April 9-12
Taipei-Taiwan
2019

3rd International Workshop on
Sediment Bypass Tunnels

Prediction of Future Agriculture Water Demand in Thailand Using Multi Bias Corrected Climate Models

Winai Chaowiwat, Kanoksri Sarinnapakorn, Sutat Weesakul

Abstract

Climate change affects both physical and biological environments. Specifically, the changes in temperature and rainfall directly induce local hydrological change. Since water is a basic factor utilized in plant cultivation, the hydrological change will affect agricultural water demand naturally. Water demand is essential data for water managers to decide on allocating water in irrigated areas and for farmers to plan on cultivating in rain fed areas. Predicting and planning for future water demand under climate change is a challenge for planners. This study aims to predict future agricultural water demand in irrigated and rain fed areas with multi bias corrected climate model. Twenty bias corrected GCM climate data under the Representative Concentration Pathway (RCP2.5, RCP4.5, RCP6.0 and RCP8.5), rainfall and temperature data are used in evapotranspiration estimation. The Penman-Monteith, Hargreaves and modified Hargreaves evapotranspiration methods are applied for estimating the agricultural water demand. The resulting estimate of future agricultural water demand estimate can be used to adapt water and agricultural management plan in response to the impact of climate change.

Keywords: Climate change, Penman-Monteith, Hargreaves, Modified Hargreaves, Evapotranspiration, Agricultural water demand prediction

1 Introduction

Agriculture sector is the main water consumption. Water is an important factor in crop production and water demand is one of the components in water balance analysis. Water supply and water demand are essential data for a water manager to determine cultivating areas. Recently, there have been a few studies on the impact of climate change on water demand in Thailand. Even though cultivated areas and climate data are collected by related government agencies, they do not inform about the exact water demand in Thailand. Water demand does not depend on the weather only, but also on economic issues such as the market price of crop and the government policy. Thus estimating future water demand under climate change is a challenge in the future water planning. However this paper attempted to examine the climate change issue only. Evidence from climate models suggests that heavy precipitation event will become more frequent, and that the likelihood of summer drought conditions will increase in mid-latitude regions.

Potential evapotranspiration is expected to increase in al-most all regions of the world. This is be-cause the water-holding capacity of the atmosphere increases with higher temperatures, while relative humidity is not expected to increase significantly (Asadullah *et.al.*, 2012). There are some studies on the evapotranspiration under climate change. Chaowiwat and Likitdecharote (2008) applied a statistical downscaling model (SDSM) to assess the impact of climate change on the potential evapotranspiration in Lower Chao Phraya River Basin, Thailand. Koontanakulvong *et. al.* (2012) found that the rainfall in Ping, Wang, Yom and Nan Basin will decrease in the near future (2015-2039), compared with the past 30 year average data and it will increase in the far future (2075-2099). Seasonally, rainfall will decrease during rainy season and increase in dry season. Possible impacts towards agricultural area are the change in runoff pattern, fluctuation of rainfall pattern, and more extreme events (drought & flood). The irrigated water demand will increase in the future due to an increase in temperature in the near future and far future, more water deficit is expected especially in the dry season. The objective of this study is to propose the agriculture water demand prediction by using multi bias corrected climate model. Penman-Monteith (PM), Hargreaves (HG) and modified Hargreaves (MHG) evapotranspiration method were used to develop the coefficient of calibrated Hargreaves (HG) and modified Hargreaves (MHG) evapotranspiration for adjusting the values corresponding to the standard Penman-Monteith evapotranspiration. The results can be used to prepare a water management plan in future in response to the future climate condition. Furthermore it can identify the potential of water deficit risk area in the future.

2 Study area

Thailand is located in the tropical zone of South-East area of the continent between latitude 5°37’ N - 20°27’N and longitude 97°22’E – 105°37’E covering 513,115 square kilometers. The climate of Thailand is under the influence of monsoon winds of seasonal character, i.e., southwest monsoon and northeast monsoon. The southwest monsoon, which starts in May, brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially on the windward side of the mountains. Rainfall during this period is caused not only by the southwest monsoon, but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones, which produce a large amount of rainfall. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid-May and ends in mid-October, while northeast monsoon normally starts in mid-October and ends in mid-February. Regarding agricultural areas in Thailand, cultivated areas are separated into two types corresponding to the water supply, land deformation and farming behaviors: irrigated area (37,129 km^2) and rain fed area (116,322 km^2). Land use of agricultural areas in year 2016 collected by Land Development Department (LDD) is shown in Figure 1. In this study, the focus is on 9 main economic plants that farmers usually cultivate in wet and dry seasons including cereals, vegetables and melons, fruit and nuts, oilseed crops, root crops with high starch, beverage and spice crops, leguminous crops, sugar crops, and other crops.

