Chapter 2
Assessment of Water Availability Under Climate Change Scenarios in Thailand

Abstract This paper investigates the potential impact on climate change on future water availability in Thailand. For this study, entire country was divided into nine Hydrological Response Units (HRUs) and the hydrological modeling was performed by Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) for each HRU using the future decadal climate data obtained from the Regional Climate Model (RCM) named Providing Regional Climates for Impact Studies (PRECIS) which was further bias corrected by using ratio method for two emission scenarios A2 and B2. The simulation shows that the water availability in the future decades at the different HRUs varies for the dry and wet season. In case of dry season, the coastal HRUs show a decline in water availability in the near future then tending to increase to the similar amount as of current situation in the late part of century. However, in case of wet season all the HRUs shows increasing trend of water availability in future. Nonetheless, considering the whole country for dry season the water availability is expected to be decreased in the early part of the century followed by an increasing trend by the end of the century relative to present water availability for both scenarios. Similarly a univocal increasing trend of water availability is expected for wet season indicating the possibility increased frequency and intensity of floods.

Keywords Climate change · HEC-HMS · PRECIS · Water availability · Thailand

2.1 Introduction

Southeast Asia is expected to be seriously affected by the impacts of climate change due to the high dependency of economy on agriculture and water resources in the region (IPCC 2007). The region's water resource is already affected by the rapid population growth, urbanization, agricultural and hydropower demand. Recent extreme events in Thailand shows it is under water crisis, in addition the intensity of the extreme events are also expected to increase in the future (Graiprab et al. 2010). Two most important problems attributed by climate change in the region are floods

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and droughts (SEA START RC 2009). Flooding negatively affects the crops, livelihoods and infrastructure throughout the country whereas drought affects the crop production specifically in the Northeast region (Kranz et al. 2010). Similarly, studies show that the impact of climate change are regional and its affects are also concentrated at regional scale (Chiew et al. 2009; Dore 2005) although the water management policies target at national scale.

Climate change is anticipated to have significant alteration of the global water cycle through changes in temperature and precipitation (Sharma and Babel 2013). The change in precipitation regime, in terms of intensity and frequency inclusive of spatial distribution has already been reported worldwide (Jiang et al. 2007a; Dore 2005). Contemporary studies of state of art on climate change impacts on hydrology in various watersheds in the world validate changes in the annual and seasonal pattern of flows (Li et al. 2013; Boyer et al. 2010; Jiang et al. 2007b). The increasing demand of freshwater by virtue of factors such as population growth and land use change has forced water resources under threat. Additionally, climate change has rendered its availability in the future towards more uncertainty (Davis and Simonovic 2011).

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) released in 2001 reported intensification of the global hydrological cycle with its implications on surface and groundwater resources (IPCC 2001). Although several studies (Babel et al. 2013; Nohara et al. 2006; Arnell 2003) have been conducted to understand the impacts on river runoff by using the advanced global hydrological models that are driven by ensembles of climate models yet the influence of climate change at national scale and its variation with basin scale is still under dilemma (Minville et al. 2008).

For the last two decades GCMs have confirmed to be an essential tool for climate change impact assessment studies (Weart 2010). Although the simulated scenarios are advisable for the regional to national scale studies, they are less suitable for basin level studies due to their coarse spatial resolution. Several techniques have been developed to overcome this issue but still there is a demand to further develop the existing methods for impact assessment studies. Bias correction has been successfully applied in many parts of world for linking GCMs and hydrological models of impact assessment (Koutroulis et al. 2013; Leander and Buishand 2007). In addition although several hydrological models are available, HEC-HMS is a versatile semi-distributed model and its performance has been accepted in many basins in the world (Chu and Steinman 2009; Sharma et al. 2007).

Despite of the significant progress on the basin level climate change impacts assessment studies, a comprehensive study comprising of basin scale study attributing to national level water availability is necessary for Thailand. With limited adaptive capacity, the people are expected to be severely threatened by the additional influence of climate change. In order to address this issue, this paper presents the analysis of the future changes in local climate at hydrological response units (HRUs) and assesses their impact on national scale water availability to help in managing water resources more efficiently and prepare necessary plans for adaptation in changing climatic conditions.

