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Impact of Climate Change Assessment on Agriculture Water Demand in Thailand

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Abstract – **In recent times, global climate change has induced extreme rainfall in terms of frequency, duration, pattern and intensity in many countries, including Thailand. Thailand has faced more flooding events and drought frequencies in the last few years, and is currently experiencing severe drought conditions and water shortages. The main consumers of water in Thailand is the agricultural sector, where climate change has caused damage to cultivated areas in both wet and dry seasons. Especially in 2015 and into 2016 Thailand has experienced drought phenomena. The Thai government has attempted to solve the drought problem by encouraging farmers to stop cultivating paddy rice in dry season and change the type of crop to less water consuming plants. It is therefore proving necessary to adapt water management policies and practices to ensure water demand side can be met on the water supply side, especially when the current water storage is limited, as in the current drought situation. The purpose of our study was to assess the impact of climate change on rainfall, temperature, and water demand in the main river basin in Thailand. The future climate model adopted in this study is focused on 7 general circulation model datasets with Representative Concentration Pathways (RCPs) 4.5 and 8.5 scenarios. The results show that the changing climate will result in about a 15% increase in water demand in both scenarios. The high risk water deficit areas include the Ping, Yom, Nan, Chi and Mun River Basins due to increasing water demand and decreasing rainfall. The Salween River Basin has the highest risk of a water deficit with the greatest increase in water demand of 32.6%.**

Keywords – climate change, water demand, general circulation model, statistical bias correction, evapotranspiration

1. INTRODUCTION

The agriculture sector is the main consumer of water. Water is the most important factor in crop production and the demand for water is one of the components in water balance analysis. Therefore, water supply and water demand are essential data for a water manager to determine the locations of cultivation areas. There have been few studies on the impact of climate change on water demand in Thailand. Even though data on cultivated areas and climate are collected by related government agencies, they do not provide useable information on the exact water demand situation in Thailand. Water demand does not depend on the weather only, but also on economic issues such as the market price for agricultural products and government policy. Predicting and planning for future water demand under conditions of climate change is the challenge for planners. This paper examines the climate change issue only.

Evidence from climate models also suggests both that heavy precipitation events 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 almost all regions of the world. This is because of the water-holding capacity of the atmosphere increases with higher temperatures, while relative humidity is not expected to increase significantly [1]. Some studies on evapotranspiration under climate change have been undertaken [2]. A statistical downscaling model (SDSM) was applied to assess the impact of climate change on the potential evapotranspiration in the Lower Chao Phraya River Basin, Thailand. In [3] it was found that the rainfall in the Ping, Wang, Yom and Nan River Basins will decrease in the next 25 years as compared with the past 30-year average data but is likely to increase in the far future (2075-2099). Seasonally, rainfall will decrease during the rainy season and increase in the dry season. The possible impacts on agricultural areas will be changes in runoff patterns, fluctuation of rainfall pattern, and more extreme events (drought & flood). The demand for water for irrigation will increase in the future due to an increase in temperature in the near future and far future. More water deficits are expected especially in the dry season.

The objective of this study was to assess the impact of climate change on water demand in Thailand. The results can be used to prepare a water management plan for the future response to changing climate conditions. Importantly it also identifies the potential water deficit risk areas in Thailand.

2. STUDY AREA

Thailand is located in the tropical zone of South-East area of the continent between latitude 5°37’ N - 20°27’ and longitude 97°22’ – 105°37’ 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. The 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. In the agricultural areas of Thailand, cultivated areas can be separated into two types corresponding to the water supply, land deformation and irrigated areas (37,129 km^2) or rain fed areas (116,322 km^2). The irrigated areas receive water from the government agency or Royal Irrigation Department. Land use in the agricultural areas is shown in Figure 1. In this study, the focus is on the major economic plants that farmers usually cultivate in wet and dry seasons including major rice, second rice, sugarcane, cassava and maize.

