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Assessment of hydrologic variations under climate change scenarios using fully-distributed hydrological model in Huai Luang Watershed, Thailand

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Abstract

Huai Luang Watershed is mostly covered by agriculture area and the most population work on farm. The water is an essential factor to support communities in the watershed. Recently in Huai Luang watershed has faced serious problems on water resources such as drought and flood event. Water is a medium that is very vulnerable to the impact of climate changes. Therefore, the objective of the research was to evaluate the effect of climate changes on hydrologic variation in Huai Luang Watershed. This research utilized MIKE SHE for fully distributed hydrological model and coupled with MIKE 11 to model water cycle in watershed. This study used observed streamflow data from Kh.103 station for calibration and validation model. The models were calibrated from the period of 1 January 2004 to 31 December 2006 and validated 1 January 2011 to 31 December 2013. The calibration and validation results indicated agreement between observed and simulated data. The R^2, NSE, PBIAS, and RSR values of calibration of daily streamflow were 0.60, 0.53, 5.34, and 0.69 respectively. Meanwhile validation period resulted better performance (R^2 = 0.70, NSE = 0.68, PBIAS = -4.13, and RSR = 0.57) than calibration. After Model was developed, then the impacts of climate changes on the watershed response were evaluated using MIKE SHE Model in order to determine the quantities of water resources in 30 years past (1986-2015) and 30 years (2021-2050) later. Eventually, the results showed that the annual actual evapotranspiration has decreased significantly. The increase of overland flow quantity in future projection was tied by the decrease of actual evapotranspiration. Meanwhile, water in unsaturated and saturated zone of historic and future period were not significant changes. It can be safely said that climate changes in watershed do not significantly influence water resources in unsaturated and saturated zone.

Keywords: Climate changes, Water balance, Water resources, MIKE SHE model, MIKE 11 model

1. Introduction

Huai Luang Watershed is a socioeconomic area specially in Udon Thani Province, Northeast of Thailand. Based on the land use map in 2008 from the Land Development Department of Thailand, the watershed was dominated by agriculture 68 % of the total area. Population in Huai Luang Watershed mostly work as farmers. Its inhabitants farm by using rainwater and irrigation systems. The most widely grown crops are rice, cassava, sugar cane, and plantations. Nevertheless, the problem of land use conversion in the upstream area, communities moving and cultivation pattern around Huai Luang River has grown rapidly [1].

The climate changes have become major issues affecting water resources condition in the Huai Luang Watershed. Huai Luang River is water resources to supply water to farming region. In any case, however water supply is insufficient, consequently occurs drought event [2]. In opposite, flood event occurs frequently in urban area [3]. Huai Luang Watershed has also showed a significant increase in annual rainfall erosivity. The increase in rainfall erosivity may have significant effects on soil erosion and water storage in the watershed [4, 5]. The developed climate scenarios have assessed that the climate change issues will affect rice harvest and the other crops in Huai Luang Watershed [6].

The Huai Luang Watershed have showed the climate variation trend in term of an increasing rainfall by 20% during 32 years recently from 1982-2013[7]. In Huai Luang Watershed, the potential impact on only water in saturated zone has been assessed by using a set of numerical models (HELP3 and SEAWAT) and the result have shown, all future climate conditions, that the depths of the groundwater water table are projected to continuously increase [5]. This change trend possibly will affect water resources condition in Huai Luang Watershed.

As agriculture area, water is the essential medium which can be influenced by climate change. The climate change will affect all storages of water resources. The movement of water between those storages in different stages takes a vital role in climate change issue [8, 9]. In the water cycle system, the rainfall reaches land surface and infiltrates into the soil after wetting vegetation or canopy. After the soil gets saturation and the rest of water reaches deeper layer (percolation) gradually and eventually reaches the saturated zone [10]. In the air, water vapor as storage takes an important part in Earth's energy balance and controls the Earth's climate change fundamentally [11].

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Nowadays there are many hydrological models that have developed and existed. A hydrological model is a simplification of a real-world system that help in understanding, predicting, evaluating and managing water resources in watershed area [12]. The hydrological model types are categorized as lumped model, semi-distributed model, and distributed model [13]. A lumped model is a model that generally assume a watershed at an observation point (e.g., the HBV model) [14], meanwhile semi-distributed model is referred to a model which divides watershed into hydrologic response units (e.g. SWAT Model) [15, 16]. The other model is fully-distributed model that creates watershed in grids (e.g. MIKE SHE Model) and can use experimental data at each grid [17].

Several researchers have reviewed several hydrological models and found that SWAT, MIKE SHE, HSPF, DWSM, AnnAGNPS, and AGNPS could simulate all components of water resources components [18]. In general, MIKE SHE and SWAT showed better performances when compared with other models. The other researchers have also evaluated three hydrological distributed watershed models: MIKE SHE, APEX, SWAT [19]. The result shows that MIKE SHE Model (fully-distributed hydrological model) was more accurate than that simulated by either the SWAT or the APEX model in an area dominated by agriculture area.

This research utilized a fully-distributed hydrological model-MIKE SHE Model and coupled with MIKE 11 to model all components water resources in Huai Luang Watershed. This model is appropriate to be applied in purpose to show accurate and integrated result in Huai Luang area mostly covered by agriculture area. MIKE SHE Model can describe processes based on physical meaning and can simulate the complete hydrological processes of integrated surface and groundwater [20].

As a physically based model, MIKE SHE Model relies upon physical laws of nature and representative data from the site undergoing hydrological model [21]. MIKE SHE Model is classified as fully-distributed hydrological model. MIKE SHE Model can divide watershed into elementary units (i.e. areas are divided as a grid net where water flows from one grid point to another when water drains through the watershed) [22].

The ultimate goal of this research is to evaluate water resources on climate changes in Huay Luang Watershed, Thailand. The evaluation would be particularly focused on various changes in rainfall, actual evapotranspiration (AE), overland flow (OL), water in unsaturated zone (UZ), and water in saturated zone (SZ). The outcomes of this research will contribute in providing information on planning and management of water resources in Huai Luang Watershed.

2. Materials and methods

The basic data requirements to build and run a MIKE SHE Model depend on the purpose of the research that must be made between conceptualization and the practicality of simulation time. In this research, land use (baseline year in 2012), Digital Elevation Model (DEM), soil distribution, rainfall and the other meteorological data are the basic model data required in applying MIKE SHE Model. Rainfall and meteorological data for baseline period (1986-2015) were collected from seven rainfall stations and one meteorological station. Meanwhile a projected land use data used in this study has been projected for a year of 2029 and rainfall and meteorological data (2021-2050) were derived from Intergovernmental Panel on Climate Change (IPCC) filed in AR5 documents. After the development of MIKE SHE Model was done, it could simulate the condition of water resource for baseline (1986-2015) and future scenario (2021-2050). The flow chart of the methodology (Figure 1) was designed to guide the ultimate goal of this study. The detail of input and output data involved to this study is shown in the flow chart of the methodology.