2.2 Study Area

Thailand lies within 5°37′–20°28′ north latitude and 97°21′–105°38′ east longitudes. The study includes the 25 major river basins in Thailand covering an area of approx. 5,13,000 km^2. All major river basins were grouped into nine HRU (Hydrological Response Unit) based on the physiographic characteristics for easiness in hydrological modeling. Figure 2.1 shows all the HRUs considered in this study. Elevations vary from 0 to 1,350 masl with higher altitudes found in the northern part of the country. Tropical wet climate dominates the country however; the south and east experience a tropical monsoon climate. The ranges of maximum and minimum temperatures are from 28–36 °C and 13–25 °C respectively. Temperature varies significantly with location; higher in the plains whereas low in hills. The wet season starts with the monsoon from May to July which extends up to October to November contributing 75 % of total rainfall and consecutively leaving rest part of the year dry with very low available water. Dry period extends longer in the Northeast part of the country even up to May/June. The average annual rainfall of the country is about 1,574 mm which also changes with location. The annual rainfall is about 1,200 mm in the northern mountainous region, 1,300 mm in the central plain, below 1,000 mm in the western strip of the north-east plateau and increases to 1,600 mm towards the Far East end of the north-east plateau. The east coast peninsula receives additional rainfall from the northeast monsoon during November through January and annual rainfalls of 1,800 mm and 2,500 mm are observed over the eastern and western coasts of the peninsula respectively.

2.3 Methodology

2.3.1 Data Collection

2.3.1.1 Hydro-meteorological Data

Daily precipitation data of 95 meteorological stations covering the whole of Thailand were collected for the period of 1971–2010 from Thai Meteorological Department (TMD). The distribution of the numbers of stations from the basins was done based on the area of the HRU and spatial distribution of the stations. Data collected from all stations were used for creating Thiessen polygons for determining the distribution of rainfall in the HRUs. Missing data were generated by creating linear regression models based on observed and gridded daily precipitation dataset from APHRODITE (http://www.chikyu.ac.jp/precip/). The daily river discharge data of all 25 major river basins was collected from Royal Irrigation Department (RID) for a period of 1992–2000. However, in order to set up the model for the nine HRUs the river discharge of the major rivers was used.

