An Assessment of Future Climate Change and Water Condition in Upper Ping River Basin under A2 and B2 Scenarios during 2015–2074

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Abstract

According to research findings, due to global warming, an increase in the average temperature has been observed in the mountainous areas of the world, including the northern part of Thailand, and this is likely to affect water resources. This study aims to investigate the impact of climate change on the variations in temperature and rainfall in Mae Rim watershed (MRW), a tributary of Ping River in Northern Thailand under the progress of A2 and B2 emission scenarios during 2015–2074, and to review and evaluate the water conditions in future climate scenarios in the watershed, with an emphasis on rain fed agriculture. The results indicated that, in both A2 and B2 scenarios, maximum and minimum temperature (Tmax and Tmin) during the 2045–2074 period will be higher than the 2015–2044 period, and the Tmin under A2 scenario will be greater than the B2 scenario. As for rainfall conditions, less changes are expected to be found in the rainy season, but there is likely to be an increasing trend in the dry season. Upon using the drought indices of the generalized monsoon index (GMI) and the standardized precipitation index (SPI) to evaluate for the water condition in the watershed, it was found that SPI and GMI values under both A2 and B2 scenarios followed a similar trend. The drought events in the 2015–2044 period were found to be greater than the 2045–2074 period.

Key words: Temperature/ Rainfall variability/ Generalized Monsoon Index (GMI)/ Standardized Precipitation Index (SPI)/ Water condition

1. Introduction

Human activity has contributed to a high rate of emission of greenhouse gases into the atmosphere, which is associated with climate change, which is now widely recognized as the major

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environmental problem of the World. A significant impact of climate change on agricultural production systems is water conditions (Fischer et al., 2005; Agoumi, 2003). The two important characteristics of climatic change which affect agriculture are climate change over a long-term period and climate variability over a short-term period (van de Steeg et al., 2009). Thus, an early warning facility regarding extreme events such as floods and droughts is crucial for developing and implementing the various measures for preparation and response strategies (WMO, 2010). The Intergovernmental Panel on Climate Change (IPCC) has developed long-term emission scenarios under the various developments policy and changes of: population, economic growth, society, technology and environment. There are four main scenarios with different narrative storylines, namely; A1, A2, B1 and B2 implemented during the Third Assessment Report (TAR) and the Fourth Assessment Report or AR4 (IPCC, 2000 and IPCC, 2007).Recently, the Representative Concentration Pathway (RCPs) was introduced and was implemented in most of the 5th Assessment Report of Working Group I on the Physical aspects of the its study (van Vuuren et al., 2011; IPCC, 2013). These scenarios have been globally and widely used in the analysis of possible impacts of climate change and options to adaptation and mitigation. In Thailand, several studies were conducted on the impact of climate change in different climate models by researchers for example Chinvanno et al. (2008), who used a general circulation model (GCM) of ECHAM4 with regional climate model (RCM) of PRECIS, Chotamonsak et al. (2011), who used GCM of ECHAM5 with RCM of WRF, and Saengmanee et al. (2011), who used the climate models of CCMA CGCM3.1, MPI_ECHAM5, CNRM_CM3, IPSL_CM4, and GFDL_ CM2.0.

This study focuses on the impact of climate change on agricultural water conditions, associated with rainfall variability on a small to medium watershed scale. Drought indices are applied to gain better understandings of agricultural water conditions associated with climate variability and change. There are many drought indices, which have been used in different contexts, but commonly there are four classes; meteorological, hydrological, agricultural and socio-economical. For agricultural drought evaluation, the indices of Palmer Drought Severity Index (PDSI) and

Standardized Precipitation Index (SPI) are widely used (Ezzine et al., 2014). Since 2009, the WMO recommended SPI as the global standard hazard index to measure extreme conditions (droughts and floods) and their degrees of severity. The advantages of SPI are that it is: simple to calculate, requires only rainfall data, it is possible to be determined at different time scales, and can be compared over different regions. However, it has some limitations due to its localised character. For a good spatial interpolation, it requires a good density and distribution of meteorological stations. For PDSI, it is based on the equation of water balance including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. The principal advantage of the PDSI is its 'standardized' nature, which facilitates the quantitative comparison of drought incidence at different locations and different times. However, the empirical relationships used to define the index are limited by many factors in the calculating process (Lloyd-Hughes and Saunders, 2002). An index suggested by Woli et al. (2012) is the agriculture reference index for drought (ARID). ARID is a simple index based on soil water balance of a reference grass, which can be defined as a ratio of actual transpiration to potential evapo-transpiration. Additionally, in tropical monsoon countries, including Thailand, the generalized monsoon index (GMI) is used as a tool for assessing rainfed crops, such as rice (Chaudhary, 1999). GMI is a very simple method of calculation by rainfall in monsoon months weighting by crop water requirement in crop growth stage. Since the limit of weather data recorded on a local scale, in this study, SPI and GMI are chosen to study agricultural wetness or dryness conditions.

To understand the impact of climate change on the variation of temperature and rainfall in local watershed scales in the northern part of Thailand, the Mea Rim watershed (MRW), a sub-watershed of the Ping River, is used for this study. The climate data under the A2 (a fragmented world) and the B2 (a localized world emphasizing sustainable development) emission scenarios during the 2015–2074 period downscaled by the regional climate model of ECHAM4-PRECIS are used. The objectives of this study are twofold; (1) to investigate the variation and change of temperature and rainfall in MRW, and (2) to review and evaluate the water conditions in the future climate scenarios in the watershed.

2. Materials and Methods

2.1 Study area

This study was conducted in the mountainous area of Northern Thailand. Mae Rim watershed (MRW), a sub-watershed of the Upper Ping River (UPR), Northern Thailand is located between 18°54′ and 19°11′ latitude and 98°35′ and 98°58′ longitude. The MRW has a drainage area of about 515 km^2 and the altitude range is between 320 m and 1,350 meter above sea level (m.a.s.l.), with an average slope of 34%. About 42% of the watershed area has a steep slope (>35% slope) and about 28% of the area has a slope of between 20 and 35%. The dominant process of soil formation is clay eluviation on igneous rock formations, and the variation between the profiles is caused by erosion, colluviation, and land-use changes over time (Hermann et al., 2007). Agricultural areas cover about 8.5% and are mostly under rainfed cultivation practices. The average annual total rainfall is 1100 mm, and the average temperature is 24.1°C. The watershed drainage stream flows to the Ping River in the Mae Rim district which is located 17 kilometers north of Chiang Mai City.

2.2 Data

The study of atmospheric temperature change would be better if maximum temperature (Tmax) and minimum temperature (Tmin) are used separately instead of using the daily average temperature (Lobell et al., 2007) because the changes in Tmax and Tmin would impact the differences in the variation of the Diurnal Temperature Range (DTR = Tmax−Tmin) in different seasons. The change in DTR is highly correlated to cloud cover, soil moisture, and precipitation (Lauritsen and Rogers, 2012). This study will use both Tmax and Tmin temperatures.