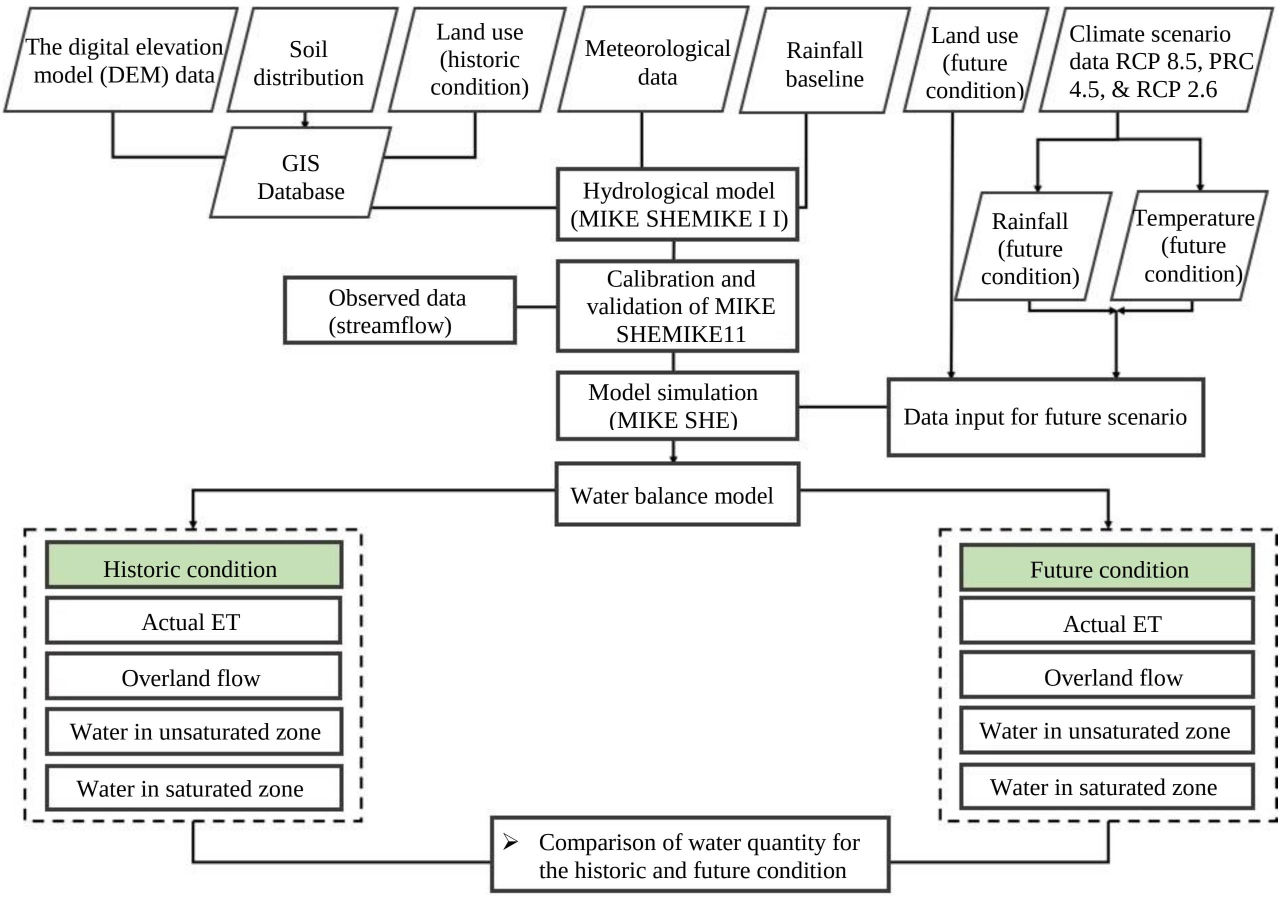

Figure 1 The flow chart of methodology

2.1 Description of the study area

This study area belongs to Huai Luang Watershed which is the sub basin of Mekong basin. The Huai Luang watershed is located in Northeast Thailand (Figure 2). The watershed, including Huai Dan Sub-watershed, drains an area of 4110.17 km^2. The area covers Udon Thani, Nong Bua Lam Phu and Nong Kai Provinces. The elevation of the watershed ranges from 87 to 638 m above mean sea level. With a length of 149.7 km, Huai Luang Watershed originates in Phu Phan Mountains, passes through Udon Thani city, and joins the Mekong River in Phonpisai District, Nong Kai Province.

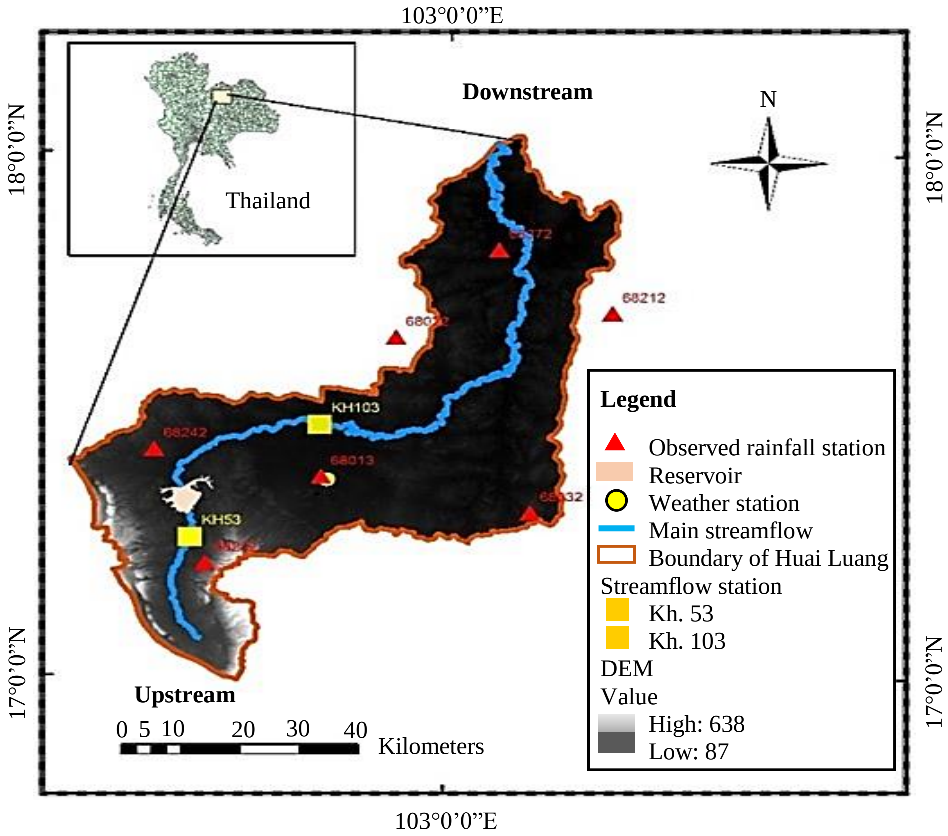

Figure 2 Huai Luang Watershed

2.2 Hydrological model

However, in developing hydrological model, it must be referring to the basic concept of hydrological model. The hydrological balance equation is based on the principles of conservation of mass in a closed system: any change in the water content of a given soil volume during a specified period must be equal to the difference between the amount of water added to the soil volume and the amount of water withdrawn from it. In its simplest form, the hydrological balance of a catchment is described by the equation [23]:

$$\text{IN} = \text{OUT} \pm \Delta S \qquad (1)$$

Where;

IN: Water inflow to the hydrological unit;

OUT: Water outflow from the hydrological unit;

ΔS: Change in storage within the selected hydrological unit.