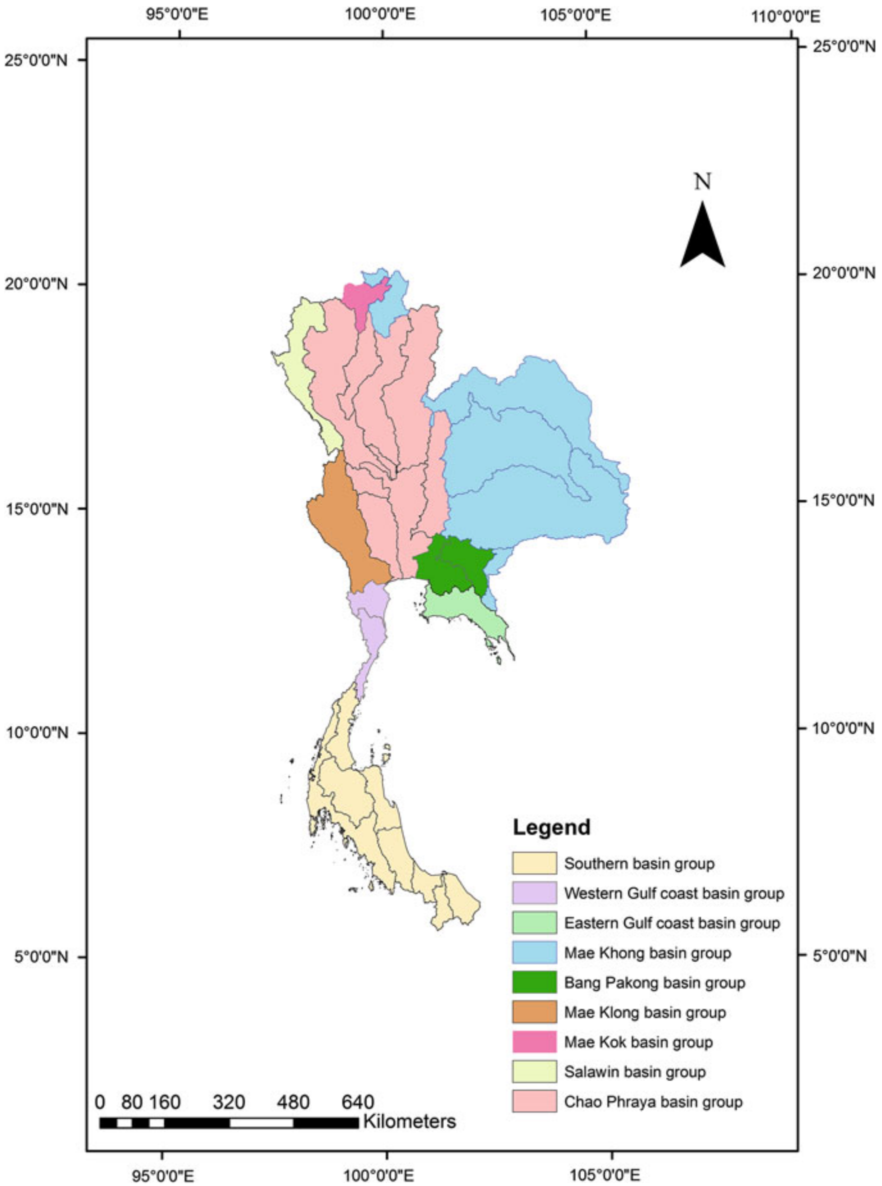

Fig. 2.1 Nine modeled hydrological response units in Thailand for future water availability

2.3.1.2 Future Climate Data

Outputs of the regional climate model (RCM) PRECIS developed by the Hadley Centre of the UK Meteorological Office was used for generating the future gridded climatic dataset. The PRECIS RCM is based on the atmospheric components of the

ECHAM4 GCM from the Max Plank Institute for Meteorology, Germany. The PRECIS data are produced by the Southeast Asian System for Analysis, Research and Training (SEA START) Regional Center for entire Southeast Asian region with a resolution of 0.2° × 0.2° (approximately 22 × 22 km^2). These data comprise of datasets of A2 and B2 emission scenarios from ECHAM4 A2 and B2. The PRECIS data over the periods of 1971–2000 and 2011–2100 for both A2 and B2 scenarios were obtained from SEA START Regional center (http://gis.gms-eoc.org/ClimateChange/index_en.asp).

2.3.1.3 Other Data

The 90 m resolution Digital Elevation Model (DEM) for whole Thailand was downloaded from the Shuttle Radar Topography Mission (SRTM) website: http://glcf.umd.edu/data/srtm/. Soil data and its classification were done based on Food and Agriculture Organization (FAO) recommendations. The land use and land cover map for 2005 was retrieved from Land Development Department (LDD), Government of Thailand.

2.3.2 *Methodological Framework*

Figure 2.2 represents the framework followed for assessing the impacts of climate change on water availability in Thailand. This study also emphasizes the importance of bias correction for the precipitation data obtained from RCM at basin level. Statistical comparison was done with raw RCM and bias corrected data to evaluate the outputs with the observed data for the current time period. Simultaneously the

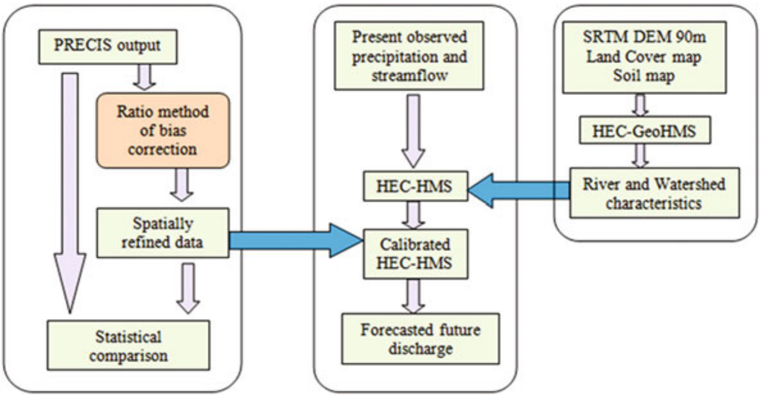

Fig. 2.2 Methodological framework followed to assess the impact of climate change on future water availability in Thailand

semi-distributed hydrological model HEC-HMS version 3.5, developed by United States Army Corps of Engineers was also set up for each HRU by using the outputs of HEC-GeoHMS. The bias corrected precipitation output was then fed into HEC-HMS to simulate the future decadal water availability for A2 and B2 scenarios.