2.2.1 Observed climate data

The daily meteorological data regarding Tmax and Tmin (°C) and rainfall (mm) during the period 1988–2007 from the three stations located on different elevations in and nearby the study area are calculated to form the monthly data. The stations are Mae Rim (340 m a.s.l.), Pang Dha (720 m a.s.l.) and Mea Hao (720 m a.s.l.). The data were then used to compare and verify to obtain simulated data of a baseline period.

2.2.2 Climate projection

It was according to IPCC SRES (Special Report Emissions Scenarios) (IPCC, 2001) that the A2 and B2 scenarios during the period 1988–2074 were used in this study. The datasets of A2 and B2 were simulated using the General Climate Model (GCM) of ECHAM4 (with a resolution of about 250 x 250 km) and downscaled to a higher resolution of about 20 x 20 km using the PRECIS (Providing Regional Climate for Impacts Studies) Regional Climate Model (RCM), called ECHAM4-PRECIS. The simulated data were used for the baseline period during 1988–2007 and for the future period during 2015–2074. The 30 year period is sufficiently long enough to filter out any interannual variation and reasonably short enough to express climatic trends of studied areas (McGregor and Nieuwolt, 1982 and WMO, 2013). In this study, the future period is separated into two periods consisting of 30 years each, the first and the second period covers 2015–2044 and 2045–2074, respectively. The scenario data sets are available from the Center of Excellence for Climate Change Knowledge Management (CCKM) website(REF),www.cckm.or.th/cckm_new/

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The climatic data sets during the baseline period of the observed and the simulated scenarios (A2 and B2) were compared to investigate the differences or any bias, based on correction methods recommended by Hashino et al. (2006) and Chinnavanno et al. (2010). Since the bias between the observed and the simulated data in each month of both temperature and rainfall were found to be of a relative highly degree, a monthly rescaling of the data was performed. The rescaling of the rainfall data by bias-correction of month j and year i (P_j^i) is achieved using the following transformation function;

$$P_j^i = \beta_j(\hat{P}_j^i), \quad (1)$$

where the function β_j is estimated from the slope value of the correlation between the observed and the simulated data of month j (j=1 to 12) during the baseline period; the $\hat{P}_j^i$ is the simulated rainfall data of month$j$ and year i. As for the rescaling of the temperature data by bias-correction (T_j^i), it is obtained from the following formula;

$$T_j^i = \hat{T}_j^i + B_j, \quad (2)$$

where the function B_j is the monthly average value of the residue between the observed and the simulated data of month j during the baseline period and $\hat{T}_j^i$ is the

ECHAM4-PRECIS simulated temperature of date *j* and month *i*.

2.3 Wetness and drought index

To evaluate the water condition of MRW, the two indices of agricultural drought, Standard Precipitation Index (SPI) and Generalized Monsoon Index (GMI), were used. To test for fitting between the values of SPI and GMI, the Pearson's linear correlation coefficient (r) were used.

2.3.1 Standardized precipitation index (SPI)

SPI value (WMO, 2012) was developed by American scientists McKee, Doesken, and Kleist in 1993 as an indicator for monitoring wet or dry periods. It is a powerful, flexible index and simple to calculate. Monthly precipitation is the only required input parameter for SPI. The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution by fitting a gamma or a Pearson Type III distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation.

The SPI was designed to quantify the precipitation deficit for multiple timescales. These timescales reflect the impact of drought on the availability of the different water resources: soil moisture conditions respond to precipitation anomalies on a relatively short scale; groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. (1995) originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month timescales. In this study, the SPIs of four months, from June to September, which are under the influence of the southwest monsoon, are calculated by comparing with the result of GMI. The criterion for a drought (wet) event for any of the timescales is a continuously negative (positive) result and which reaches an intensity of ≤ −1.0 (≥+1.0). In order to evaluate for wet/drought condition by using the SPI, the values of SPI are classified using the following system:

Level	SPI	Wet/Drought condition
1	≤ −2.0	Extremely dry
2	−1.5 to −1.99	Severely dry
3	-1.0 to -1.49	Moderately dry
4	−0.99 to 0.99	Near normal

5	1.0 to 1.49	Moderately wet
6	1.5 to 1.99	Very wet
7	≥ 2	Extremely wet

2.3.2 Generalized monsoon index (GMI)

GMI value was developed in 1982 as an agro-climatic index (Sukamoto et al., 1984). It is a simple tool to monitor rainfall conditions during the monsoon as well as the overall crop conditions. The Thai Meteorological Department uses GMI value to assess the impact of rainfall on agriculture in Thailand (Meteorological Department, 2013). This study used the GMI for comparison with the SPI in the local watershed scale in the Upper Ping River Basin (UPRB) to assess the probability of water stress or over wetness having an impact on crop production in the future conditions under the two climate scenarios (A2 and B2).

The value of GMI is calculated from the monthly rainfall during the southwest monsoon season. For Thailand, the southwest monsoon season starts from mid-May and culminates around mid-October. Thus, the GMI of Thailand is calculated by using the data on the amount of rainfall from June to September that is the rain fed growing season under the influence of the southwest monsoon, to be the value for GMI_{sw}. The weighting factor of the rainfall in each month is specified by the crop growth stages as the planting starts in the early days of the rainy season. The highest water requirement for crop is in the flowering/reproductive stage. The GMI_{sw} is defined as follows:

$$GMI_{sw} = w_6P_6 + w_7P_7 + w_8P_8 + w_9P_9 \quad (3)$$

where w and P are the weighting factor and the monthly rainfall, respectively. The numbers 6, 7, 8, and 9 are the southwest monsoon months of June, July, August, and September, respectively. The weighting factors for the monthly rainfall are 0.125, 0.125, 0.5, and 0.25, respectively. These weights are linked to the crop water requirements in a general way. The GMI is in the unit of millimeter (mm). The GMI is then transformed to percentile rank (GMI_{pct}) in an ascending order by making use of the values of GMI to get the ranging number, and then calculated to obtain GMI_{pct} using the following equation:

$$GMI_{pct} = \frac{r*100}{(n+1)} \quad (4)$$

where r is the ranging number and n is total number of years.