The concept of hydrological balance will be used by hydrological models to simulate water cycle in watershed scale. MIKE SHE model is a hydrological model which has advanced and flexible system. MIKE SHE model has a set of equipment of pre- and post-processing devices, and simple solution techniques for simulating water movement in the watershed. The MIKE SHE model includes the major water movement processes covering actual evapotranspiration, overland flow, water flow in unsaturated and saturated zone, and their interactions of each components. The water movement processes can be simulated at any levels of spatial distribution, and MIKE SHE model can be adjusted based on the aims of study. The MIKE SHE model will be allowing the user to develop the model description according to the user's conceptual model of the basin [24].

Thus, the MIKE SHE model could be connected to river modelling (MIKE 11) to help modelling water flow in channel or river accurately. The computational core of MIKE 11 model is a hydrodynamic simulation engine. MIKE 11 model is a fully dynamic and one-dimensional modelling package. MIKE 11 model includes complete tool to simulate complexity of river flow in a watershed.

This research used MIKE SHE Model and coupled by MIKE 11 Model to particularly calculate every component of the water resources. The research developed a coupled MIKE SHE/MIKE 11 model applied for Huai Luang Watershed. MIKE 11 channel connections coupled with adjacent MIKE SHE Grid. The link of MIKE SHE and MIKE 11 Model is determined automatically by point coordinates of the river channel which defined by hydrodynamic model of MIKE 11. Links are only defined at the coupling reach in the hydrodynamic model. Although MIKE 11 is taken for building a complete river model, and MIKE SHE only has water exchange in coupling reach yet coupling of MIKE SHE and MIKE 11 Model is completely dynamic [25].

2.3 Watershed discretization

The digital elevation model (DEM) used is 30 m x 30 m resolution. The grid cell was constructed using grid squares of 90 m for running the MIKE SHE Model. The reason using cell size 90 was to reduce model time running model because Huai Luang has a large area of watershed (4110.17 km^2).

2.4 Simulation time steps

For efficient simulation the overland time step is always less than or equal to the unsaturated zone time step, and the UZ time step is always less than or equal to the saturated zone time step [26]. In this study, maximum allowed OL steps was 1 hour, 6 hours for UZ, and 12 hours for SZ. Meanwhile the MIKE 11 model for Channel flow was 2 minutes.

2.5 Land use

Land use data was not directly applied to MIKE SHE Model. Land use data determined the specific parameters of vegetation in the model. In this study, Land use of 2012 was used for running MIKE SHE Model in baseline period and land use scenario of 2029 was used to run future scenarios period.

In running long term of historic and future scenarios, simply LAI was applied to run hydrological modelling using LAI of 2008. LAI of 2008 can represent all of periods due to classified to normal year. Average LAI value of 2008 is graphed in Figure 3.

Land use data was needed to generate Leaf Area Index (LAI) distribution by using platform of Google Earth Engine. As graph in Figure 3, LAI that was retrieved from platform is The MCD15A3H version 6 MODIS Level 4, Combined Fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI) product is a 4-day composite data set.

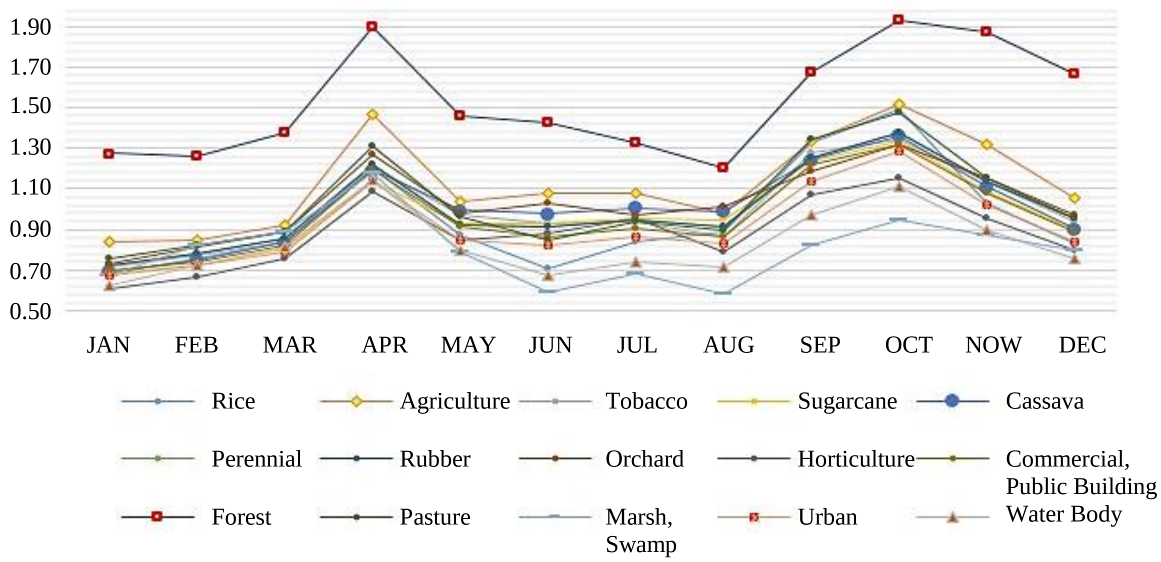

Figure 3 Leaf area index (year of 2008)

The LAI value followed the pattern of wet and dry season. The higher LAI occurred in wet season during September, October, and November and also in April. The LAI value significantly decreased on the other months (dry season) such as January, February, March, May, Jun, July, and August.

LAI is defined as the one-sided green leaf area per unit ground area in broad leaf canopies and as one-half the total needle surface area per unit ground area in coniferous canopies. FPAR is defined as the fraction of incident photosynthetically active radiation (400-700nm) absorbed by the green elements of a vegetation canopy [27].

Besides to retrieve LAI data, Land use information also made modeller easier to calibrate manning parameter (overland flow) for distributed value. MIKE SHE and MIKE 11 model use the Manning M is equivalent to the Stickler roughness coefficient.

2.6 Soil distribution

Soil distribution in Figure 4 was used for modeling the movement of water through soil layers. In Huai Luang Watershed, there are seven soil types (Clay, Clay Loam, Loam, Loamy Sand, Sandy Loam, Silt Loam, and Silty Clay). Every soil type has differences in soil texture, hydraulic conductivity, and specific yield and specific storage. Soil types in Huai Luang Watershed are the most covered by sandy loam approximately 94.99% of total area so that can help to simplify calibrated parameters.

2.7 Rainfall and temperature

The coupled MIKE SHE and MIKE 11 Model required climatic input data (such as rainfall and temperature). Rainfall and meteorological data for baseline period was collected from seven rainfall stations and one meteorological station within Huay luang Watershed. Air temperature and the others meteorological (wind speed and humidity) data were collected from Udon Meteorology station in Huai Luang Watershed. ETref (Reference Evapotranspiration) was calculated using the FAO modified Penman-Montieth method. Wind speed, minimum and maximum temperature and minimum and maximum relative humidity were input for the computation of ETref using ETref Calculator with version 3.2.