2.3.3 Ratio Method of Bias Correction

The ratio method for bias correction was derived from Braun et al. (2011) which involves three steps. The first deals with determining monthly precipitation over the reference period followed by estimation of the monthly biases by using the mean monthly precipitation and the RCM dataset. Finally the calculation of the fine spatial resolution projected output is calculated based on the observed reference period and monthly bias computed data. Due to handling enormous amount of data for this research; in addition to the satisfactory performance of this method in other basins (Chen et al. 2013; Mpelasoka and Chiew 2009), the particular method was selected. Figure 2.3 illustrates the stepwise flowchart of the bias correction technique.

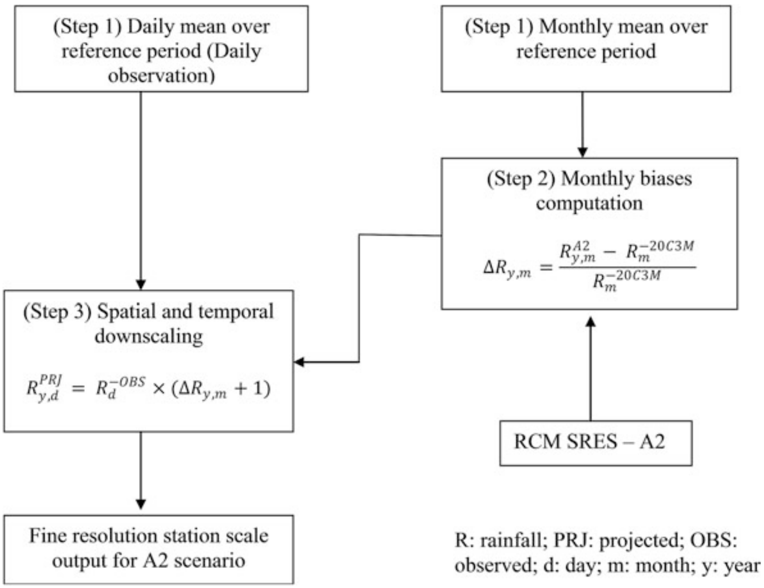

Fig. 2.3 Methodological flowchart for bias correction technique showing A2 scenario (as an example) applied in this study

2.3.4 Hydrological Model

HEC-HMS model was selected to simulate the discharge in all HRUs. HEC-HMS model set up includes the setting of basin model, meteorological model and define the control specifications. The basin parameters including sub-basin area, centroid, slope of basin and longest flow are pre-requisite for HEC-HMS which was further derived by basin delineation from HEC-GeoHMS version 1.1 in ArcView GIS 3.2. The outputs of HEC-GeoHMS for all HRUs were imported to HEC-HMS to set up the model for those particular HRUs. Since the model was run for longer period of time, continuous loss model was chosen. Clark unit hydrograph transformation, constant monthly baseflow and lag routing methods were selected to develop the model for the HRUs. The meteorological model was developed by Thiessen Polygon Weight method. Further details on basin/HRU development can be found in USACE 2000. Observed hydrological and meteorological data for the period of 1995–2003 and 2004–2010 was used for calibration and validation of the model respectively.

2.4 Results and Discussion

2.4.1 Comparison of RCM and Bias Corrected Values

Table 2.1 shows the comparison of the raw RCM and bias corrected rainfall data with the observed for reference period for all nine HRUs. The results clearly indicate that the bias correction gives better results in representing the present day climate. It can be observed that for Chao Phraya and Western Gulf HRUs the raw

Table 2.1 Comparison of RCM simulated and bias corrected average annual precipitation values with the observed precipitation