The GMI_{pct} is defined as the strength of rainfall impacting on the main crop condition (Sukamoto et al., 1984). In

Thailand, the GMI_{pct} rank is categorized as follows:

Level GMI_{pct} Crop condition

1) 0-20 Severe drought impact
2) 21–30 Drought impact
3) >30–40 Moderate drought impact
4) >40–60 Normal crop condition
5) >60–90 Possible above normal crop
6) >90–100 Possible excessive moisture

3. Results

3.1 Validation of rescaled simulated climate data

The comparison of temperature and rainfall between the observed data and the simulated data obtained from ECHAM4-PRECIS RCM in the A2 and B2 emission scenarios. This shows that the simulated Tmax and Tmin are higher than those of the observed data. However, for rainfall, the simulated data from the model are much lower than the observed data. The discrepancy may due to the low resolution (20x20 km) of the downscaling grid and the high spatial variation of Tmax and Tmin at different elevations in the mountainous areas. However, after rescaling using the bias correction, the simulated values showed a better agreement with the observed values, as shown in Figure 1. In addition, for higher variations in both the amounts and timing of the rainfall, we observed higher values for standard deviation (SD) and lower values for correlation coefficient (r^2). Nevertheless, the relation is compatible and acceptable for further analysis.

3.2 Future climate scenario in MRW

As far as the overall surface temperature is concerned, the average seasonal Tmax and Tmin in MRW tend to increase during the period from 1988 to 2074, as shown in Figure 2. The increasing trend is obviously found to be higher in the A2 scenario than in the B2 scenario. The increase in Tmin temperature or night-time temperature is higher than Tmax or day-time temperature. The optimized increasing trend (per 10 years) in the A2 scenario in the case of Tmin occurred in the warm period of the dry season, by 0.41°C, and the same in the case of Tmax occurred in rainy season by, 0.33°C. As for the rainfall trend, a very slight decreasing trend is found in the rainy season, but a small increase is found in the cold dry and warm dry seasons in both A2 and B2 scenarios.

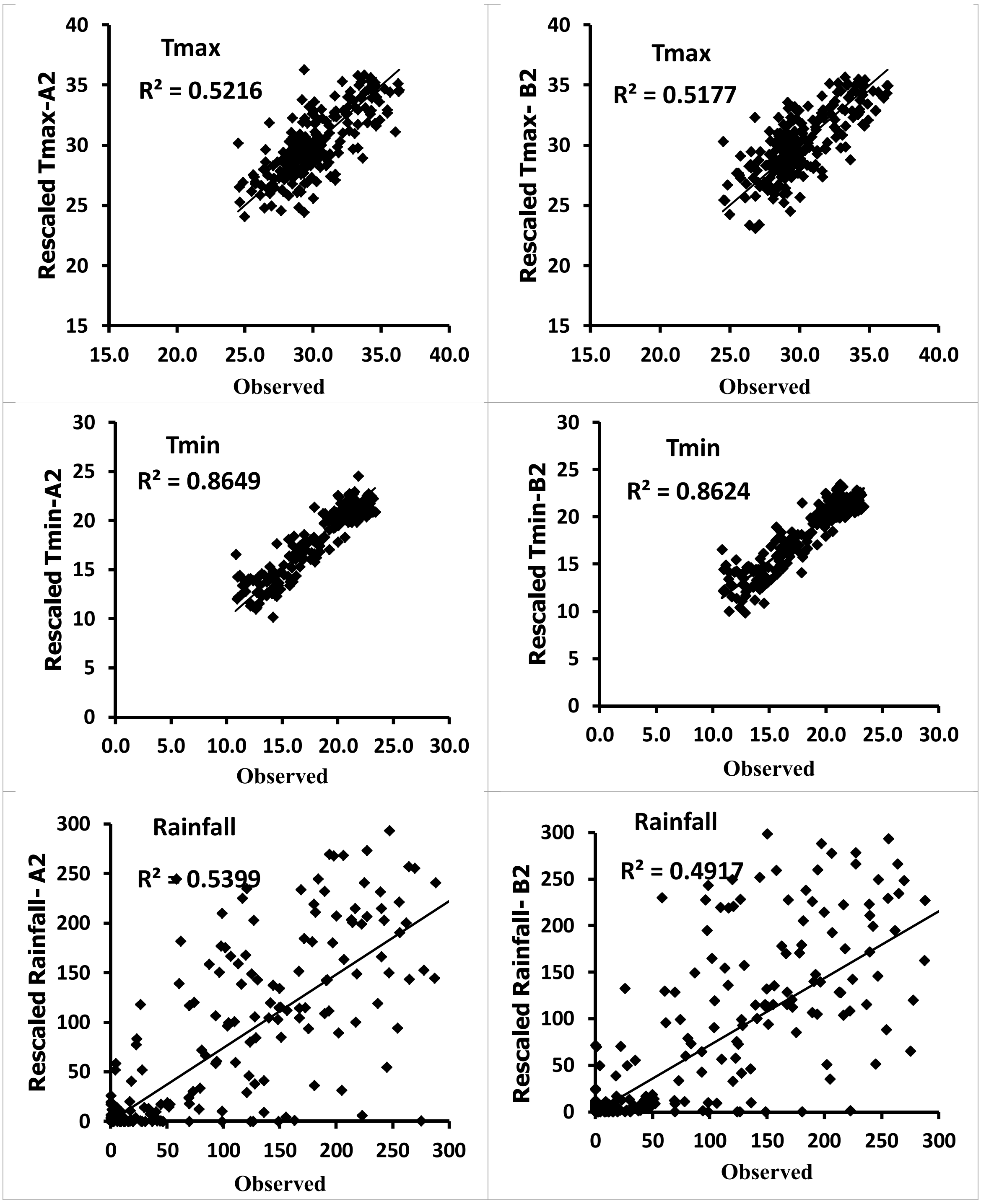


Figure 1: Correlation between the monthly obervation and rescaled simulation data which projected by ECHAM4-PRECIS reginal climate model under A2 and B2 emission scenarios of temperature, maximum (Tmax) and minimum (Tmin), and rainfall over Mae Rim Watershed, Northern Thailand during 1988-2007.