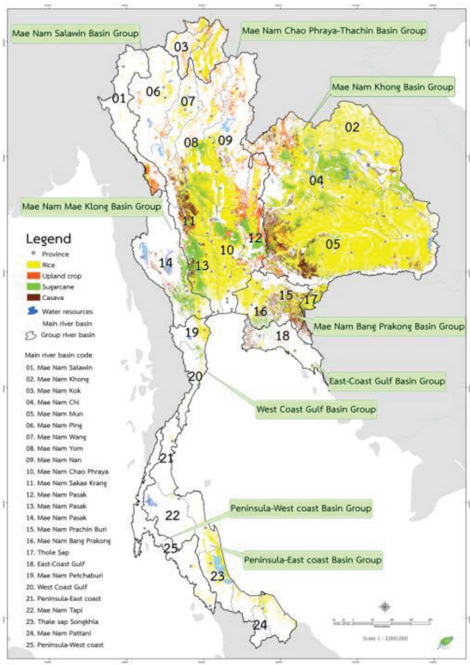

Figure 1 Land use for agricultural area in Thailand

3. Data

Rainfall data from 111 rain gauge stations and 101 weather stations was made available by the Thai Meteorological Department (TMD). Our dataset included figures for daily rainfall and temperature in the period 1979–2006. For the Global Circulation Model (GCM) precipitation and temperature were downloaded from Lawrence Livermore National Laboratory (https://pcmdi.llnl.gov/projects/esgf-llnl/). The time period covered by this data was divided into 2 periods: present (1979 – 2006), near future (2015 – 2039). The selected climate scenarios are Representative Concentration Pathways (RCPs) 4.5 and 8.5 which were presented in the fifth assessment report (AR5) of IPCC. The RCP 8.5 is the high emission which is consistent with the future of no policy changes to reduce emissions. The RCP 4.5 is the intermediate emissions which the radiative forcing is stabilized shortly after year 2100, consistent with the future of relatively ambitious emissions reductions [4].

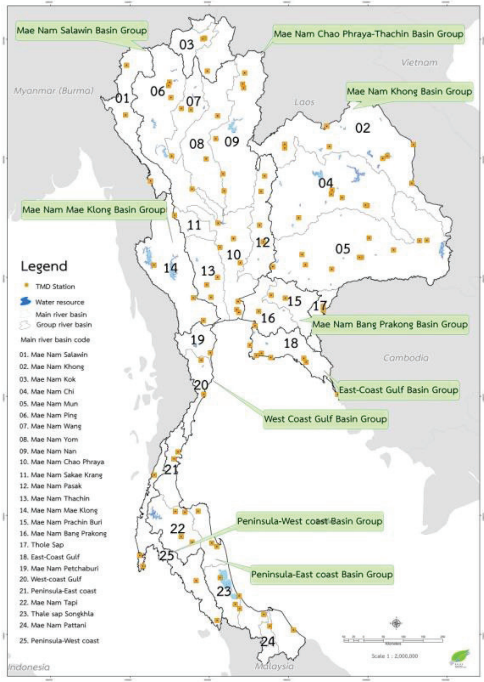

Figure 2 Distribution of weather stations

4. Methodology

The impact assessment process can be conducted by correcting the bias of GCM climate data for investigating climate change in the main group of river basins and estimating the agriculture water demand in Thailand. The procedures were as follow:

4.1 Bias Correction of GCM Climate Data

The statistical bias correction of GCM rainfall by the Gamma-Gamma (GG) transformation method is exploited to downscale the global to the river basin scale [5,6]. This method can reduce biases in terms of frequency and quantity at rain gauge station locations. The concept of transformation is to construct the cumulative distribution function (CDF) of GCM and observed rainfall, and then find the truncated GCM rainfall that optimizes suitable gamma parameters. The α and β of both datasets are found in equation 1. Next CDF of truncated GCM rainfall (x_{Trunc}) with gamma parameters is constructed in equation 2. The minimum truncated observed rainfall of 0.1 millimeter is set as the threshold value. In equation 3, α and β are found by using maximum likelihood estimation method.