HRU name	Observed (mm) (2001–2010)	RCM simulated		Bias corrected	
		Absolute value (mm)	% change	Absolute value (mm)	% change
Salawin	1,190 ± 47	1,042 ± 55	−12.46	1,157 ± 34	−2.78
Mae Kok	1,730 ± 63	1,321 ± 78	−23.65	1,645 ± 45	−4.88
Mae Khong	1,944 ± 127	2,122 ± 141	9.16	2,001 ± 114	2.94
Chao Phraya	1,076 ± 162	1,432 ± 154	33.09	1,119 ± 148	4.00
Mae Klong	1,612 ± 27	1,578 ± 45	−2.11	1,602 ± 31	−0.63
Bang Pakong	1,422 ± 44	1,332 ± 64	−6.37	1,401 ± 47	−1.46
Eastern Gulf	1,908 ± 96	1,515 ± 75	−20.61	1,834 ± 91	−3.89
Western Gulf	1,063 ± 89	1,432 ± 78	34.72	1,134 ± 92	6.65
Southern	2,221 ± 124	2,850 ± 98	28.33	2,336 ± 137	5.17

RCM data shows a deviation of +33.09 and +34.72 % in magnitude of observed average annual precipitation whereas removing bias in the dataset can reduce it to +4.00 and +6.65 % respectively. Similar results were also obtained in other HRUs as well however it can also be observed that simulated RCM values depend on the location of the HRU. For instance the percent deviation in simulated precipitation by RCM is higher in the coastal areas whereas in mountains and plains the simulations are in good agreement with the observed values.

2.4.2 Projected Rainfall Anomalies

The rainfall anomalies projected by bias correction of the RCM dataset were calculated for dry and wet seasons separately for 2011–2040 (2020s), 2041–2070 (2050s) and 2071–2099 (2080s). Table 2.2 represents the percent deviation in average rainfall for dry season. It is observed that Mae Kok, Mae Khong and Bang Pakong HRUs will experience higher increase in precipitation in all three future time periods for both scenarios. It can also be observed that Chao Phraya will experience an increase in precipitation up to 22 and 13.5 % for A2 and B2 scenarios respectively in 2080s relative to baseline period. Higher variation in the observed precipitation is also observed for the baseline period. The larger number of stations considered in the HRU can be attributed to this variation.

In case of wet season, Mae Kok and Mae Khong HRUs will experience an increase in precipitation up to 29.5 and 36.5 % in 2080s relative to baseline period (Table 2.3). The elevation of Mae Kok and larger spatial extent of Mae Khong

Table 2.2 Projected rainfall anomalies (%) for dry season in case of A2 and B2 scenarios

Basin group	Baseline (1971–2000)	2020s		2050s		2080s	
	Dry period (Nov–Apr)	A2 (%)	B2 (%)	A2 (%)	B2 (%)	A2 (%)	B2 (%)
Salawin	273.7 ± 33	0.9	−1.6	3.4	4.8	14.3	10.0
Mae Kok	397.9 ± 37	17.1	14.3	21.1	22.1	33.6	28.2
Mae Khong	408.2 ± 94	4.4	14.8	22.7	21.8	37.8	23.7
Chao Phraya	275.5 ± 102	3.1	0.8	7.4	8.4	21.9	13.5
Mae Klong	412.7 ± 21	−4.2	−6.6	−1.9	−0.5	8.4	4.4
Bang Pakong	364.0 ± 24	23.6	23.9	29.3	29.7	32.0	30.6
Eastern Gulf	450.3 ± 51	4.0	1.5	6.5	8.0	17.6	13.3
Western Gulf	318.9 ± 61	−12.9	−15.0	−10.8	−9.6	−1.4	−5.0
Southern	666.3 ± 62	−4.6	−7.4	−7.4	−4.4	−2.4	−3.0

Table 2.3 Projected rainfall anomalies (%) for wet season in case of A2 and B2 scenarios

Basin group	Baseline (1971–2000)	2020s		2050s		2080s	
	Wet period (May–Oct)	A2 (%)	B2 (%)	A2 (%)	B2 (%)	A2 (%)	B2 (%)
Salawin	916.3 ± 52	−0.6	2.8	2.6	2.4	14.3	2.3
Mae Kok	1,332.1 ± 72	12.7	16.8	16.7	15.7	29.5	16.9
Mae Khong	1,535.7 ± 133	14.1	18.4	19.8	20.9	36.5	26.2
Chao Phraya	800.5 ± 181	1.2	4.2	3.7	4.1	16.2	3.3
Mae Klong	1,199.3 ± 43	7.2	10.9	10.7	10.4	23.2	10.3
Bang Pakong	1,057.9 ± 56	11.3	13.5	12.5	14.7	31.9	17.1
Eastern Gulf	1,457.7 ± 102	2.7	6.2	6	5.7	18	5.7
Western Gulf	744.1 ± 118	−3.0	0.3	0.2	−0.1	11.6	−0.1
Southern	1,554.7 ± 132	1.0	5.4	8.8	8.7	21.4	15.4