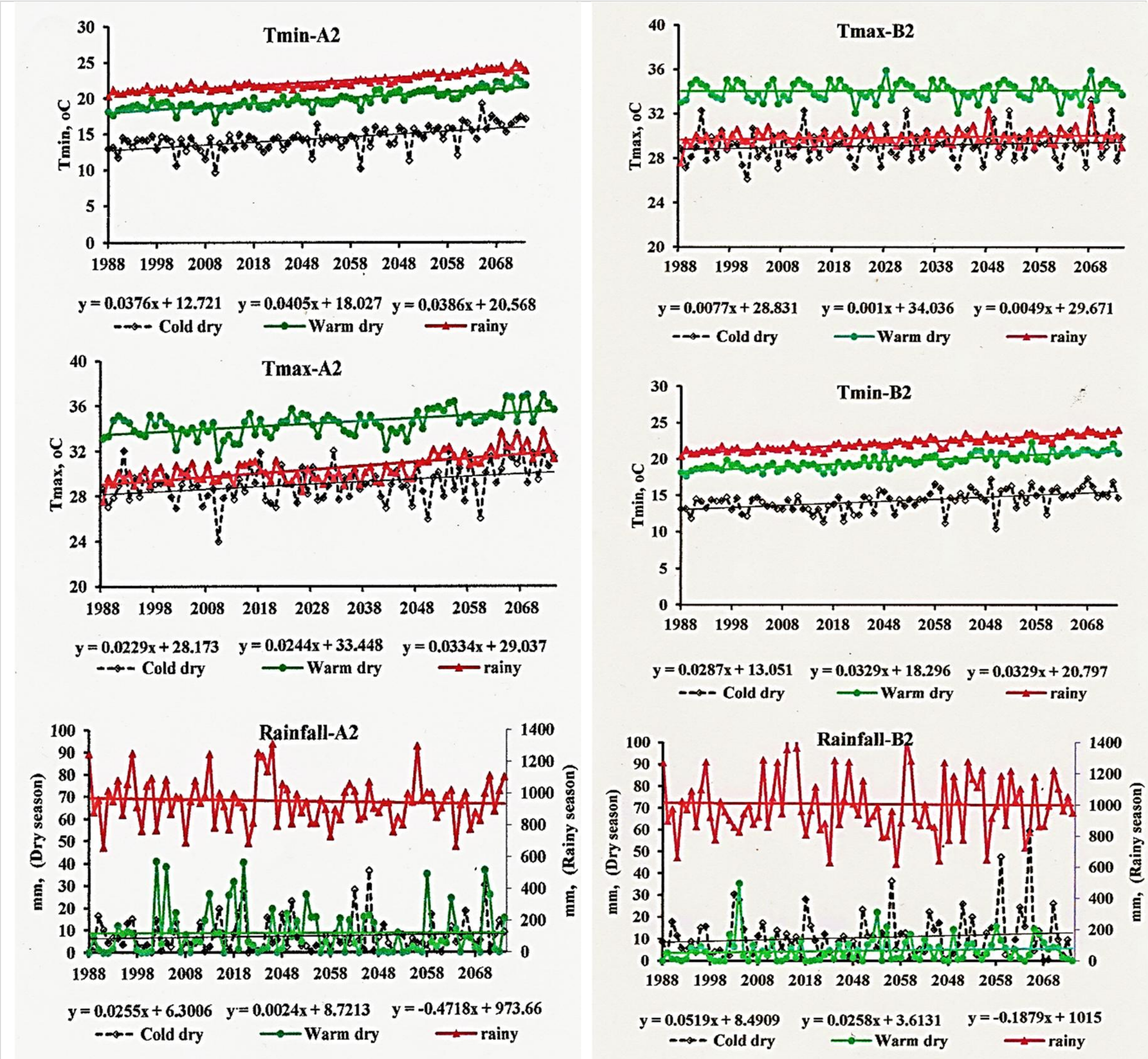


Figure 2: Varitions of the average seasonal maximum and minimum temperature (Tmax and Tmin) and rainfall of rescaled A2 and B2 emission scenarios (predicted by ECHAM4-PRECIS reginal model) by cold dry, warm dry and rainy season during 1988-2074.

However, the differences between the results of Tmax, Tmin, and rainfall in the first 30 years (2015–2044) and in the second 30 years (2045–2074) were found to be the percentages of departure from the baseline, as shown in Figure 3. Therefore, they were separated and categorized for comparison and discussion.

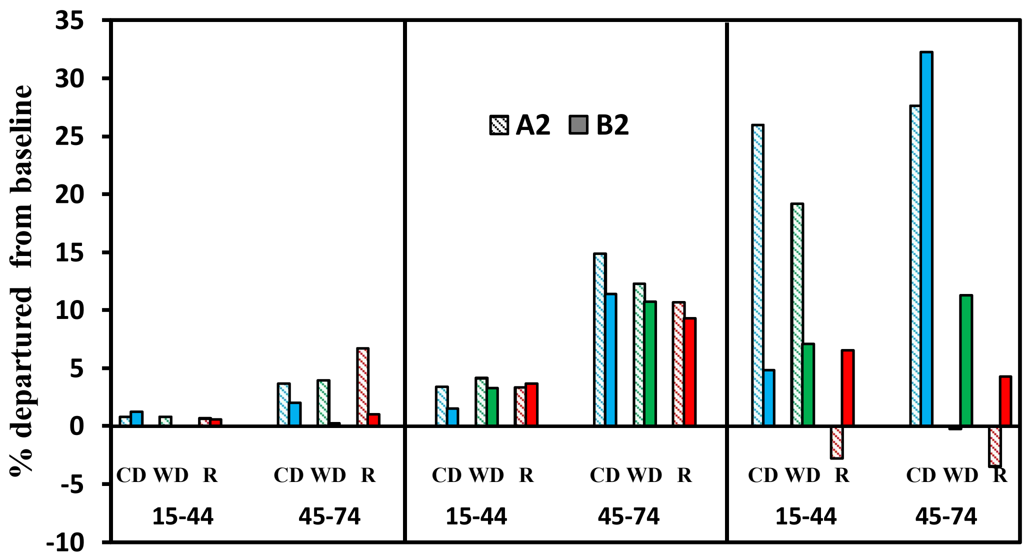


Figure 3: The increasing/decreasing percentages from the baseline seasonal maximum, minimum temperature and rainfall values in future scenarios for the two periods by 2015-2044 and 2045-2074. Note: CD=Cold Dry, WD =Warm Dry, and R=Rainy season.

3.2.1 Maximum temperature (Tmax)

In the first 30-year period, Tmax of the A2 and B2 scenarios are seen to slightly increase. But in the second 30-year period, the increase in Tmax of the A2 scenario is obviously higher than that of the B2 scenario in every season, as is clearly seen in Figure 3. The degrees of increase in Tmax in the first 30-year period from the baseline year are by 0.24°C, 0.29°C, and 0.21°C in the A2 scenario and by 0.35°C, 0.00°C, and 0.17°C in the B2 scenario, and in the second 30-year period, the degrees of increase in Tmax are by 1.07°C, 1.35°C, and 2.00°C in the A2 scenario and by 0.58°C, 0.08°C, and 0.33°C in the B2 scenario during cold dry, warm dry, and rainy seasons, respectively. The highest increase in Tmax is in the rainy season of the second 30-year period.

3.2.2 Minimum temperature (Tmin)

From Figure 3, a comparison between Tmax and Tmin reveals that the rise in the percentage of Tmin is mostly higher than that of Tmax, especially, in the second 30-year period. The degrees of increase in Tmin in the first 30-year period from the baseline year are by 0.47°C, 0.79°C, and 0.72°C in the A2 scenario and by 0.21°C, 0.61°C, and 0.77°C in the B2 scenario, and in the second 30-year period, the degrees of increase in Tmin are by 2.03°C, 2.31°C, and 2.27°C in the A2 scenario and by 1.56°C, 2.02°C, and 1.97°C in the B2 scenario during cold dry, warm dry, and rainy seasons, respectively.