Table 1 The description of GCM climate data used

Modeling group	Model designation	AGCM horizontal/vertical resolution	OGCM horizontal/vertical resolution
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	T42 L26	1°lon x 1.33° lat L40
Canadian Center for Climate Modelling and Analysis	CanESM2	T63 L35	256 x 192 L40
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
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	C48 L48	360 x 200 L50
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
Norwegian Climate Centre	NorESM1-M	144 x 96 L26	384 x 320 L53

Finally, the truncated CDF is transformed by using gamma parameters of truncated observed data in equation 4.

$$F(x: \alpha, \beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} exp\left(-\frac{x}{\beta}\right) ; \quad x \geq x_{Trunc} \quad (1)$$

$$F(x;\ \alpha, \beta) = \int_{x_{Trunc}}^{x} f(t)dt \quad (2)$$

$$F(x_{GCM};\ \alpha, \beta|_{GCM}) \Rightarrow F(x_{His};\ \alpha, \beta|_{His}) \quad (3)$$

Daily bias corrected rainfall is calculated by inversing the value in equation (3) as follows.

$$x'_{GCM} = F^{-1}\{F(x_{His};\ \alpha, \beta|_{His})\} \quad (4)$$

A limitation of the GG transformation is finding the minimum truncated value by using trial and error until the mean and standard deviation are close to those of the observed rainfall. In this study, we apply the looping optimization to find the minimum truncated value in each month. In each loop, it will cut the GCM rainfall 0.1 millimeter until it finds the mean of GCM rainfall close to observed rainfall.

To downscale average temperature and relative humidity in GCM data Normal – Normal (NN) transformation is used. The transformation procedure is similar to rainfall data but the parameters are considered normal distribution parameters as in equation 5.

$$F(x: \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{\frac{-(t-\mu)^2}{2\sigma^2}}\, dt; \quad x \geq x_{Trunc} \quad (5)$$

The statistical downscaling of GCM climate data in present period is as follow:

1) Download and set up the daily climate database under CMIP5 project such as precipitation, maximum and minimum temperature, and relative humidity.
2) Extract data from global scale to country scale that determine the boundary of grids coverage Thailand boundary.
3) Interpolate GCM data to rain gauge and weather stations
4) Investigate and fill in the missing values by using inverse distance square method
5) Develop the statistical downscale technique
6) Calibrate and validate the bias corrected GCM climate data with the observed climate data in year 1979 – 2006.

In addition, the root mean square error (RMSE), the mean absolute error (MAE), the sum absolute error, mean and standard deviation are used to compare the bias corrected GCM rainfall.

The bias correction of GCM climate data in the future period are computed as follows:

1) Construct the CDF of GCM climate in years 2015 – 2039 by using the minimum truncated value in present period.
2) Calculate the ratio of observed and bias corrected GCM in each quantile in present period and then multiply it with the future GCM climate in each quantile in years 2015 – 2039.

4.2 Agriculture Water Demand Estimation

The evapotranspiration which was used for water demand estimation was adopted from Penman-Monteith [7] and the equation is

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (6)$$

where ET_o is the reference evapotranspiration, mm day^{-1}, R_n is the net radiation at the crop surface, MJ m^{-2} day^{-1}, G is the soil heat flux density, MJ m^{-2} day^{-1}, T is the mean daily air temperature at 2 m height °C, u_2 is wind speed at 2 m height, m s^{-1}, e_s is the 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}.

Effective rainfall is estimated from monthly rainfall and potential evapotranspiration. The effective rainfall (P_{eff}) can be used USDA SCS [8] as follow:

$$P_{eff} = 25.4SF(0.04931P^{0.82416} - 0.11565) \times 10^{0.000955ET_c} \quad (7)$$

where ET_c is the potential evapotranspiration = $K_c \, x \, ET_o$, P is weekly rainfall, [mm], and *SF* is soil factor at root zone 75 mm is 1.0.

Irrigation water demand is calculated from reference to the evapotranspiration in equation (6) and effective rainfall in equation (7) as follow.

$$ET_c = K_c \times ET_o \quad (8)$$

$$W_{ir} = \frac{(ET_c + P - Re) \times A}{Eff} \quad (9)$$

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

Rain fed water demand is calculated from the water consumption of plant and percolation equation

$$W_{rf} = (ET_c + P - Re) \times A \quad (10)$$

where W_{rf} is the rain fed water demand, MCM, ET_c is water consumption of plant, *P* is the percolation, and *Re* is the effective rainfall.