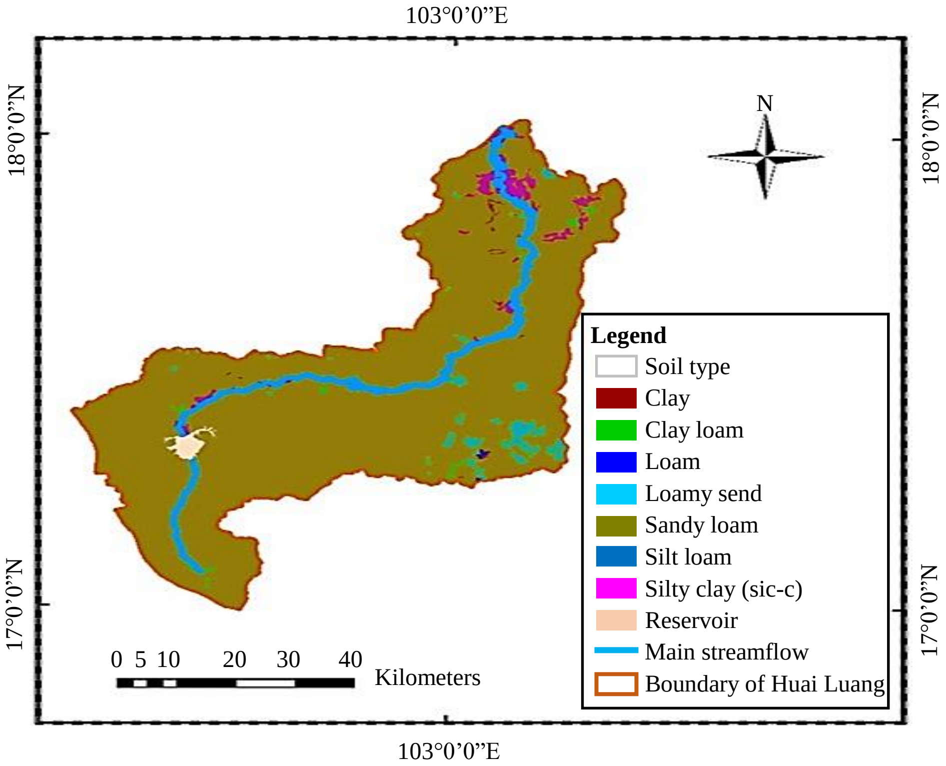

Figure 4 Soil type distribution in Huai Luang Watershed

In order to evaluate the effects of climate change on water resources in Huai Luang Watershed, further studies regarding climate change must be conducted. Climate change predictions are based on the IPCC's Fifth Assessment Report (AR5) that provides RCPs (Representative Concentration Pathways) documents. RCPs documents are developed by the regional circulation model (RCM).

In this study, RCPs were developed by CNRM-CM5 Model. CNRM-CM5 is an earth system model designed to run climate simulations. These plausible scenarios of climate change are developed based on trends and information from the area. CNRM-CM5 is the future global IPCC AR5 developed by the Center National de Researches Meteorologiques, the coordinates are 1° x 1° at latitude 42° or 1,875° x. 0.9375° at latitude 31° [28].

CNRM-CM5 product was selected based on availability, continuity, no missing data, and corrected bias in every scenario packages. CNRM-CM5 Model has developed four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). RCPs are intended to represent radiative forcing target level in 2100 increasing from pre-industrial era. The radiative is based on greenhouse gases concentration and other forcing agents [29]. Three RCPs of four RCPs available were used in this study namely RCP2.6 (relatively low radiative forcing), RCP4.5 (mean radiative forcing), and RCP8.5 (very high radiative forcing). These 3 selected scenarios are expected to give contrast value meanwhile RCP6.0 (high radiative forcing) value can slightly be represented by RCP 8.5 for this study.

Before climate data input into hydrological model, the data need to downscaling. Scaling of the climate data to correct the mean bias of the modeled climate is the simplest form of data correction. A ratio of the mean monthly sums of the observed and modeled data is determined and then used to scale the modelled data at each time step [30].

The concerned time of the climate change study was divided into 2 periods: past (1986-2015) depicted in Figure 5 and 6, and future (2021-2050) depicted in Figure 7 and 8. Rainfall and temperature of future scenario using RCP8.5, RCP4.5 and RCP2.6 were used to input data into MIKE SHE Model for future scenarios. Reference evapotranspiration of future period was estimated using minimum and maximum temperature and constant wind speed (2 m/s). When there is no wind data available for future period within a watershed, a temporary estimation value of 2 m/s can be assumed as initial.

2.8 Unsaturated Zone (UZ)

Unsaturated flow in MIKE SHE Model is calculated by vertically in one-dimension, which is sufficient for most applications. In this study, MIKE SHE Model applied the full Richards equation method. Once the unsaturated zone flow is selected for running water movement by using the Richards equation method, then the maximum time step of water flow in unsaturated zone is normally ranged from 0.5 to 2 hours. Otherwise, a maximum time step of the unsaturated zone flow is equal to the time step of saturated zone flow often works [31]. There was the important parameter which should be concerned in calibration to calibrate Model such a hydraulic conductivity in unsaturated zone. In order to apply MIKE SHE Model in Huang Luang Watershed, it can generally consider sandy loam as soil distribution in study area because sandy loam soil type cover approximately 94.99 % of total area.

2.9 Saturated Zone (SZ)

The parameters needed to calibrate water flow in saturated zone were horizontal and vertical hydraulic conductivities, specific yield, and storage coefficient. The hydraulic conductivity is a function of the soil texture and determine the ease of water can flow through the soil. The hydraulic conductivity in horizontal direction is normally 5 to 10 times higher than the hydraulic conductivity in vertical direction. In an unconfined aquifer, the specific yield defines the volume of water released per unit surface area of aquifer per unit decline in head. The specific yield is much higher than the specific storage because the water that is released is primarily from the dewatering of the pores at the water table [24].