HRU can be the causative factor for the projected increase. Surprisingly, Mae Klong and Bang Pakong HRUs show higher precipitation in order of 23.2 and 31.9 % for A2 scenario in 2080s. The influence of physical process of the mountains and sea respectively in climatology can be the attributed to this. In addition a higher variation in the observed precipitation for the baseline period is observed for Mae Khong, Chao Phraya, Eastern Gulf, Western Gulf and Southern HRUs.

2.4.3 Calibration and Validation of HEC-HMS

The HEC-HMS was calibrated and validated for all HRUs based on the observed stream flow data. The period of 1995–2003 and 2004–2010 was chosen for model calibration and validation respectively. The modeling results were evaluated based on the coefficient of determination and volumetric error. The results suggest the model estimates the runoff in good agreement with the observed runoff. However, poor relationship is observed for Mae Khong, Eastern Gulf, Western Gulf and the Southern group HRUs (Table 2.4). Multiple outlets in the coastal region can be attributed to the poor performance in these HRUs. However, the performance of the model is still in acceptable range and therefore the projection was carried out for the future time periods.

2.4.4 Projection of Decadal Water Availability at HRU Scale

Figures 2.4 and 2.5 show the simulated future water availability for A2 and B2 scenarios at all HRUs considered. The results suggest that, the future change in

Table 2.4 HEC-HMS model performance statistics during calibration and validation

HRU name	Coefficient of determination (R^2)		Volumetric error (%)	
	Calibration	Validation	Calibration	Validation
Salawin	0.78	0.76	3.87	2.56
Mae Kok	0.74	0.71	4.23	3.12
Mae Khong	0.61	0.67	8.74	6.58
Chao Phraya	0.87	0.82	1.42	2.06
Mae Klong	0.85	0.81	2.64	3.51
Bang Pakong	0.77	0.84	4.11	3.28
Eastern Gulf	0.62	0.59	−9.84	−10.71
Western Gulf	0.70	0.71	−9.71	−8.65
Southern	0.65	0.62	−8.21	−8.65

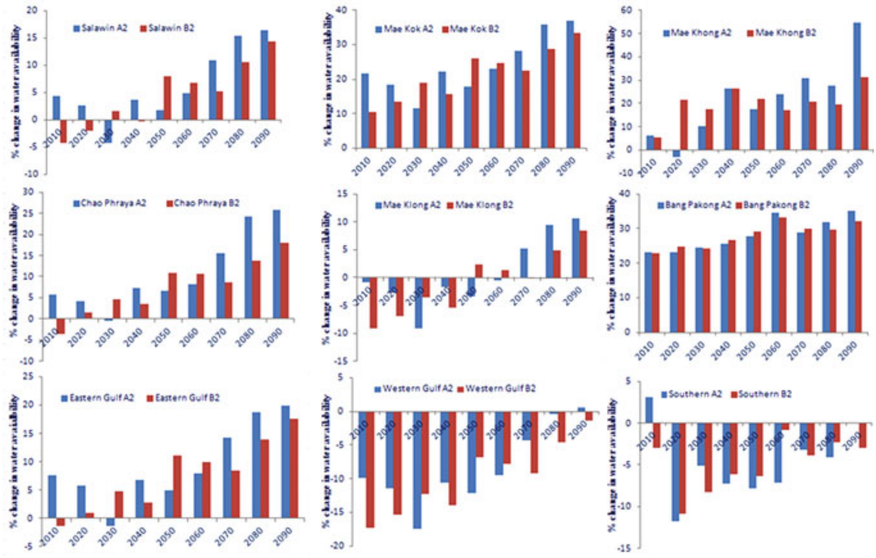

Fig. 2.4 Percent change in decadal water availability for dry season in all HRUs for A2 and B2 scenarios

water availability is univocal in some HRUs whereas it is in contradiction in others. For instance, in case of Salawin, Chao Phraya and Eastern gulf HRUs for dry season, the water availability is expected to fluctuate in the first three decades followed by an increasing trend for both scenarios. It can also be noted that, the magnitude of available water is higher for A2 scenario relative to B2. It can also be observed that for the corresponding season at Mae Kok, Mae Khong and Bang