The water demand can be estimated by using the agricultural water demand estimation model (AWADEM 1.0) which was developed by [9]. AWADEM 1.0 was developed using the MATLAB software program based on the Penman-Monteith equation. It is considered that the parameter is based on the Thai agricultural patterns and the calculated water demand in the sub river basin scale. The start date of cropping in the wet season is May 1st and the dry season November 1st. The percolation is assumed to be about 7 mm/week. The relevant weather input data employed was the 30 year-average weather as the constant variables such as wind speed, relative humidity, and sunshine hour. The procedures were conducted as follow.

1) Collect the observed and bias corrected climate data include rainfall, maximum and minimum temperature, and relative humidity.
2) Collect the annual cultivated area include the main economical plants from Office of Agricultural Economic (OAE) and Royal Irrigation Department (RID) such major rice, second rice, maize, sugarcane and cassava.
3) Collect the related parameters of evapotranspiration and water demand estimation such as Kc, cropping pattern, start and end cropping date, and cultivated areas.
4) Enter the input variables and related parameters to agricultural water demand estimation model.
5) Assess the impact of climate change by applying the water demand estimation model.

5. RESULT

5.1 Validation on Bias Corrected Climate Data

The correlation (R^2) and root mean square error (RMSE) weree employed to evaluate the performance of the bias corrected GCM climate data. It was found that the correlation between the observed and the bias corrected rainfall is about 0.84 to 0.89 and for the temperature data, 0.96, with the RMSE of the observed and bias corrected rainfall being about 16.47 to 30.88 and for the temperature data 0.23 to 0.27. Furthermore, the comparison of the mean and standard deviation of observed and bias corrected GCM data are conducted as Table 3, it shows that the difference of annual mean rainfall is about 2.53% to 3.58% and standard deviation is about 41.99% and 76.32% compared with the observed rainfall. While the difference of annual mean temperature is about 0.01°C to 0.06°C and standard deviation is about 13.71% to 26.25% compared with the observed temperature. From the result we can imply that the bias corrected climate data is representative of the future climate.

Table 2 The evaluation of performance of bias corrected GCM climate data

GCM	Rainfall		Temperature	
	R^2	RMSE	R^2	RMSE
BCC	0.87	16.47	0.96	0.25
CanESM2	0.88	26.43	0.95	0.25
CNRM	0.88	19.45	0.95	0.25
CSIRO	0.84	30.88	0.96	0.23
GFDL	0.89	23.15	0.95	0.27
MIROC5	0.89	22.74	0.95	0.23
NorESM1	0.86	19.73	0.96	0.23

5.2 Impact Assessment on Climate Change

The change of annual bias corrected in future (2015-2039) climate in RCP4.5 and RCP8.5 scenarios is shown in Table 4, it reveals that the future rainfall tend to decrease about 14.1% to 22.7% in RCP4.5 and 13.7% to 24.5% in RCP8.5. While the future temperature tend to decrease about 0.62°C to 0.88°C in RCP4.5 and 0.69°C to 0.93°C in RCP8.5.

5.3 Impact assessment on water demand

The water demand was estimated by using the present GCM climate data. It was shown that the average water demand is about 97,174 MCM/year which was separated into irrigated area 30,364 MCM/year (31%) and rain fed 66,810 MCM/year (69%). Table 5 shows the overview of future water demand of Thailand in the years 2015 - 2039 which tends to increase 15.7% in RCP4.5 and 15.5% in RCP8.5. The water demand of the irrigated area tends to increase more than for the rain fed area with 21% while rain fed area tends to increase 15.6%. CNRM GCM (Centre National de Researches Meteorologiques GCM) shows most increasing water demand about 25% in both RCP4.5 and RCP8.5. Table 6 shows the water demand of the Salween River Basin tends to increase the highest in both scenarios.