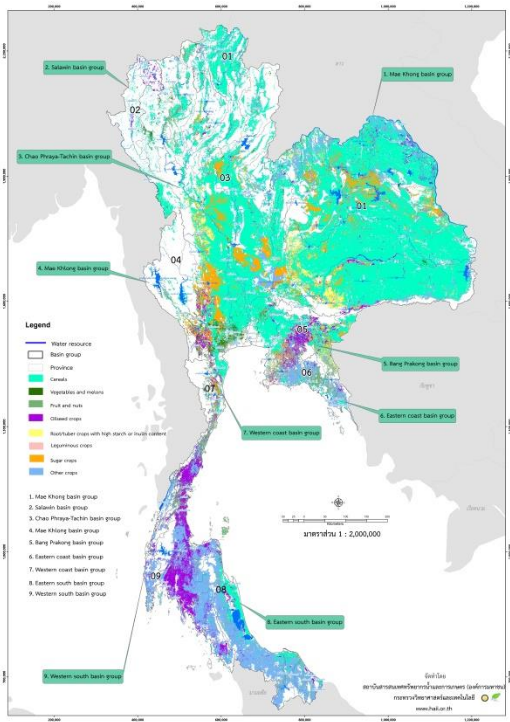


Figure 1 Land use of agricultural area in year 2016

3 Data

Observed rainfall data from 1,029 rain gauge stations and 124 weather stations shown in Figure 2 were obtained from Thai Meteorological Department (TMD). We collected daily rainfall, relative humidity, wind speed, sunshine duration, maximum and minimum temperature in the period 1979 – 2015. For the 20 general circulation models (GCM), precipitation and temperature were downloaded from Lawrence Livermore National Laboratory as shown in Table 1 (https://pcmdi.llnl.gov/projects/esgf-llnl/). The concerned time period was divided into 4 periods: present (1979 – 2006), near future (NF: 2018 – 2039), mid future (MF: 2040 – 2069), and far future (FF: 2070 – 2099). Four Representative Concentration Pathways (RCPs) (2.6, 4.5, 6.0, and 8.5), developed by IPCC, were used to project future climate change in Thailand. RCP 2.6 is a scenario low emissions in which radiative forcing reaches 3.1 W/m^2 before it returns to 2.6 W/m^2 by 2100. To reach such forcing level, ambitious greenhouse gas emissions reductions would be required over time. RCP 4.5 is a scenario of intermediate emissions which stabilizes radiative forcing shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. RCP 6.0 is a scenario of intermediate emissions which stabilizes radiative forcing shortly after year 2100, consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions. RCP 8.5 is a scenario of high emissions consistent with a future of no policy changes to reduce emissions which is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time. (Vuuren et. al., 2011)