3.2.3 Rainfall

Rainfall in the A2 and B2 scenarios tend to increase slightly in cold dry season and warm dry season, as shown in Figure 3. However, the rainfall conditions in the rainy season differ in the A2 and B2 scenarios. The trend of rainfall in the A2 scenario shows a slight decrease, whereas in the B2 scenario the trend of rainfall shows a slight increase.

3.3 Assessment of future water condition

Figure 4 illustrates a good relationship between the GMI and SPI values during the baseline period, with the r value of 0.8994 and in future periods of 2015–2074 by r=0.75 and r=0.86 in the A2 and B2 scenarios, respectively. The GMI and SPI values in this study have been calculated from the monthly rainfall data during the southwest monsoon season in the period June–September (JJAS) to indicate the situation of deficit or extreme water conditions. The results are presented in Figure 5 and Figure 6.

GMI: During the first 30-year period, the number of years of drought impact (GMI ≤30) is 10 years in the A2 scenario (inclusive of 7 years of severe drought impact) and 8 years in the B2 scenario (inclusive of 5 years of severe drought impact). As for the number of years of wetness possible above what is normal for crops (GMI ≥60), there are 9 years in the A2 scenario (inclusive of 1 year of possible extreme wetness) and 10 years in the B2 scenario (inclusive of 2 years of possible extreme wetness). In the second 30-year period, the GMI's result shows the number of years of drought impact (GMI ≤30) as 8 years in the A2 scenario (inclusive of 6 years of severe drought impact) and 9 years in the B2 scenario (inclusive of 7 years of severe drought impact). As for wet conditions occurring in the two scenarios, the number of years of rain conditions possible above the normal crop levels (GMI ≥60) is 14 years (inclusive of 3 years of possible extreme wetness) and 12 years (inclusive of 2 years of possible extreme wetness), respectively, for the A2 and B2 scenarios.

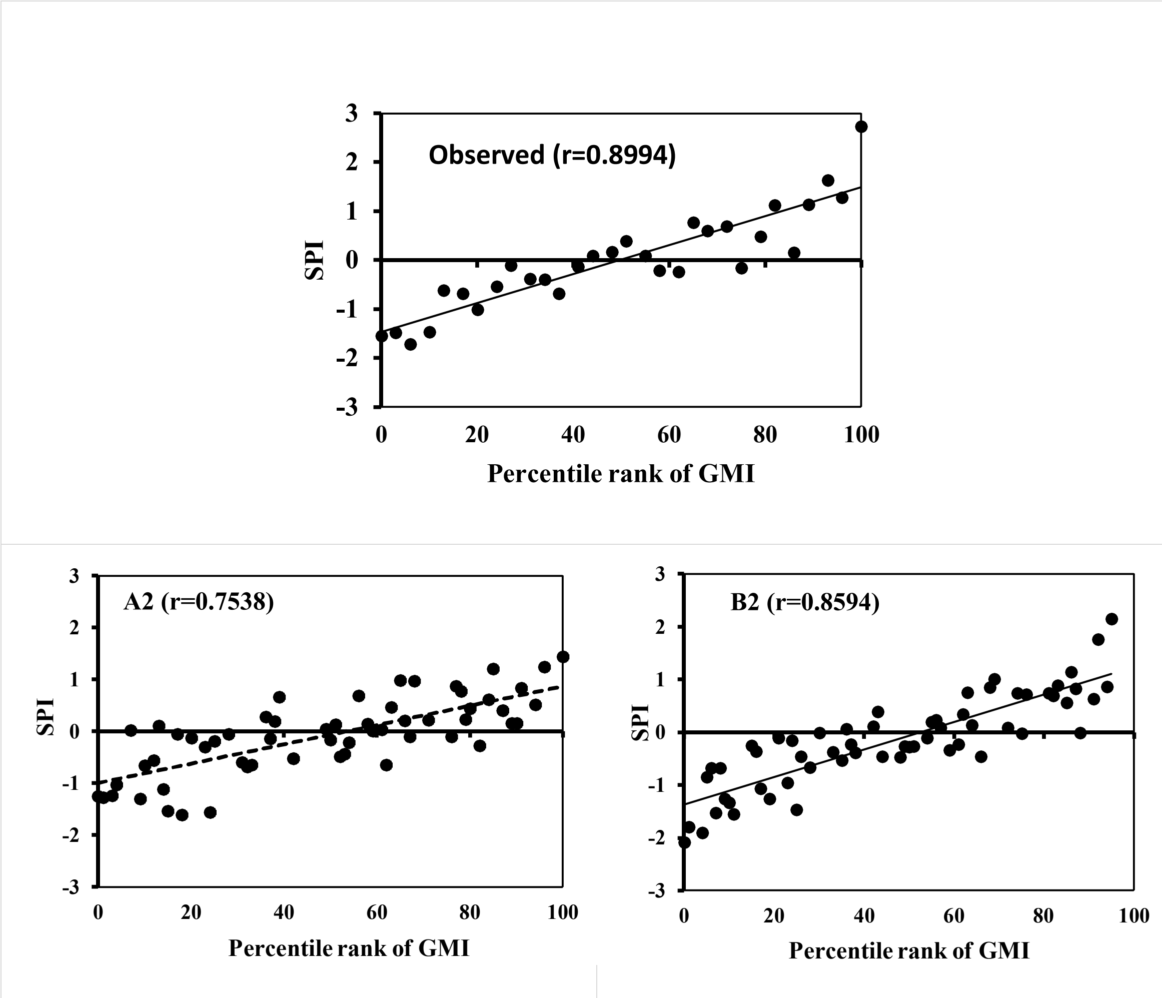
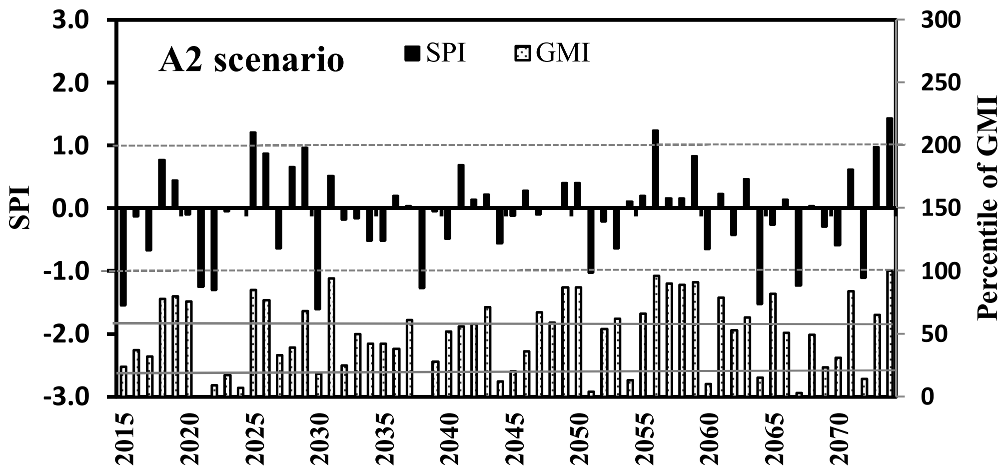


Figure 4: Relationships between SPI values and the percentile ranking of GMI values calculated from observed and the simulated monthly rainfall in June – September of A2 and B2 emission scenarios (predicted by ECHAM4-PRECIS regional model and rescaled) during 2008-2074.