Table 3 The comparison of mean and standard deviation of observed and bias corrected GCM

Observed/GCM	OBS Mean	Diff, %	OBS SD	Diff, %
(a) Rainfall (mm/year)				
Observed	1,342	-	145.44	-
BCC	1,390	3.58	196.01	35.89
CanESM2	1,376	2.53	239.07	65
CNRM	1,384	3.1	211.32	46.7
CSIRO	1,386	3.28	255.98	76.32
GFDL	1,377	2.6	226.56	56.17
MIROC5	1,386	3.24	219	50.86
NorESM1	1,389	3.44	204.84	41.99
(b) Temperature (ºC)				
Observed	27.73	-	0.63	-
BCC	27.74	0.01	0.77	23.16
CanESM2	27.78	0.05	0.72	14.59
CNRM	27.79	0.06	0.73	17.74
CSIRO	27.77	0.04	0.71	13.71
GFDL	27.76	0.03	0.79	26.25
MIROC5	27.77	0.04	0.73	17.08
NorESM1	27.75	0.03	0.7	11.58

Remark OBS = Observed data, Diff = Difference

The second rank of water demand is the Mekong River basin and Chao Phraya - Tha Chin in both scenarios. However, there are some river basins that show an increasing trend such as the Southern West Coast, Southern East Coast, and East Coast Gulf. Figure 3 displays the difference between the water demand of CNRM GCM under RCP4.5 and RCP8.5 scenarios; it shows the highest increasing water demand will be distributed in Upper Chao Phraya River Basin while in the Southern part of Thailand water demand will tend to decrease compared with the present period. The overview of changing water demand shows the high risk of water deficit area in Ping, Yom, Nan, Chi and Mun River Basin. The irrigated area in Ping and Yom River Basin and the rain fed area in Nan, Chi, and Mun River Basin is possible to take the deficit risk due to more increasing water demand and decreasing rainfall.

Table 4 The changes of annual bias corrected (BC) rainfall and temperature in each scenario

GCM	Pr rain, mm/ year	Difference, %		Pr temp, ºC	Difference, %	
		RCP4.5	RCP8.5		RCP4.5	RCP8.5
BCC	1390	-38.9	-36.9	27.74	0.61	0.72
CanESM2	1376	-22.9	-21.7	27.78	1.11	1.23
CNRM	1384	-32.7	-34.4	27.79	0.47	0.62
CSIRO	1386	-9.5	-7.3	27.77	0.81	0.88
GFDL	1377	-2.7	-3.5	27.76	1.19	1.18
MIROC5	1386	-15.6	-20.5	27.77	0.9	0.9
NorESM1	1389	-11.7	-15.4	27.75	0.66	0.65
Average	1384	-19.2	-20	27.76	0.82	0.88

Remark Pr = present period

Table 5 The changes of annual mean agricultural water demand in irrigated and rain fed area in each scenario

Scenario/%Diff	Area	Observed	BCC	CanESM2	CNRM	CSIRO	GFDL	MIROC5	NorESM1	Average
Baseline	Irrigated	31,110	30,148	30,454	30,227	30,588	30,540	30,282	30,309	30,364
	Rain fed	65,966	66,090	67,233	66,400	67,207	67,513	66,535	66,690	66,810
	Total	97,076	96,238	97,687	96,627	97,795	98,053	96,817	96,999	97,174
%Difference in RCP4.5	Irrigated	-	28.1%	21.6%	27.9%	17.3%	13.6%	20.6%	18.0%	21.0%
	Rain fed	-	22.9%	12.5%	23.7%	8.2%	5.8%	12.9%	7.4%	13.3%
	Total	-	24.5%	15.4%	25.0%	11.1%	8.2%	15.3%	10.7%	15.7%
%Difference in RCP8.5	Irrigated	-	26.2%	18.2%	28.0%	20.5%	14.3%	19.8%	19.9%	21.0%
	Rain fed	-	20.4%	8.7%	24.0%	10.3%	5.5%	12.9%	10.0%	13.1%
	Total	-	22.2%	11.6%	25.3%	13.5%	8.3%	15.1%	13.1%	15.5%