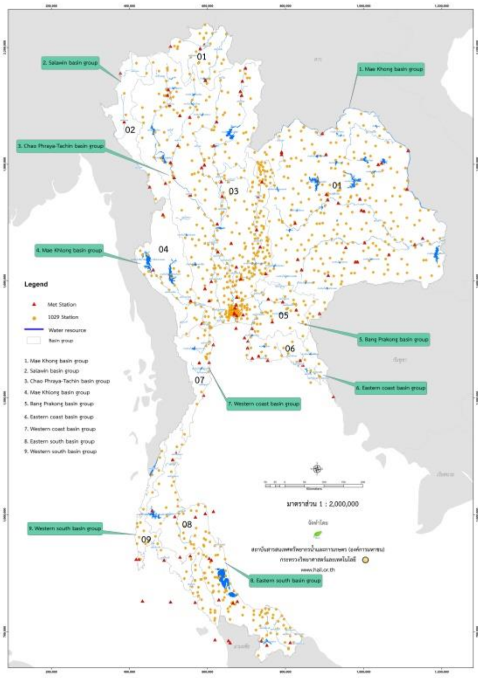


Figure 2 Rain gauges stations and weather stations in study area

Table 1 Description of GCM climate data used

Modeling group	Model designation	AGCM horizontal/vertical resolution	OGCM horizontal/veritical resolution
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	T42 L26	1°lon x 1.33° lat L40
Beijing Normal University - Earth System Model	BNU-ESM	2.8125 lon 2.7906 lat	1 lon 0.3344 lat
Canadian Center for Climate Modelling and Analysis	CanESM2	T63 L35	256 x 192 L40
National Center for Atmospheric Research	CCSM4	1.25lon x 0.9 lat L26	1.1° lonx0.27° –0.54° lat L60
The Community Earth System Model, version 1–Biogeochemistry	CESM1_BGC	1.25 lon 0.9424 lat	
The Community Earth System Model, version 1–Community Atmospheric Model version 5	CESM1_CAM5	1.25 lon 0.9424 lat	
Centre National de Researches Meteorologiques	CNRM-CM5	TL127 L31	1° lon x 1° lat L42
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3.6.0	T63 L18	1.875° lon x 0.9375° lat L31
The EC-Earth consortium	EC_EARTH	1.125 lon 1.1215 lat	1 lon x 0.3 –1.0 lat
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	FGOALS-g2	128 x 60 L26	360 x 196 L30
	FGOALS-s2	R42 L26	0.5 –1 lon x 0.5 –1 lat L
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	C48 L48	360 x 200 L50
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	96 x 95 L39	2 lon x 2 lat L31
	IPSL-CM5A-MR	144 x 143 L39	2 lon x 2 lat L31
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies	MIROC-ESM	T42 L80	256 x 192 L44
Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	T85 L40	256 x 224 L50
Max Planck Institute for Meteorology	MPI-ESM-LR	T63 L47	GR15 L40
	MPI-ESM-MR	T63 L47	GR15 L40
Meteorological Research Institute	MRI-CGCM3	TL15x L48	1 lon x 0.5 lat L51
Norwegian Climate Centre	NorESM1-M	144 x 96 L26	384 x 320 L53

4 Methodology

The study consists of 2 main procedures: estimating evapotranspiration and estimating agriculture water demand in main river basins in Thailand.

4.1 Evapotranspiration Estimation

Since GCM data is inadequate and too coarse to be used at local scale, the GCM data is corrected for biases by using Gamma-gamma (GG) bias correction method (Chaowiwat *et. al.*, 2016, Sharma *et.al.*, 2010). Then the bias corrected GCM climate data is applied to calculate evapotranspiration in the river basin scale. The performance of 20 bias corrected GCM precipitation data is about 0.52 to 0.62 in correlation (r) and 3.44 to 4.47 in RMSE (Chaowiwat *et. al.*, 2016). However, only temperature and precipitation from future GCM climate data are used. This study attempts to develop an evapotranspiration estimate under future climate condition. The modified Penman-Monteith method (Allen *et. al.*, 1998) is used as the best approximation, and thus referred to as the baseline estimation. It is calculated from relevant weather data including relative humidity, wind speed, sunshine duration, maximum and minimum temperature. In this study Hargreaves (HG) and modified Hargreaves (MHG) methods are exploited to calculate the evapotranspiration by using only temperature and precipitation. Thus it is necessary to adjust HG and MHG evapotranspiration values corresponding to the standard evapotranspiration; the coefficients of HG and MHG evapotranspiration are calculated by using linear regression. The study time period is divided into 2 periods: calibrated period (1961 – 1990) and validated period (1991 – 2015).

The Penman-Monteith (PM) (Penman, 1948) equation is used for calculating standard evapotranspiration as follow.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where ET_o is reference evapotranspiration, mm day^{-1}, R_n is net radiation at the crop surface, MJ m^{-2} day^{-1}, G is soil heat flux density, MJ m^{-2} day^{-1}, T is mean daily air temperature at 2 m height °C, u_2 is wind speed at 2 m height, m s^{-1}, e_s is saturation vapour pressure, kPa, e_a is actual vapour pressure, kPa, e_s - e_a is saturation vapour pressure deficit, kPa, Δ is slope vapour pressure curve, kPa °C^{-1}, and γ is psychrometric constant, kPa °C^{-1}.