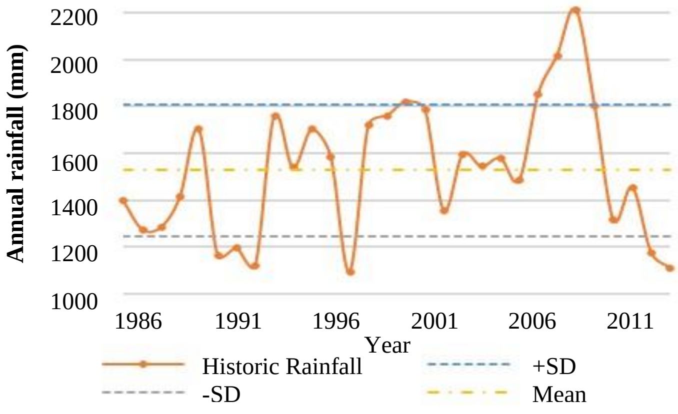

Figure 5 The annual rainfall for the historic period

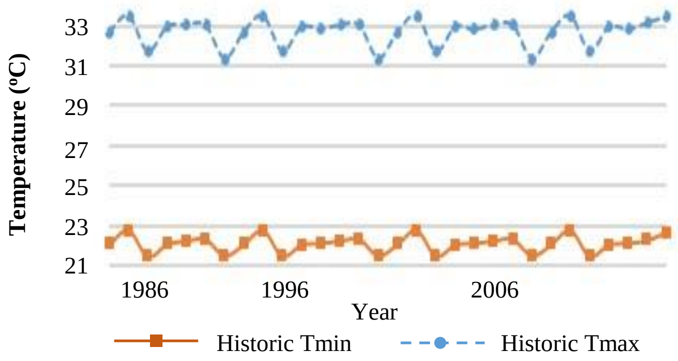

Figure 6 Average annual min and max T of historic period

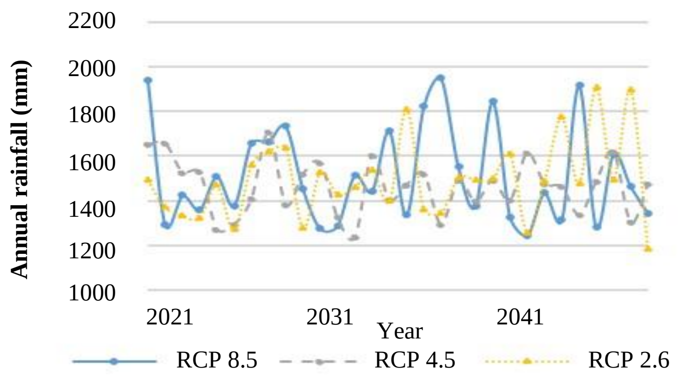

Figure 7 The annual rainfall for the RCPs scenarios

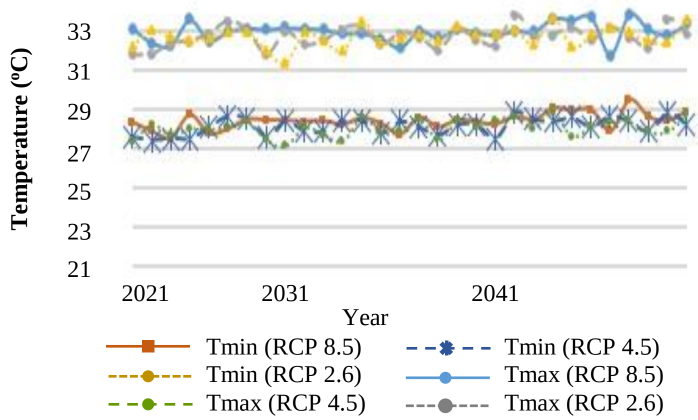

Figure 8 Average annual min and max T of future scenarios period

2.10 Overland flow

The finite difference method was chosen in the model simulation, the basic parameter required for the simulation of overland flow are Manning number and detention storage. The Manning M is the inverse of the commonly used Manning n. Type of the Manning number M data used in MIKE SHE model is spatial distribution for a whole watershed area.

Manning number M can dominantly modify routing overland flow or runoff towards the river flow. If Manning M is higher values, so that water will be flowing with faster movement toward Main River. Another parameter which influences for overland flow is detention storage which significantly affects routing water towards the streamflow and water table in unsaturated zone. Large values of detention storage can reduce the runoff flowing into the river, meanwhile the increase of ponding water that may increase water table level [32].

2.11 River flow

Based on available data and condition in Huai Luang Watershed, it needed to develop MIKE SHE Model coupled with MIKE 11. The coupling model was created in purpose of calibration works. The initial step of MIKE SHE Model coupled to MIKE 11 model is to develop a MIKE 11 HD model with working separately with MIKE SHE Model. Then, MIKE SHE model was coupled with MIKE 11 model by creating main river networks in which MIKE 11 HD must interact or exchange water with MIKE SHE Model.

MIKE 11 Model was coupled to simulate streamflow or river flow only during calibration works. MIKE SHE Model was to calculate runoff meanwhile the streamflow can accurately be calculated by MIKE 11. MIKE 11 is a model which is a 1-dimensional river model. After coupled model (MIKE SHE-MIKE 11) performed well, MIKE 11 Model was taken off from a coupling package. Then the runoff and other storages for the whole watershed was only simulated by MIKE SHE Model.

In building up MIKE 11, the model needed the input file such as river network, cross-sections, boundary data, and hydrodynamic parameter. River network was input into MIKE 11 as shapefile data. Cross-sections of river was observed for 250 points in along Huai Luang River started from outlet of reservoir until downstream Huai Luang River as shown in Figure 9.

When MIKE SHE and MIKE 11 Model were coupled, cross sections were specified for each branch along the MIKE 11 river network. However, there are not all stream network in Huai Luang Watershed having cross section data so that the coupling MIKE SHE and MIKE 11 was only applied in Huai Luang River after reservoir to downstream as shown in Figure 9. Therefore, the coupling MIKE SHE and MIKE 11 for an entire watershed can be still developed technically by defining the upstream boundary in MIKE 11 Model and it must be added outflow discharge of reservoir as initial water flow from upstream. This technique has solved problem of not having data cross section in upstream river.

In the hydrodynamic model, every node in the river network must be input the river hydraulics data, such as cross-section of river and river bed roughness. Halfway between each H-point is a Storing Q-point. This position is where MIKE 11 calculates the simulated flow in river, which must be constant between the H-points. Simulated streamflow in MIKE 11 was calculated at chainage 44739.7 for calibration compared with observed streamflow station (Kh.103).

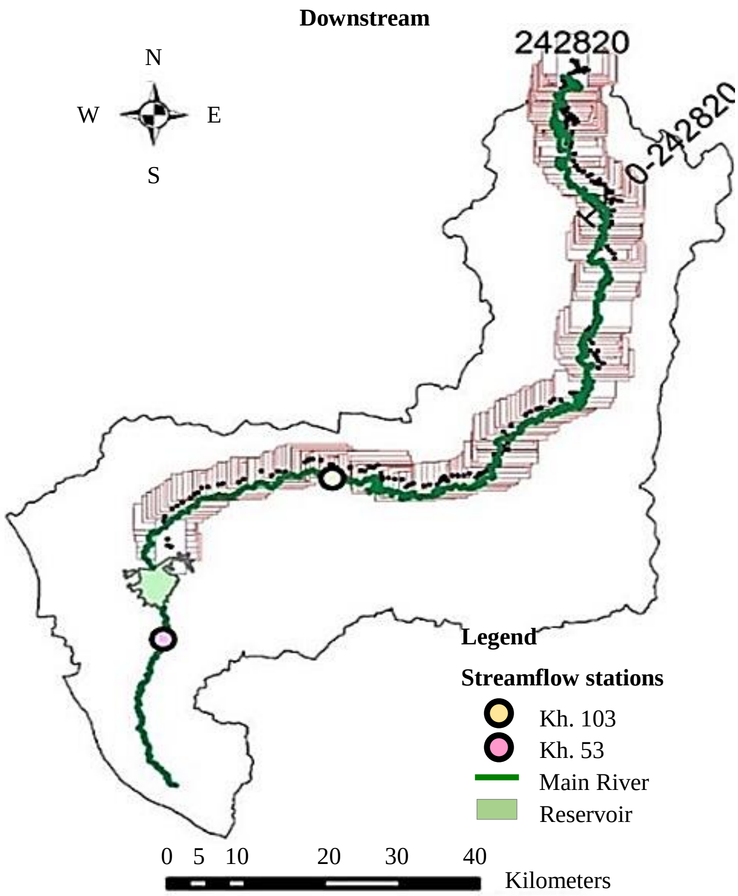

Figure 9 MIKE 11 cross-section of Huai Luang River

2.12 Performance evaluation methods

Theoretically, the parameters for a physically distributed hydrological model can all be calculated in the field. However, calibration is often required to better reproduce the measured watershed variables and to improve the simulation results because measured values may not always be available. The criteria used to evaluate model performance is the overall agreement between predicted and measured data. The following statistical steps will be used to measure the accuracy of model performance during the simulation periods.