Table 6 The changes of annual mean agricultural water demand in each scenario

Data	River basin group	BCC	CanESM2	CNRM	CSIRO	GFDL	MIROC5	NorESM1	Average
Present BC GCM, MCM/year	1. Mekong River basin	41,981	42,668	42,163	42,620	42,982	42,052	42,394	42,409
	2. Salween River basin	737	749	740	744	743	741	746	743
	3. Chao Phraya- Tha Chin	43,046	43,519	43,185	43,688	43,614	43,357	43,325	43,391
	4. Mae Klong River basin	3,727	3,785	3,748	3,776	3,802	3,807	3,754	3,771
	5. Bang Pakong River Basin	4,084	4,225	4,110	4,205	4,186	4,140	4,098	4,149
	6. East Coast Gulf	837	856	842	871	852	861	842	851
	7. West Coast Gulf	1,086	1,097	1,084	1,106	1,102	1,098	1,087	1,094
	8. Southern East Coast	682	726	697	723	711	702	694	705
	9. Southern West Coast	58	63	59	63	62	60	59	61
	Average	96,238	97,687	96,627	97,795	98,053	96,817	96,999	97,174
Difference in RCP4.5, %	1. Mekong River basin	28.8	16.9	29.8	12.5	11.0	17.9	10.7	18.2
	2. Salween River basin	42.9	29.7	39.8	28.2	26.1	32.9	28.8	32.6
	3. Chao Phraya- Tha Chin	25.4	17.5	25.1	13.4	10.0	17.3	14.5	17.6
	4. Mae Klong River basin	11.6	3.9	9.9	3.5	-5.1	3.8	0.3	4.0
	5. Bang Pakong River Basin	6.5	4.6	10.2	-0.4	-6.8	0.9	-1.4	1.9
	6. East Coast Gulf	-28.5	-28.6	-27.8	-36.7	-41.3	-36.0	-38.1	-33.9
	7. West Coast Gulf	9.1	10.6	13.0	2.8	-1.0	7.5	4.1	6.6
	8. Southern East Coast	-38.8	-32.2	-30.6	-47.5	-45.9	-46.4	-42.4	-40.6
	9. Southern West Coast	-58.1	-61.0	-57.3	-71.0	-69.8	-70.7	-66.7	-65.0
	Average	24.5	15.4	25.0	11.1	8.2	15.3	10.7	15.7
Difference in RCP8.5, %	1. Mekong River basin	26.1	12.6	30.5	15.1	10.4	18.2	13.4	18.0
	2. Salween River basin	40.5	26.0	39.2	30.6	25.4	33.4	29.6	32.1
	3. Chao Phraya- Tha Chin	23.3	14.2	25.0	15.9	10.6	16.2	16.7	17.4
	4. Mae Klong River basin	10.2	1.7	9.6	4.6	-4.7	4.4	2.5	4.0
	5. Bang Pakong River Basin	4.4	1.0	10.4	1.3	-6.6	1.0	1.3	1.8
	6. East Coast Gulf of	-29.9	-30.6	-27.9	-36.0	-41.3	-35.3	-35.9	-33.9
	7. West Coast Gulf of	8.2	7.6	13.0	4.8	-0.2	7.5	5.6	6.6
	8. Southern East Coast	-38.8	-34.1	-31.6	-48.3	-46.5	-46.1	-42.3	-41.1
	9. Southern West Coast	-58.0	-62.6	-57.5	-71.9	-70.0	-70.0	-66.3	-65.3
	Average	22.2	11.6	25.3	13.5	8.3	15.1	13.1	15.5