The Hargreaves equation (HG) was first proposed by Hargreaves (Hargreaves et al., 1985, Droogers and Allen, 2002) to estimate evapotranspiration using extraterrestrial solar radiation (Rs) and temperature data, as shown in Equation 2:

$$ET_{HG} = 0.0023 \times R_A(T + 17.8)\sqrt{T_{max} - T_{min}} \quad (2)$$

where ET_{HG} is the reference crop HG evapotranspiration expressed in millimeters per day; R_A is the extraterrestrial solar radiation in millimeters per day; T is the mean air temperature in degrees Celsius; T_{max} is the maximum air temperature and T_{min} is the minimum air temperature both in degrees Celsius.

Similarly, the Modified-Hargreaves equation was first proposed by Droogers and Allen (2002) , where all variables are the same as in (2) except for an additional term for daily precipitation, as shown in Equation 3:

$$ET_{MHG} = 0.0023 \times R_A(T + 17)(T_{max} - T_{min} - 0.0123P)^{0.76} \quad (3)$$

where ET_{MHG} is the reference crop MHG evapotranspiration expressed in millimeters per day; RA is the extraterrestrial solar radiation in millimeters per day; T is the mean air temperature in degrees Celsius; T_{max} is the maximum air temperature; T_{min} is the minimum air temperature both in degrees Celsius; and P is the precipitation in mm per day.

The calibrated Hargreaves (CHG) equation is used for adjusting the evapotranspiration as follow.

$$ET_{CHG} = a_1 \times ET_{HG} + b_1 \quad (4)$$

where ET_{CHG} is the calibrated HG evapotranspiration expressed in millimeters per day; a_1 and b_1 are the coefficients of the generalized Hargreaves equation.

The calibrated modified Hargreaves (CMHG) equation is used for adjusting the evapotranspiration as follow.

$$ET_{CMHG} = a_2 \times ET_{MHG} + b_2 \quad (5)$$

where ET_{CMHG} is the calibrated MHG evapotranspiration expressed in millimeters per day; a_2 and b_2 are the coefficients of the generalized modified Hargreaves equation.

4.2 Agricultural water demand estimation

An agricultural water demand estimation can be calculated from relevant input variables including effective rainfall, reference evapotranspiration, percolation, and cultivated areas. We consider the parameters based on Thai agricultural pattern and calculate water demand at the sub river basin scale. The start dates of cropping in wet and dry seasons are May 1 and November 1, respectively. The percolation is assumed to be 7 mm/week. The provincial cultivated areas and cropping pattern information was collected from Office of Agricultural Economics. The cultivated area of each crop that is used in estimating water demand varies during years 1979 – 2005. The future cultivated area is assumed to be the same as the average existing cultivated area. From the annual cultivated area record at provincial level, the ratio of land use and boundary of provinces and sub basins are used to transform provinces base to sub basins base. The input variables are transformed from weather stations data to gridded data by inverse distance square method, and they can be calculated the provincial data by using the ratio of gridded data to provincial boundary. The agricultural water demand is estimated based on 20 bias corrected GCM temperature and rainfall data; the ensemble mean of water demand is calculated to represent the multiple water demand results.

Effective rainfall is estimated from weekly rainfall and potential evapotranspiration. The USDA SCS (1993) method can be used to comput effective rainfall (P_{eff}) (Chapagain, 2009) as follows:

$$P_{eff} = 25.4SF(0.04931P^{0.82416} - 0.11565) \times 10^{0.000955ET_c} \quad (6)$$

where ET_c is the potential evapotranspiration, P is weekly rainfall, [mm], and *SF* is soil factor at root zone 75 mm is 1.0,

Irrigation water demand is calculated from the reference evapotranspiration in equations (4) and (5) and effective rainfall in equation (6) as follows.

$$ET_c = K_c \times ET_o \quad (7)$$

$$W_{ir} = \frac{(ET_c + P - P_{eff}) \times A}{Eff} \quad (8)$$

where W_{ir} is irrigation water demand, MCM, ET_c is water consumption of plant, P is percolation in paddy field, mm, Re is effective rainfall, mm, K_c is crop requirement coefficient, Et_o is reference evapotranspiration, A is irrigated area, m^2 and Eff is efficiency of irrigation.