In addition, Correlation Coefficient (R^2), Nash and Sutcliffe Efficiency Coefficient (NSE), Percent Bias (PBIAS), and RMSE-observations standard deviation ratio (RSR) are the basic comparison statistics. In general, that model performance can be judged "satisfactory" for watershed-scale models daily, monthly, or annual $R^2 > 0.60$, NSE > 0.50, and PBIAS $\leq \pm 15\%$ [33].

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}}\right] \quad 0 \leq R^2 \leq 1 \tag{2}$$

$$NSE = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \tag{3}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S) \times 100}{\sum_{i=1}^{n}(O_i)}\right] \tag{4}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}}\right] \tag{5}$$

3. Results and discussions

3.1 Model calibration and validation

The number of adjustable parameters during the calibration of a distributed hydrological model such as MIKE SHE should be as small as possible [34]. The purpose of calibration and validation is to compare simulated hydrographs and observed hydrograph in water catchment.

This study used observed streamflow data for calibration and validation. The observed streamflow data of Kh.103 station was used for calibration and validation. The model was calibrated for the period of 1 January 2004 to 31 December 2006 and validated 1 January 2011 to 31 December 2013. The selected years for calibration and validation were considered according to available and no missing value in those periods. MIKE SHE Model is a model classified to fully-distributed model and avoided to calibrate many parameters. The selected years (2004-2006 for calibration and 2011-2013 for validation) are years which have available, continuous, and no missing data for every input data.

The model calibration was done by manual and automatic method. First, auto-calibration was run to reduce range/error of every parameter value and to estimate the possible max and min value. In advance, Auto-calibration also provides also simulation options such as sensitivity and optimization parameter. Sensitivity parameter option can help to determine the most influenced parameters to hydrologic process.

Using manual trial-and-error of the calibration parameters was to figure out the best value of calibrated parameters. After running calibrations, each parameter of the hydrologic processes in running manual/auto calibration can narrow out the sensitive calibration parameters as tabulated in Table 1.

Table 1 Calibrated parameter values of MIKE SHE model in Huai Luang Watershed

Model	Components (Module)	Calibration parameters	Calibrated value
MIKE SHE	Overland flow (finite difference)	Manning number (M) or	1.7-8
		Manning number (n)	0.58-0.12
		Detention storage	30
		Initial water depth (mm)	0
	Unsaturated flow (Richard Eq.)	Sandy loam (94.99% covered by sandy loam in study area) Saturated hydraulic conductivity, (Ks in m/s)	5E-08
	Actual evapotranspiration	C_{int} (mm)	0.2
		C_1	0.3
		C_2	0.2
		C_3	20
		AROOT (1/m)	0.25
	Groundwater flow or saturated flow (finite difference)	Hydraulic conductivity horizontal K_h (m/s)	0.8E-05
		Hydraulic conductivity vertical K_v (m/s)	0.9E-05
		Specific yield	0.475
		Specific storage (1/m)	0.00576
MIKE 11	Channel flow	Leakage coefficient (1/s)	1E-005
		Manning number in channel (M) or	35
		Manning number in channel (n)	0.028

3.2 Streamflow hydrograph

The calibration and validation results indicated agreement between observed and simulated data. Table 2 and Figures 10-15 clearly indicate that both the calibration and validation periods satisfy all the statistical criteria of the daily model. R^2, NSE, PBIAS, and RSR value of calibration of daily streamflow were 0.60, 0.53, 5.34 and 0.69 respectively. Meanwhile verification period resulted better performance (R^2 = 0.70, NSE = 0.68, PBIAS = -4.13, and RSR = 0.57) than calibration. In general, this model performance can be judged "satisfactory" for watershed-scale models daily $R^2 > 0.60$, NSE > 0.50, PBIAS ≤ ±15% [33].

Table 2 Statistics performance of daily streamflow at Kh.103 station

Statistical indicators	Calibration period (2004-2006)	Validation period (2011-2013)
R^2	0.60	0.70
NSE	0.53	0.68
PBIAS	5.34	-4.13
RSR	0.69	0.57

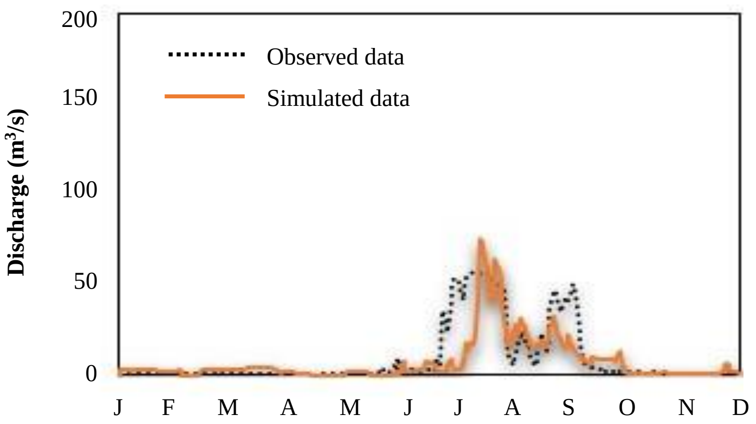

Figure 10 Observed and simulated daily streamflow for the calibration period of 2004

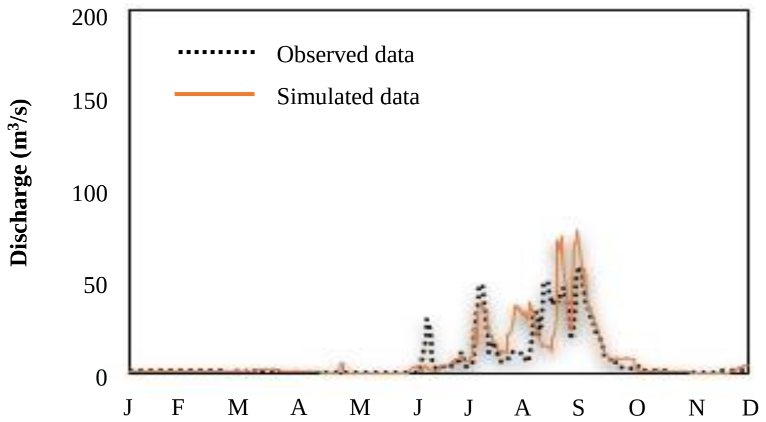

Figure 11 Observed and simulated daily streamflow for the calibration period of 2005