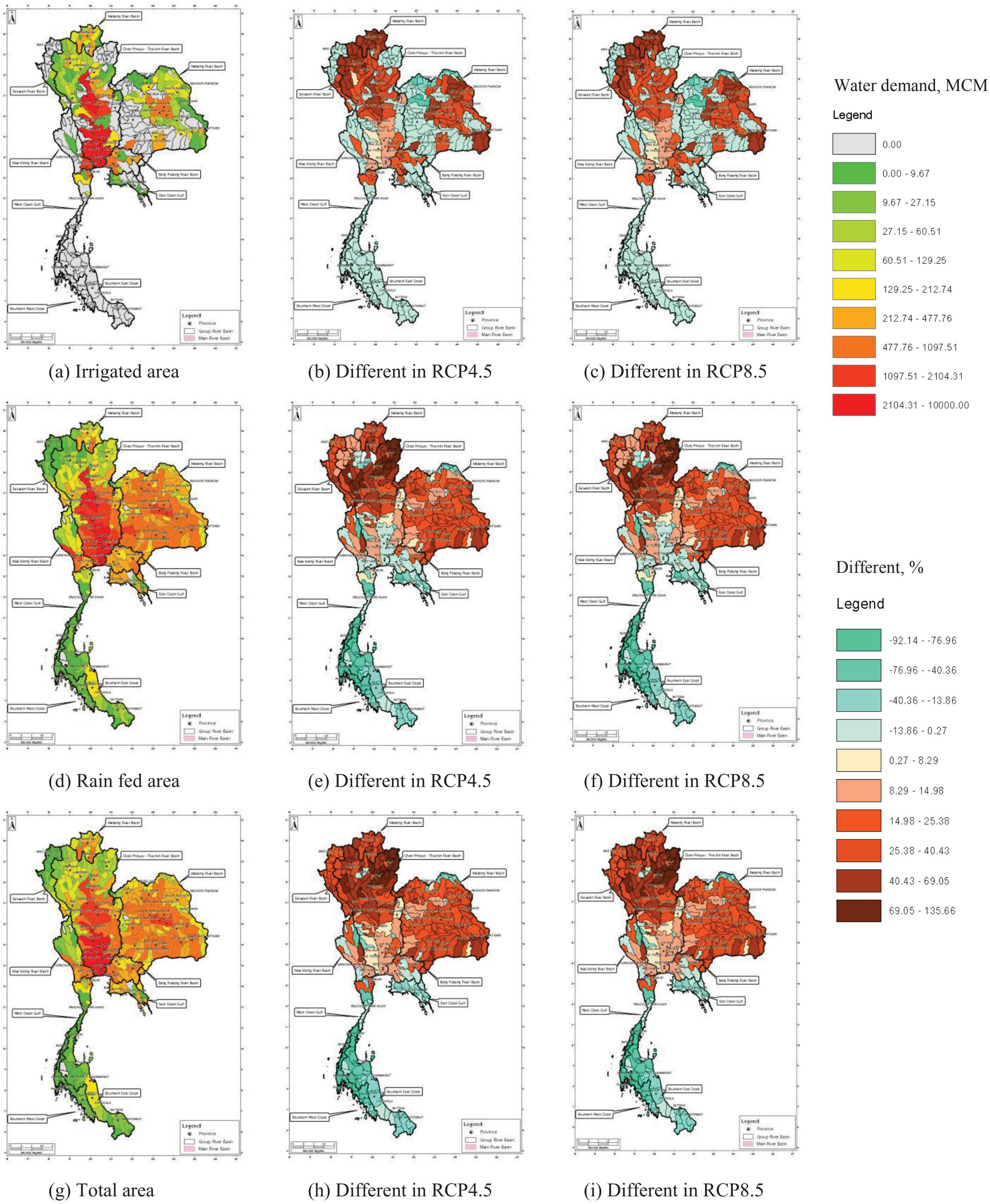

Figure 3 The water demand in present period and difference in near future period in CNRM RCP4.5 and RCP8.5

6. CONCLUSION

The results of our impact assessment on regional climate in the future in year 2015 -2039 reveals the decreasing rainfall (-20% to -19.2%) and increasing temperature (0.82 ºC to 0.88 ºC). The overall view of water demand of Thailand owing to the changing climate is that there is an increasing trend in demand of 15% in both RCP4.5 and RCP8.5 scenarios. The Salween River Basin is the highest risk area for water deficit with the highest increase in water demand of 32.6%. Furthermore, the impact of climate change in spatial terms will induce higher water demand in the RCP4.5 than in the RCP8.5. However, while the changing water demand depends on the local climate change, our analysis shows that the upper part of Thailand tends to increase more than lower part of Thailand.

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