Rain fed water demand is calculated from the water consumption of plant and percolation as follow.

$$W_{rf} = (ET_c + P - P_{eff}) \times A \quad (9)$$

where W_{rf} is rain fed water demand, MCM, ET_c is water consumption of plant, P is percolation, and P_{eff} is effective rainfall, and A is rain fed area, m^2

5 Result

5.1 Calibration and validation of evapotranspiration

Pearson correlation (r), root mean square error (RMSE) and mean absolute error (MAE) are employed to evaluate the performance of developed evapotranspiration methods which include Hargreaves method (HG), calibrated Hargreaves method (CHG), modified Hargereaves (MHG) method, and calibrated modified Hargrave (CMHG) method (shown in Table 2). It is found that the correlation between Penman-Monteith and other evapotranspiration methods in calibrated period is about 0.65 to 0.70, while the average RMSE of Penman-Monteith and other evapotranspiration methods is about 0.90 to 1.77. For the validated period, the correlation between Penman-Monteith and other evapotranspiration methods is about 0.58 to 0.62 and RMSE is about 1.28 to 2.17. The CHG evapotranspiration estimation provides better correlation than CMHG evapotranspiration estimation. The results indicate that the coefficients of CHG and CMHG can be applied in future evapotranspiration estimation.

Table 2 Calibration and validation of daily evapotranspiration using 4 methods

Period	Statistic inference	HG	CHG	MHG	CMHG
Calibrated Period (1979 – 1990)	**r**	0.70	0.70	0.65	0.65
	RMSE	1.77	0.90	1.51	1.09
	MAE	1.60	0.74	1.30	0.88
Validated Period (1991 – 2015)	**r**	0.62	0.62	0.61	0.58
	RMSE	2.17	1.28	2.08	2.04
	MAE	1.69	0.85	1.38	0.99

5.2 Water demand prediction

Water demand is estimated by using present GCM climate data. Shown in Table 3, the average total water demand from CHG and CMHG method is about 85,306 MCM/year and 85,156 MCM/year. The water demand of irrigated area and rain fed area by using CHG (CMHG) is about 23,233 (23,287) MCM/year and 62,074 (61,869) MCM/year, respectively. The overview of future water demand of Thailand by using CHG method in near future tends to increase 11.8% in RCP2.6, 11.3% in RCP4.5, 11.4% in RCP6.0 and 11.2% in RCP8.5, respectively. While The future water demand by using CMHG method in near future tends to increase 11.6% in RCP2.6, 11% in RCP4.5, 11.3% in RCP6.0 and 10.9% in RCP8.5, respectively. In Table 4, it shows the water demand of Southern East Coast River Basin tend increase highest in all scenarios. The second rank of increasing water demand is Southern West Coast and West Coast Gulf River basin in all scenarios. From Figure 3 shows the water demand of Thailand in all scenario tend to increase 9% to 13.8% in both wet and dry season. RCP8.5 scenario shows most increasing water demand scenario about 10.9% to 13.8% as show in Figure 3. The highest increasing water demand will occur in Southern East Coast River Basin.

