry season for each period of average values. Furthermore, there will be increased rainfall variation affecting runoff volumes. It implies more frequent occurrences of both high water (wet) and low water (dry) years. Consequently, water supply will be uncertain. The frequent occurrence of dry years leads to increase the risk of water shortages. Simultaneously, the frequent occurrences of wet years will increase flood risk. Therefore, to mitigate floods and droughts, careful water management is needed in the large reservoirs upstream of the Chao Phraya basin (Bhumibol dam and Sirikit dam) and related reservoir in adjacent basin like Pasak dam.

These findings should be useful for water allocation management and appropriate use of water resources under climate change condition in the Chao Phraya basin. In addition, the approaches used in this research study can be applied to the study of other river basin areas also.

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