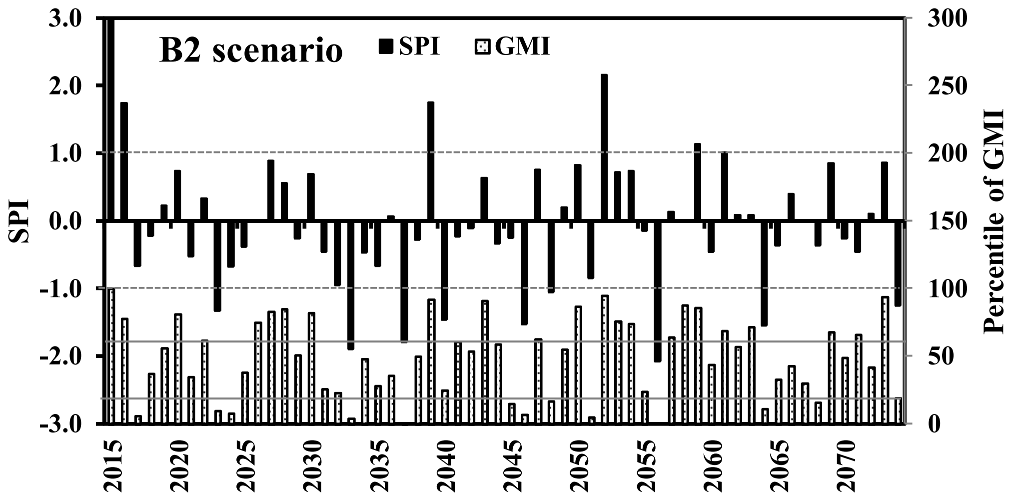


Figure 5: Standardized precipitation index (SPI) and Generalized monsoon index (GMI) calculated from simulated rainfall which predicted by ECHAM4-PRECIS regional climate model with A2 (above) and B2 (below) emission scenarios in monsoon month (June-September) during 2015-2074. Dash lines and solid lines are the lowest critical values for wetness/drought of SPI and GMI, respectively.

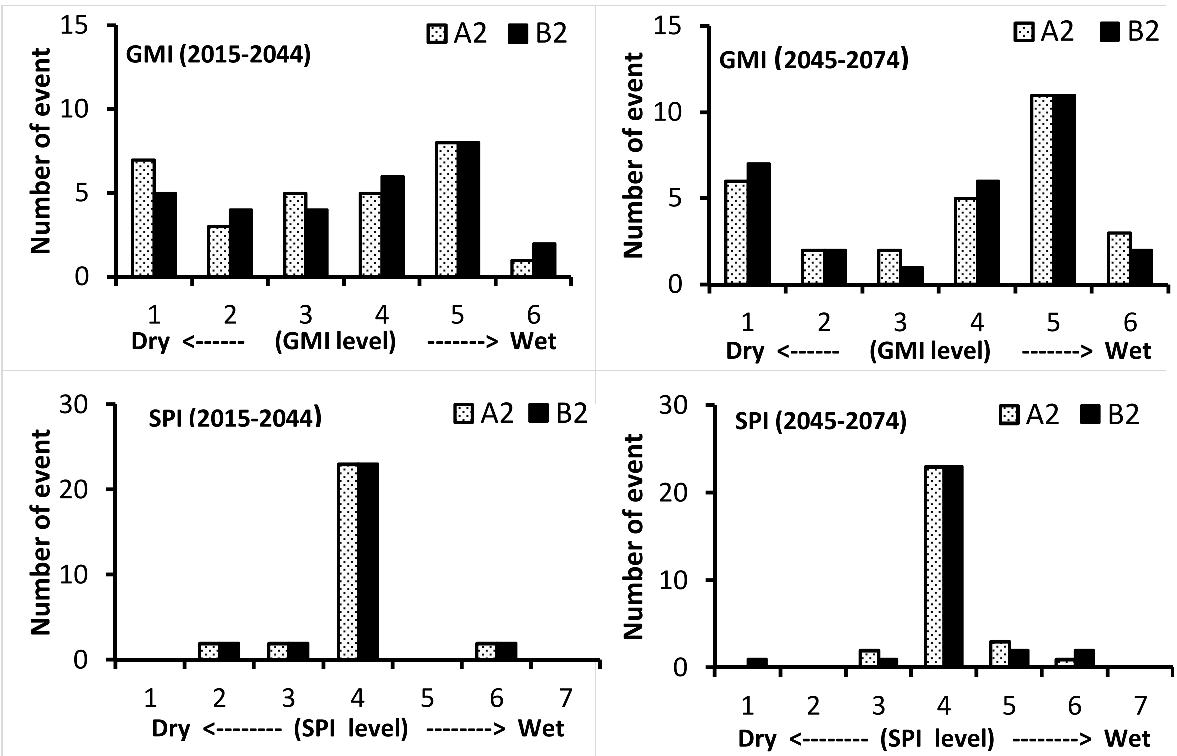


Figure 6: Comparison of number of events occurring within the level between the standardize precipitation index (SPI) and generalized monsoon index (GMI) in the future emission scenarios of A2 and B2 during the first 30-year period (2015-2044) and the second 30-year period (2045-2074)

SPI: As for the SPI for the four months (JJAS), the results indicating hydrological drought/wetness during the periods show rare wetness conditions and a few instances of severe dryness in both A2 and B2 scenarios, as shown in Figure 6. In the second 30-year period, instances of both severe wet (SPI ≥1.5) and severe dry (SPI ≤-1.5) conditions are also few in number in both A2 and B2 scenarios.

Comparison between the event numbers in the levels of GMI and SPI is shown in Figure 6. The result of SPI mostly found in normal level while the value of GMI level scattered over the scale. The normal level of SPI values may be accounted for, by the high interannual variability of monthly rainfall in the area. For GMI, it corresponded with the medium and strong El Nino and La Nina events in the area (Ueangsawat, 2013). Thus the GMI is a better indicator for wetness and/or drought evaluation in the UPRB and northern Thailand.

For both A2 and B2 scenarios, the occasional chances of anomaly with respect to both wet and dry events are similar. However, the probability that there is an occasion of extreme dry events occurring is higher in the first period than in the second period, while the probability that there is an occasion of extreme wet events occurring is higher in the second period than in the first period.