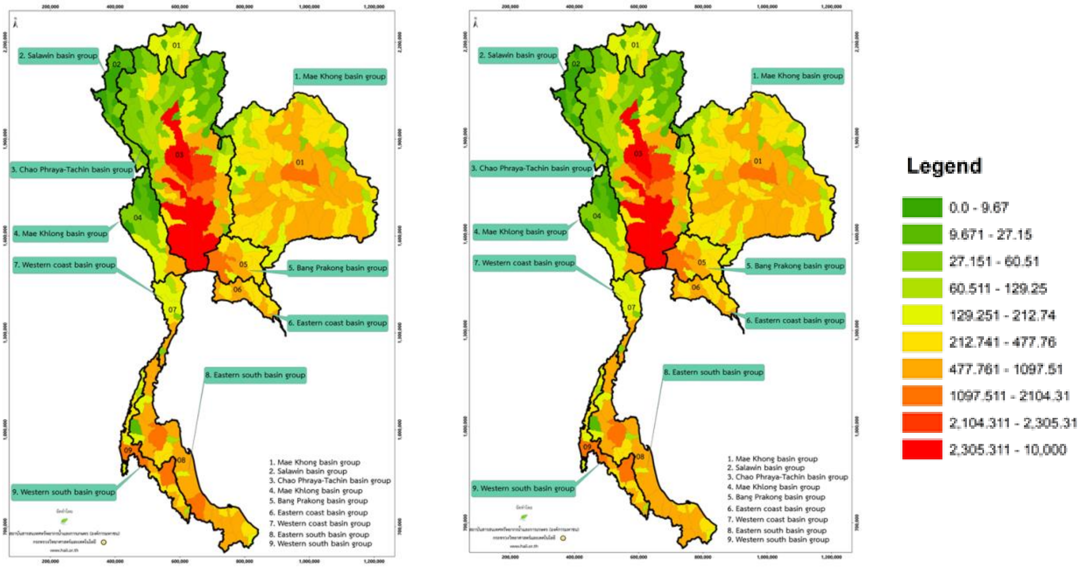
Table 3 Agricultural water demand by CHG and CMHG method in present period

River Basin Group	CHG (MCM/year)			CMHG (MCM/year)		
	Irrigated	**Rain fed**	**Total**	**Irrigated**	**Rain fed**	**Total**
1. Mekong River basin	3,829	24,840	28,669	3,811	24,664	28,475
2. Salween River basin	95	191	286	94	191	285
3. Chao Phraya- Tha Chin	13,899	10,873	24,771	13,963	10,832	24,795
4. Mae Klong River basin	730	933	1,663	736	938	1,674
5. Bang Pakong River Basin	2,357	2,190	4,547	2,364	2,192	4,556
6. East Coast Gulf	143	2,902	3,045	143	2,912	3,055
7. West Coast Gulf	603	1,008	1,610	606	1,014	1,620
8. Southern East Coast	1,254	13,448	14,702	1,248	13,435	14,684
9. Southern West Coast	324	5,689	6,013	322	5,691	6,014
Total	**23,233**	**62,074**	**85,306**	**23,287**	**61,869**	**85,156**

Table 4 The changes of annual mean agriculture water demand by CHG and CMHG method in each scenario

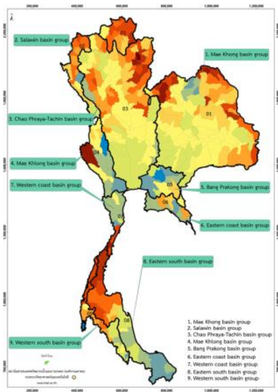
River Basin Group	Historical (MCM/year)	Difference (%)											
		RCP2.6			RCP4.5			RCP6.0			RCP8.5		
		NF	MF	FF	NF	MF	FF	NF	MF	FF	NF	MF	FF
CHG method													
1. Mekong River basin	28,669	13.4	12.7	12.1	10.1	11.5	8.64	14.0	13.5	11.0	9.90	10.4	11.6
2. Salween River basin	286	10.7	9.87	9.57	8.95	8.53	5.11	10.8	13.1	7.95	7.79	7.24	7.73
3. Chao Phraya- Tha	24,771	9.26	9.37	8.55	8.72	9.66	7.93	10.2	10.6	9.14	7.89	9.18	10.4
4. Mae Klong River	1,663	2.72	3.24	2.32	3.54	4.37	3.35	1.50	2.60	1.14	2.75	5.13	6.31
5. Bang Pakong River	4,547	0.31	1.06	0.02	0.46	2.21	1.16	-	0.95	0.03	-	2.09	3.63
6. East Coast Gulf	3,045	9.33	10.0	8.88	9.90	11.7	11.2	6.40	8.46	7.65	9.86	13.2	15.1
7. West Coast Gulf	1,610	13.2	12.1	11.8	13.3	13.6	13.4	11.4	11.5	8.66	13.5	15.8	16.7
8. Southern East Coast	14,702	17.1	16.0	15.1	19.9	20.1	20.4	15.0	13.5	13.5	21.2	23.2	23.8
9. Southern West	6,013	13.3	12.5	11.6	16.4	17.1	17.8	9.26	8.92	10.3	18.0	20.4	21.1
Total	**85,306**	**11.7**	**11.4**	**10.6**	**11.2**	**12.2**	**10.7**	**11.4**	**11.2**	**9.93**	**11.2**	**12.6**	**13.7**
CMHG method													
1. Mekong River basin	28,475	13.4	12.7	12.0	10.1	11.1	7.94	14.1	13.3	10.2	9.79	9.66	9.99
2. Salween River basin	285	10.6	9.75	9.38	8.86	8.06	4.44	10.7	12.7	7.08	7.62	6.54	6.13
3. Chao Phraya- Tha	24,795	9.34	9.41	8.57	8.80	9.49	7.62	10.3	10.4	8.63	7.90	8.79	9.52
4. Mae Klong River	1,674	2.53	2.98	2.09	3.36	3.99	2.84	1.41	2.28	0.53	2.49	4.53	5.24
5. Bang Pakong River	4,556	0.30	0.96	-	0.41	1.91	0.72	-	0.74	-	-	1.55	2.61
6. East Coast Gulf	3,055	9.42	9.85	8.73	9.80	11.1	10.4	6.50	8.11	6.73	9.65	12.2	13.4
7. West Coast Gulf	1,620	12.6	11.5	11.2	12.7	12.8	12.4	11.0	10.9	7.65	12.9	14.8	15.1
8. Southern East Coast	14,684	16.2	15.0	14.0	19.0	18.8	18.9	14.3	12.4	11.7	20.2	21.6	21.3
9. Southern West	6,014	12.5	11.5	10.5	15.5	15.8	16.3	8.59	7.72	8.43	17.1	18.7	18.5
Total	**85,156**	**11.6**	**11.1**	**10.2**	**11.0**	**11.7**	**10.0**	**11.3**	**10.8**	**8.96**	**10.9**	**11.7**	**12.1**