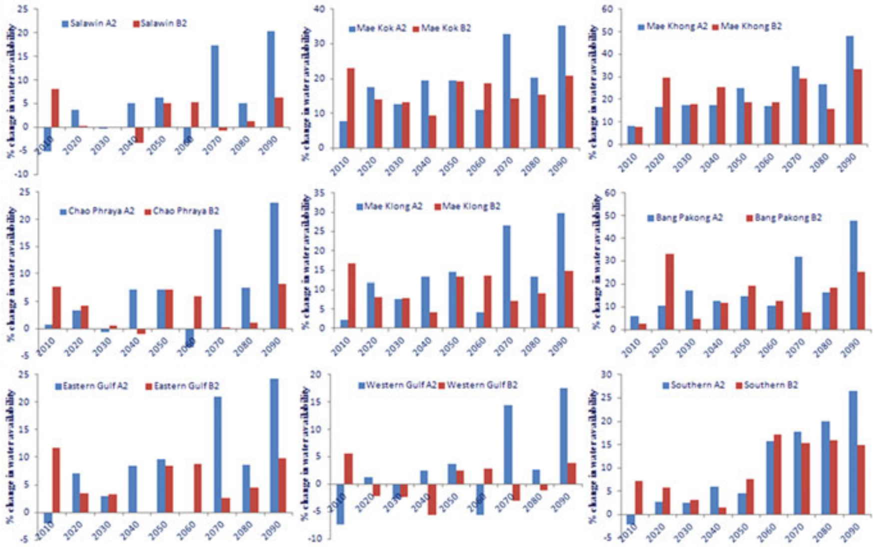

Fig. 2.5 Percent change in decadal water availability for wet season in all HRUs for A2 and B2 scenario

Pakong HRUs an increasing trend in available water persists for both scenarios. A contradictory decreasing trend is expected for the coastal HRUs particularly Western and Southern HRUs. However simulation suggests that in Mae Klong HRU, the water availability will be reduced in the first half followed by an increase at the latter half of century. The projected rainfall in those HRUs can be attributed to the pattern of the simulated runoff. Simulation also suggests the southern and western basin groups are expected to experience a decline in the water availability for early part of the century up to 17 and 12 % for 2010s and 2020s respectively relative to present water availability. The projected spatial variability in the water availability due to climate change may significantly affect the long term water management plans.

Simulation of future water availability for wet season suggests a relatively lesser altercation for many HRUs in the country. An increasing trend in water availability is observed for Mae Kok, Mae Khong, Mae Klong, Bang Pakong and the Southern HRUs where the stream flow is expected to increase for all the decades relative to the baseline period for both scenarios. The Salawin, Chao Phraya and Western Gulf shows higher fluctuation in water availability for the decades however; the water availability is expected to increase up to 21, 25 and 17 % for the respective HRUs for 2080s in case of A2 scenario leading to higher focus on increased intensity of flood. Eastern Gulf HRU shows a positive fluctuation in the water availability although an increase up to 23 % is expected for 2080s in case of B2 scenario.

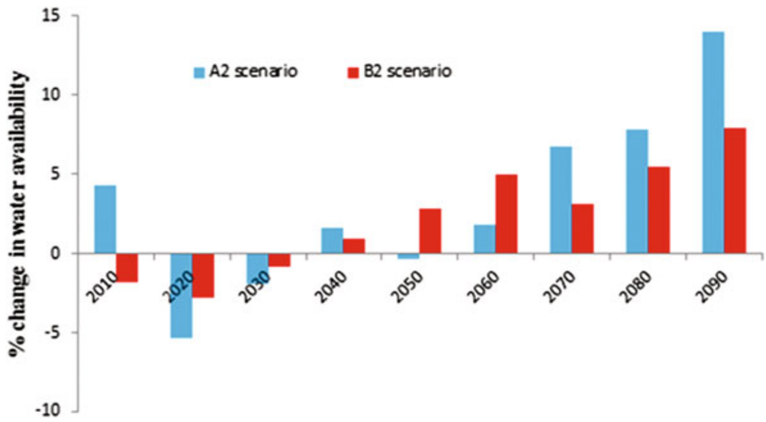

Fig. 2.6 Projected percent change in decadal water availability at national level for A2 and B2 scenarios in case of dry season

Nevertheless, for all HRUs an increasing trend or minor positive fluctuation in water availability is expected for all decades and the possibility of low intensity and frequent foods in wet season in the region.