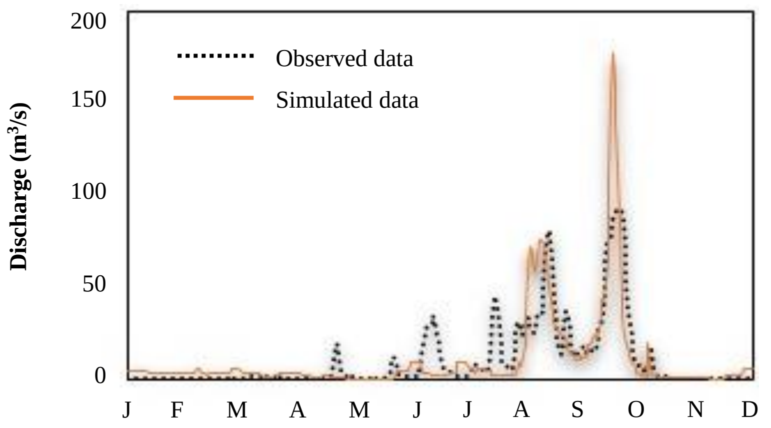

Figure 12 Observed and simulated daily streamflow for the calibration period of 2006

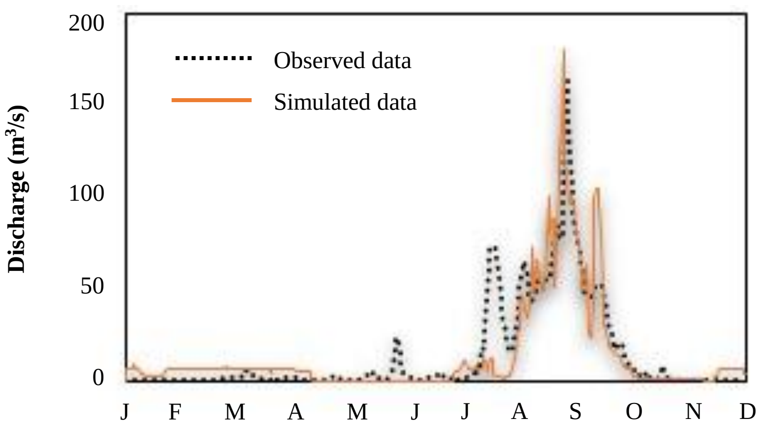

Figure 13 Observed and simulated daily streamflow for the validation period of 2011

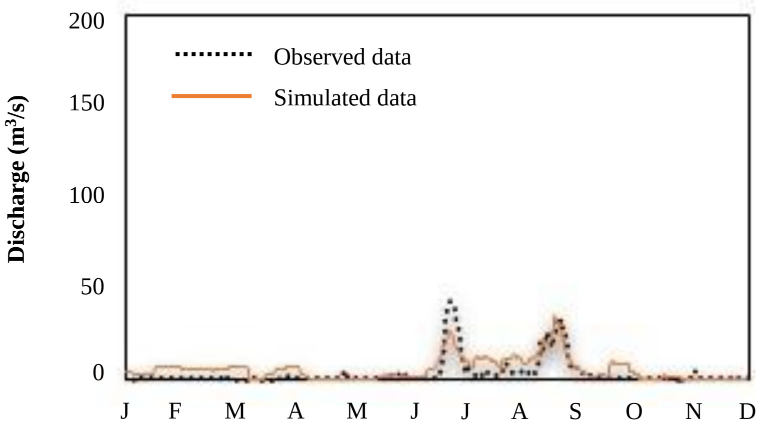

Figure 14 Observed and simulated daily streamflow for the validation period of 2012

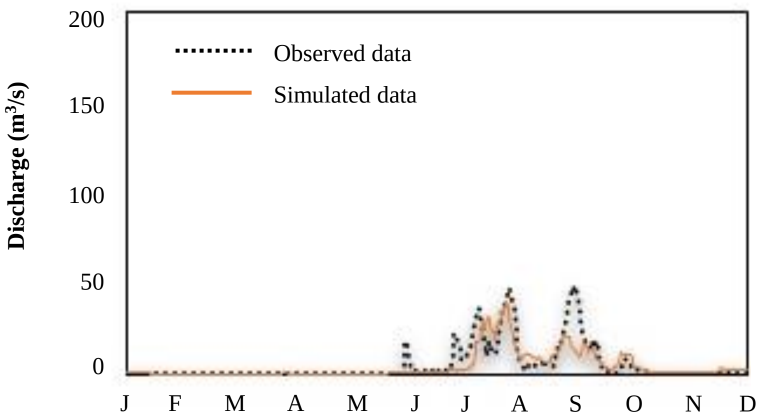

Figure 15 Observed and simulated daily streamflow for the validation period of 2013

3.3 Water balance

The water balance utility is a post-processing tool for generating water balance summaries from MIKE SHE simulations. Water balance output can include area normalized flows (storage depths), storage changes, and model errors for individual model components (e.g., unsaturated zone, saturated zone, overland flow, evapotranspiration, etc.) [31].

The results show that most of the rainfall is returned to the air through ET losses representing a big portion of the total rainfall during calibration and validation periods. Meanwhile the amount of base flow and overland flow which flow to river cannot be calculated for the whole river because the MIKE SHE and MIKE 11 model was only connected with a part of Huai Luang Watershed just from the reservoir outlet to the downstream of Huai Luang River.

Table 3 shows that the overall model has been calibrated and validated properly which was confirmed with the water balance error about-0.02% (both of calibration and validation periods). The water balance error was obtained by balancing all the major hydrological components simulated in the model including rainfall, actual evapotranspiration, runoff and changes in the other storages. This error was then divided by the total rainfall and presented as a percentage error [26].

Table 3 Water balance summary of Huai Luang Watershed

Components (*along main river after reservoir to downstream)	Calibration			Validation		
	2004	2005	2006	2011	2012	2013
	mm	mm	mm	mm	mm	mm
Rainfall	1,595	1,543	1,578	1,803	1,315	1,455
OL-storage change	438	222	126	548	65	119
UZ-Storage change	-36	32	-4	-1	-7	26
OL to river*	86	241	318	178	83	153
Actual ET	1,051	1,005	1,112	1,019	1,149	1,122
OL-boundary outflow	9	11	13	12	4	7
SZ-storage change	23	5	0	27	-1	6
Base flow to river*	20	23	21	212	21	22
River to base flow *	0	0	0	0	0	0
SZ-infiltration incl. Evap	319	342	356	373	278	321
SZ-exfiltration incl Evap	362	371	356	421	298	340
Total error	-5	-3	6	1	-1	0

The small water balance errors show that overall developed model has run well for all storages of water resources and its interaction between the storages. The result of water balance error also gives the confident in running model not only in calibration and validation period, but also for long term period (1986-2015 and 2021-2050). The model running was conducted by three scenario simulations. The first simulation, the model run hydrology cycle from 1986 to 2015 and 2021-2050 with RCP8.5 scenario resulted error -3.59%. The second simulation, the model run hydrology cycle from 1986 to 2015 and 2021-2050 with RCP4.5 scenario resulted error -3.43%. The last simulation was conducted from 1986 to 2015 and 2021-2050 with RCP2.6 scenario resulted -3.37%. The small error of water balance indicates a good model performance.

3.4 Effect of climate change on AE (Actual Evapotranspiration)

The simulated actual AE values of the historic and future scenarios have been calculated. The minimum and maximum annual AE of baseline period were 893 mm occurred in 1992 and 1233 mm in 1996. The average annual AE was approximately 1,079.37 mm of baseline period and standard deviation was ±75.85 mm. Meanwhile in future scenarios, the minimum and maximum annual AE for RCP8.5, RCP4.5 and RCP2.6 Scenarios varied 667 mm ─ 863 mm, 701 mm ─ 867 mm, and 703 mm ─ 864 mm respectively. The average annual AE for RCP8.5, RCP4.5 and RCP2.6 scenarios were 793.93 mm, 811.33 mm, and 798.50 mm.