Remark: NF:Near future, MF: Mid future, FF: Far future

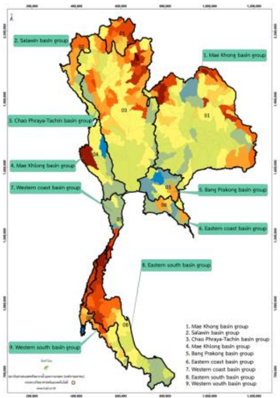


(a) CHG method (b) CMHG method

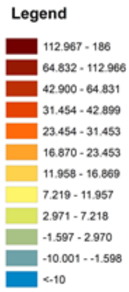
Figure 3 The present agriculture water demand by using CHG and CMHG method

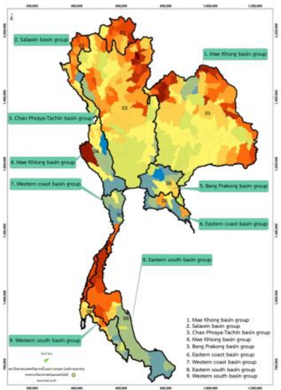


(a) RCP2.6

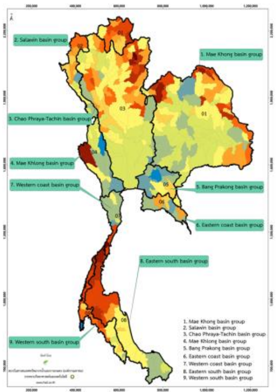


(b) RCP4.5



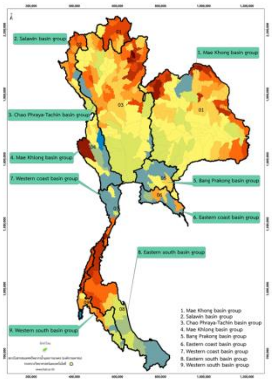


(c) RCP6.0

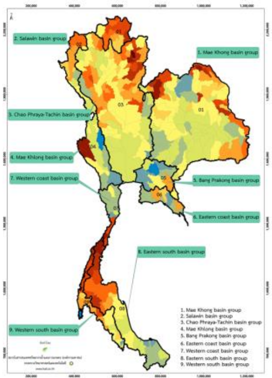


(d) RCP8.5

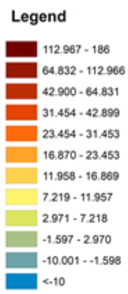
Figure 4 The difference of agriculture water demand with CHG method in near future period