4. Discussion

Our study reports an agreement with the global level results that the future climate in Thailand will have a tendency to be warmer with longer summers and higher annual total rainfall with heavier rainfall during the rainy season than compared with historical records. However, the change in temperature and rainfall and their impact depend on location and season. In the northern and northeastern part of Thailand, the impact of climate change during 2006–2025 (using CCAM with scenario 2×CO_2) on rainfall is that, in the two regions, the rainfall may increase from the normal 50% and 20%, respectively, in addition, the impact on the temperature may become higher. However, until 2030, the greatest impact could be cases of increased frequency and intensity of extreme events (Norse, 2003).

Previous studies found that temperature indicated faster warming conditions during the night-time period (Tmin) than during the daytime period (Tmax) in recorded historical climate conditions (IPCC, 2007a) and in climate model scenarios (Lobell et al., 2007). This study reveals a similar result in both A2 and B2 climate scenarios from the ECHAM4-PRECIS RCM model. The study establishes the understanding that Tmin shows faster warming than Tmax, especially during the 2045–2074 period in all the seasons in MWB. The change in DTR in cold dry, warm dry and rainy seasons in the A2 and B2 scenarios in the study periods are presented in Table 1. The results show that the DTR decreases consistently throughout the time. The asymmetric nature of the diurnal warming of Tmax and Tmin leads to a decreasing response of plant vegetation growth and carbon sequestration (Peng et al., 2013). Also, in dry conditions, daytime (Tmax) warming can reduce photosynthetic activity through enhanced evapotranspiration, and reduced soil water content. However, the impacts of the greenhouse warming will have an effect on water resources, as suggested by IPCC working group II (IPCC, 1996). The impacts are indicated especially by changes in precipitation as regards timing, pattern, intensity, distribution, and amount of precipitation, all of which respond to the frequency and severity of droughts and floods. Although the results of this study reveal that the total rainfall and seasonal rainfall show a small change in the next 30 years and 60 years, the trend of rainfall during the dry season has been on the increase. These results show that the climate in the study area may have changed with a shift in the seasonal time, which would affect the water use and supply planning, especially for agriculture, as forewarned by FAO (2011). There are some drought indices being developed for use as tools for defining the severity of drought or wetness by making use of the rainfall data information. The indices would go a long way in assisting the water sector in decision-making regarding planning and management, both in the present time and in future (Wehner et al., 2011; Burke et al., 2006).

Additionally, the IPCC Working Group II (IPCC, 1996; IPCC, 2007b) reviews of evidence regarding the impacts of greenhouse warming of water suggests that the variation in precipitation is the main function affecting the increase or decrease of runoff from a watershed. While the influence of evapotranspiration on the amount of runoff in a watershed should surely be taken into consideration, as rising potential evapotranspiration (ET) with increasing simulated air temperature will affect the availability of moisture in the area. As for the frequency and severity of droughts and floods as consequences of global warming, the report suggests that it has a high level of uncertainty, and that the impacts will vary among basins (Ficklin et al., 2009; Jha et al., 2004). The frequency and severity of droughts could increase in some areas as a result of a decrease in the total rainfall, but there could also be more frequent dry spells and higher evapotranspiration.

Table 1: The diurnal temperature range (DTR=Tmax-Tmin) in NDJF for cold dry, MAMJ for warm dry and JASO for rainy season calculated from the simulated Tmax and Tmin in A2 and B2 emission scenarios in three periods.

Periods	DTR (°C)					
	A2 emission scenario			B2 emission scenario		
	Cold dry	Warm dry	Rainy	Cold dry	Warm dry	Rainy
1988-2007	15.2	15.1	8.4	15.4	15.1	8.3
2015-2047	15.0	14.9	8.3	15.2	14.8	8.0
2048-2087	14.6	14.5	8.2	14.5	13.8	7.2

In this study, the two drought indices, the standardized precipitation index (SPI) and the generalized monsoon index (GMI), were used to quantitatively evaluate dry and wet conditions on a watershed scale. Because of the high SD values of rainfall in the area, the level defining of GMI show better than of SPI. However, the results of the SPI and the GMI of the A2 and B2 scenarios are similar in many ways. The severe events consist of droughts in the first 30-year period during 2015–2044 with greater frequency than in the period of 2045–2074 which shows the number of occurrences of wet events to be greater than the number of occurrences of drought events. Although, the results are not forecasted, but have stimulated concern for the sake of planning in order to minimize the risk of water use, especially for rain fed agriculture, which is mostly found in the UPRB and the northern region of Thailand. The results indicate that agriculture in the area should be adapted to the seasonal shifts and the changes in temperature by coupling the same with short-term climate prediction.

5. Conclusions

The simulated data Tmax and Tmin and rainfall by ECHAM4-PRECIS climate model in Mae Rim watershed under A2 and B2 emission scenarios showed a reasonably agreement with the observed data during the baseline period, 1988-2007. The impacts of climate change in the watershed by using the simulated data during 2015-2074 found that the increasing rate of temperature was found in Tmin higher than Tmax, in A2 higher than in B2 scenarios and in the second 30-year period (2045-2074) higher than the first 30-year period (2015-2044). The highest increase of Tmin would be occurred during the cold season. For rainfall amount in both emission scenarios, cold season would receive higher rainfall amount than the rainy season. Evaluation of agricultural water condition by GMI and SPI, the results revealed a similar trend under A2 and B2 emission scenarios. The frequency of the extreme events (drought and wetness) would be higher during 2045-2074 than 2015-2045.

6. Acknowledgments

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7. References

Agoumi, A. 2003. **Vulnerability of North African countries to climatic changes: adaptation and implementation strategies for climatic change**. International Institute for Sustainable Development (IISD), Winnipeg, Manitoba, Canada.

Burke, E.J., Brown, S.J., and Christidis, N. 2006. Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model. **Journal of Hydrometeorology** 7: 1113-1125.

Chaudhary, J.L. 1999: Assessment of rice crop production by using generalized monsoon index-A case study for bastar district in Chhattisgarh region. **Indian Journal of Agricultural Research** 33(1): 45-50.

Chinavanno, S., Luang-Aram, V., Saengmanee, C., and Thanakitmetavut, J. 2010. **Performance of climate change scenarios of Thailand from the results of the PRECIS regional model: A Technical Report**. START center, Chulalongkorn University, Thailand.

Chinavanno, S., Luang-Aram, V., Saengmanee, C., and Thanakitmetavut, J. 2008. Developing high resolution climate scenarios for Southeast Asia region and Mekong River basin for 1960-2100. *In*: Jintrawet, A. and Chinvanno S. (eds): **Climate Change in Southeast Asia and Assessment on Impact, Vulnerability and Adaptation on Rice Production and Water Resource** (pp 6-10). Thailand.