2.4.5 Projection of Decadal Water Availability at National Scale

Figure 2.6 indicates the national level water availability for the future climate. It can be observed that majority of the HRUs indicates an increasing trend of water availability in dry season, yet at national scale the water availability results demonstrates a dropdown up to 6 % for A2 scenario in 2020s compared to the baseline period of 77,061 MCM. The simulation also illustrates ahead of 2040s, an increase in magnitude is expected with maximum value at 13 and 7.5 % for A2 and B2 scenarios in 2080s. The reduced stream flow in the early decades for most of HRUs attributed to climate change is the influencing factor for the reduced water availability for corresponding time intervals. The results indicate that at national level proper plans for energy and other associated sectors are necessary to be evaluated since in the early decades the water availability is expected to decrease.

In contrast to dry season, wet season water availability is expected to have an increasing trend at national level irrespective of basin scale projection (Fig. 2.7). An increase in water availability of 31 and 17 % are expected for 2080s in case of A2 and B2 scenarios respectively at national scale compared to 183,050 MCM for baseline period which calls for improved land use planning. It can also be noted that the national level water availability is influenced by the size of the HRU considered. The severity in magnitude of precipitation for A2 scenario is the contributing factor

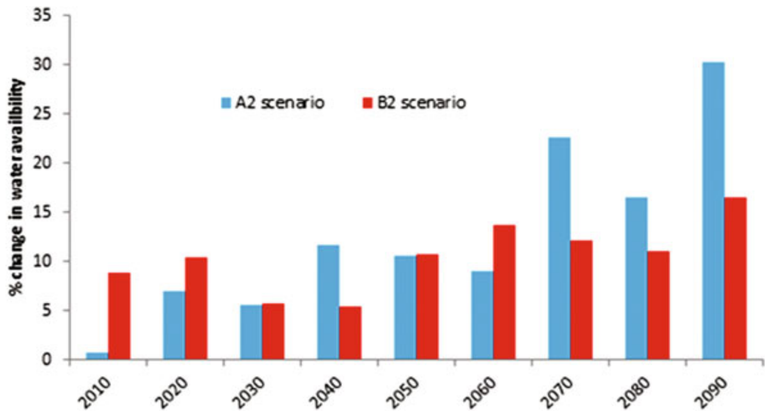

Fig. 2.7 Projected percent change in decadal water availability at national level for A2 and B2 scenarios in case of dry season

for the higher stream flow generation. For instance the stream flow generated for dry season follows similar trend as that of Chao Phraya and Mae Khong HRUs. Similarly for wet season the water availability trend follows similar as that of Mae Klong and Southern basin group HRUs.

2.5 Conclusions

The present study examines the future water availability for Thailand grouped at different HRU and national scale under two different climate change scenarios. The outputs of PRECIS RCM were selected to construct the climate change scenarios for the study area. A comparison of raw RCM outputs and bias correction results suggest the future climate data can be significantly corrected by ratio method of bias correction. Further, bias correction of results illustrates Mae Kok, Bang Pakong, Mae Khong and Southern basin HRUs are expected to have an increase in precipitation ranging from 21.4 to 37.8 % and 15.4 to 30.6 % for A2 and B2 scenarios respectively considering both dry and wet seasons by 2080s. Hydrological model simulation suggests that for both scenarios and seasons; all HRUs show similar trend except for Mae Klong, Bang Pakong, Western and Southern HRUs where dry season indicates different trend relative to that of wet period. Although, in all cases the extreme water availability is observed in 2080s ranging from −7 to 47 % and −17.8 to 54 % for wet and dry periods respectively relative to baseline period. The national level water availability varies from −5.5 % in 2020s to +13 % 2090s and +1 % in 2010s to +29 % in 2080s. The increasing trend of water availability indicates better water management plan for the increased risks of flood in the nation.

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