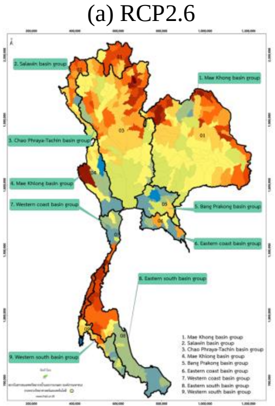


(a) RCP2.6

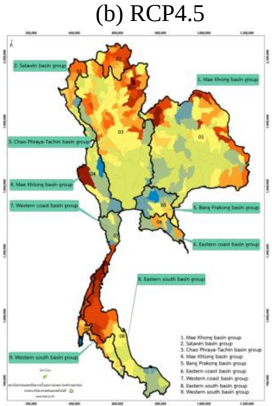


(b) RCP4.5





(c) RCP6.0



(d) RCP8.5

Figure 5 The difference of agriculture water demand with CMHG method in near future period

6 Conclusions

From evapotranspiration estimation, it is found that the water demand with CHG estimation provides better correlation than CMHG estimation (higher correlation and lower RMSE). As a consequence of climate change, water demand in Thailand tends to increase trend with an upward trend of 9% to 13.8% in all scenarios. The Southern East Coast River Basin has the highest risk of water deficit due to the largest increase in water demand at 17% to 18.3%. The predicted water demand is higher in RCP8.5 than in other scenarios. However, the change in water demand depends on the local climate change; the demand in the lower part of Thailand tends to increase more than the upper part of Thailand.

Acknowledgement

The authors gratefully acknowledge the contributions of Thai Meteorology Department for observed rainfall data distribution, Lawrence Livermore National Laboratory for GCM climate data, and Office of Agricultural Economics for crop cultivated areas

References

Asadullah, A.M., Butts, M., Glennie, P., Jorgensen P.L., Madsen H., Riegels, N., (2012) "Water resources climate change guidelines," Jan, 2012, pp.22-23.

Chaowiwat, W., and Likitdecharote, K., "Effect of Climate Change on Potential Evapotranspiration Case Study: Lower Chaopraya Basin", paper presented at First Annual NPRU Academic Conference, Nakhon Pathom, Thailand, Oct 2008.

Koontanakulvong, S., Sontisri, S., Jumpanil, D., Laumsupanimit, M., (2012) Final Report The Impact of Climate Change towards Irrigation Systems and Adaptation Measures (The Royol Irrigation Office Region 12: case study), Water Resources Management Research Unit, Faculty of Engineering, Chulalongkorn University, March.

Vuuren, P. D. V., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., Rose, S. K., (2011) The representative concentration pathways: an overview, Climatic Change, November, Vol. 109, Issue 1, pp 5-31.

Chaowiwat, W., Boonya-aroonnet, S. Weesakul, S., (2016), Impact of Climate Change Assessment on Agriculture Water Demand in Thailand, *Naresuan University Engineering Journal*, Vol.11, Supplement, 1, May, pp 35-42

Chaowiwat, W., Kamnoet, O. Weesakul, S., (2016), Future Drought Characteristics over Thailand by Using Bias Corrected Multi CMIP5 General Circulation Model, UNSDG conference, December, 28

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., (1998) Crop evapotranspiration: Guidelines for computing crop requirements. *Irrigation and Drainage* Paper No. 56, FAO, Rome, Italy.

Penman, H. L., (1948) Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London A(194), S.: 120-145.

Hargreaves, G.L., Hargreaves, G.H., Riley, J.P., (1985) Agricultural benefits for Senegal River Basin. *J. Irrig. and Drain Engr. ASCE*. 111:113–124.

Droogers, P., Allen, R.G., (2002) Estimating reference evapotranspiration under inaccurate data conditions. *Irrigation and Drainage Systems* 16: 33-45.

Authors

Winai Chaowiwat (corresponding Author)
Kanoksri Sirinnapakorn
Sutat Weesakul
Hydro and Agro Informatics Institute (HAII), Thailand
Email: winai@haii.or.th, kanoksri@haii.or.th, sutat@haii.or.th