Chotamonsak, C., Salath´e Jr, E. P., Kreasuwan, J., Chantara, S. and Siriwitayakorn, K. 2011. Projected climate change over Southeast Asia simulated using a WRF regional climate model. **Atmospheric Science Letters [online]** 12(2): 213–219.

Ezzine, H. Bouziane A., Ouazar, D. 2014. Seasonal comparisons of meteorological and agricultural drought indices in Morocco using open short time-series data. **International Journal of Applied Earth Observation and Geoinformation** 26: 36-48.

Food and Agricultural Organization (FAO). 2011. Climate change: major impacts on water for farming [Online].Available:http://www.fao.org/news/story/en/item/79964/icode/. [Accessed on 12 September 2013].

Ficklin, D.L., Luo, Y., Luedeling, E., and Zhang, M. 2009. Climate change sensitivity assessment of a highly agricultural watershed using SWAT. **Journal of Hydrology** 374: 16-29.

Fischer G., Shah M., Tubiello F.N., van Velhuizen H. 2005. Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990 - 2080. **Philosophical Transactions Royal Society of London B: Biological Science** 360: 2067–2083.

Herrmann, L., Spohrer, K., Schuler, U., Stahr, K., Anongrak, N., Hongsak, T. and Manajuti, D. 2007. Variability of soil resources in Northern Thailand. In: Allan, R., Forstner, U. and Salomons, W.

(eds): **Sustainable Land Use in Mountainous Regions of Southeast Asia**: **Environmental Science and Engineering** (pp 21-36). Stuttgart, Germany.

Hashino, T., Bradley, A.A. and Schwartz, S.S. 2006. Evaluation of bias-correction methods for ensemble streamflow volume forecasts. **Hydrology and Earth System Sciences Discussions** 3: 561-594.

Intergovernmental Panel on Climate Change (IPCC). 1996. **Climate Change 1995: Working group II report [Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis]**. Cambridge University Press, UK.

Intergovernmental Panel on Climate Change (IPCC). 2000. **Special Report on Emissions Scenarios (SRES).** Cambridge University Press, UK.

Intergovernmental Panel on Climate Change (IPCC). 2001. **Climate Change 2001: Working Group I: The Scientific Basis**. Cambridge University Press, UK.

Intergovernmental Panel on Climate Change (IPCC). 2007a. **Assessment Report: Climate Change 2007: Working Group I: The Physical Science Basis**. Cambridge University Press, U.K.

Intergovernmental Panel on Climate Change (IPCC). 2007b. **Assessment Report: Climate Change 2007: Working Group III: Impacts, Adaptation and Vulnerability**. Cambridge University Press, Cambridge, UK,

Jha, M., Pan, Z., Takle, E.S., and Gu, R. 2004. Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective. **Journal of Geophysical Research** 109: 1-12.

Lauritsen, R.G., and Rogers, J.C. 2012. Diurnal temperature range variability and regional causal mechanisms 1901–2002.**Journal of Climate** 25: 7216–7231.

Lloyd-Hughes, B. and Saunders, M.A. 2002. A drought climatology for Europe. **International Journal of Climatology** 22: 1571–1592.

Lobell, D., Bonfils, C., and Duffy, P. 2007. Climate change uncertainty for daily minimum and maximum temperatures: A model inter comparison. **Geophysical Research Letters** 34, LO5715:1-5.

McKee, T. B., Doesken, N. J. and Kleist, 1995. Drought monitoring with multiple time scales. In: **Ninth Conference on Applied Climatology** (pp.233-236). Dallas TX: American Meteorological Society.

McGregor, G.R., S.Nieuwolt. 1998. Tropical Climateology. 2nd ed. **John Wiley and Sons**. New York, England.

Meteorological Department. 2013. **The Assessment of Rainfall Impact on Crops in Thailand**. Meteorological Development, Bangkok, Thailand.

Nogues-Bravo, D., Araujo, M.B., Errea, M.P., Martinez-Rica, J.P. 2007. Exposure of global mountain systems to climate warming during the 21st Century. **Global Environmental Change** 17: 420-428.

Norse, D. 2003. Climate change and agriculture: physical and human dimensions. *In*: Bruinsma, J, (eds.): **World Agriculture: toward 2015/30 - An FAO Perspective** (pp. 357 – 572). FAO, Rome and Earthscan, London.

Peng, S., Piao, S., Ciais P., Myneni, R.B., Chen, A., Chevallier, F., Dolman, A. J., Janssens, I.A., Peñuelas, J., Zhang, G., Vicca, S., Wan, S., Wang S. and Zeng H. 2013. Asymmetric effects of daytime and night-time warming on Northern Hemisphere vegetation. **Nature** 501: 88–92.

Sangmanee, C., Chinvanno, S., Tanakitmethavut, J., Bunsom boonsakul, S. and Thitiwate, J. 2011. Impact of climate change on hydrological regime of Khlong Krabi Yai watershed, Krabi Province, Thailand. In: **Soil and Water Assessment Tool-Southeast Asia**, Proceeding of SWAT-SEA II Conference, January 6-7, Ho Chi Minh City, Vietnam.

Sukamoto, C., Achutuni, R., and Steyeart, L. 1984. **Development of Agroclimatic /Crop Condition Index Assessment Models. NOAA/NESDIS/AISC**. University of Missouri.

Ueangsawat, K. and Jintrawet, A. 2013. The impacts of ENSO phases on the variation of rainfall and streamflow in the Upper Ping River Basin, Northern Thailand. **Environment and Natural Resources Journal** 11(2):97-119.

Van de Steeg J.A, Herrero, M., Kinyangi, J., Thornton, P.K., Rao, K.P.C., Stern, R. and Cooper, P. 2009. **The Influence of Climate Variability and Climate Change on the**

Agricultural Sector in East and Central Africa-Sensitizing the ASARECA Strategic Plan to Climate Change. Entebbe, Uganda.

Van Vuuren, D. P., Edmonds, J. A., Kainuma, M., Riahi, K., and Weyant, J. 2011. A special issue on the RCPs. **ClimateChange**, 109:1-4.

Wehner, M.C., Easterling, D.R., Lawrimore, J.H., Heim, R. R., Vose, R. S. and Santer, B.D. 2011. Projections of Future Drought in the Continental United States and Mexico. **Journal of Hydro-meteorology** 12(6): 1359-1377**.**

World Meteorological Organization (WMO). 2012. **Standardized Precipitation Index User Guide**. WMO, Geneva, Switzerland.

Woli, P., Jones, J., Ingram, K. and Paz, J. 2013. Forecasting drought using the agricultural reference index for drought (ARID): A case study. **Weather and Forecasting** 28: 427-443.

World Meteorological Organization (WMO). 2013. Climate data and data related products : Climate normal [Online]. Available: (http://www.wmo.int/pages/themes/climate/climate_data_and_products.php) [Accessed on 3th March 2013]