The results **(**Figure 16 and 17**)** showed that in 30 years later, the annual AE has decreased significantly. The results of the simulated AE can influence significant changes of the whole hydrological balance. The calculation of AE is simply the total of the evaporation from canopy storage, the transpiration from the plants and evaporation from soil surface.

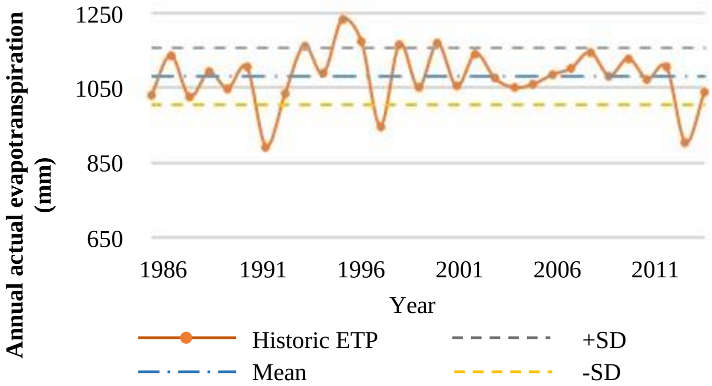

Figure 16 The annual actual evapotranspiration for the historic period (1986-2015)

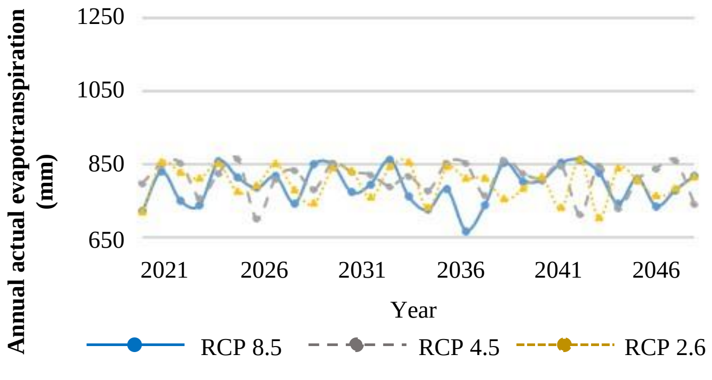

Figure 17 The annual evapotranspiration for the RCPs scenario (2021-2050)

3.5 Effect of climate change on overland storage change (OL-storage change)

As result, changes in climate change term can lead to larger relative impacts on overland storage change (OL-storage change) compared to baseline data and all future scenarios. According to Figure 18 and Figure 19, the minimum and maximum of annual OL-storage change from rainfall with baseline data, RCP8.5, RCP4.5, and RCP2.6 scenarios were 46 mm ─ 896 mm, 170 mm ─ 983 mm, 96 mm ─ 711 mm, and 97 mm ─ 913 mm respectively. The average of annual OL-storage change from rainfall with baseline data, RCP8.5, RCP4.5, and RCP2.6 scenarios valued around 367.73 mm, 491.70 mm, 405.10 mm, and 432.33 mm respectively.

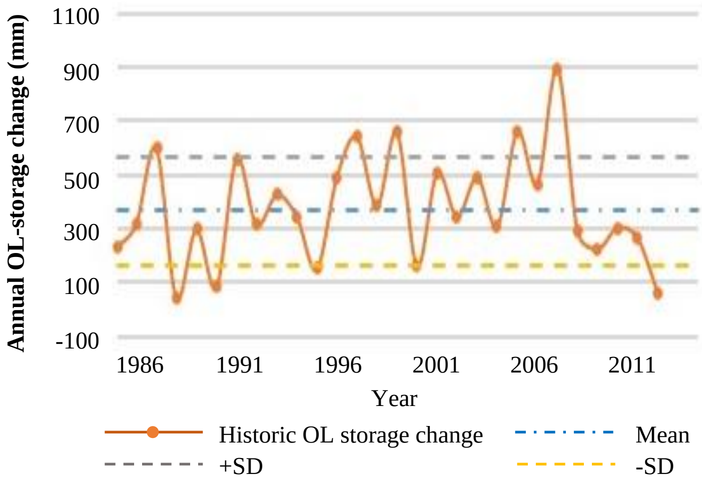

Figure 18 The annual overland storage change for the historic period (1986-2015)

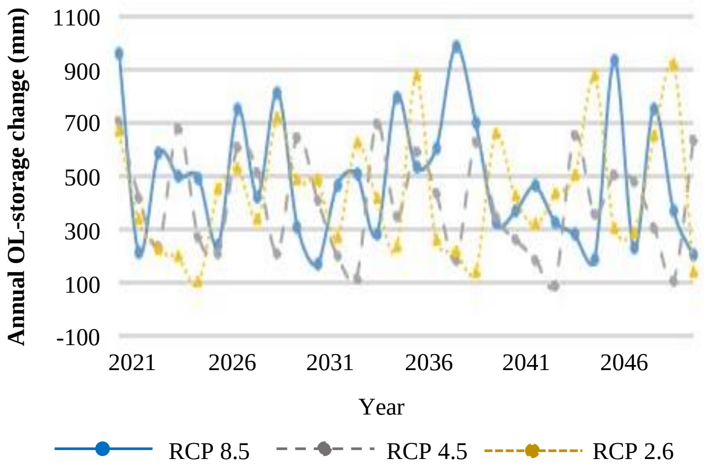

Figure 19 The annual overland storage change for the RCPs scenario (2021-2050)

The increasing change of OL-storage in future projection was strongly tied by the decrease of actual evapotranspiration. The actual evapotranspiration and overland storage are water balance components which are located on ground surface. The actual evapotranspiration and overland storage have a strong correlation. The actual evapotranspiration in baseline period resulted higher quantity than in future scenarios period and resulted the lower quantity of the annual overland storage change in baseline period than future scenarios period.

In this research, the land use data was the main factor to calibrate Manning Number (M) as the sensitive parameter of overland flow calculation. The conversion of land use in Huai Luang Watershed adjusted characteristics of over land flow. The value of Manning M normally ranges of 100 (smooth channels) to 0 (thickly vegetated river).

These findings are generally similar to previous studies as shown in Figure 18 and 19. Particularly rainfall with increasing rainfall intensity yielded high quantities of total runoff [35]. While the annual rainfall and overland flow both show an increasing trend, and the increasing trend of overland flow is more obvious. Conversely, the actual evapotranspiration and temperature present a decreasing trend [36]. An increasing trend of overland flow in future projection was caused by the two main factors. The rainfall and temperature variation are the essential two parameters of climate change that varied change in overland flow [37].

3.6 Effect of climate change on unsaturated zone storage change

Unsaturated Zone Storage Change (UZ-Storage change) which was undertaken from rainfall took smaller part than OL-storage change and actual evapotranspiration of total rainfall. In Figure 20 and 21, the minimum and maximum annual amount of UZ-storage change in baseline, RCP8.5, RCP4.5, and RCP2.6 scenarios ranged -53 mm ─ 29 mm, -38 mm ─ 36 mm, -12 mm ─ 19 mm, and -33 mm ─ 34 mm respectively.

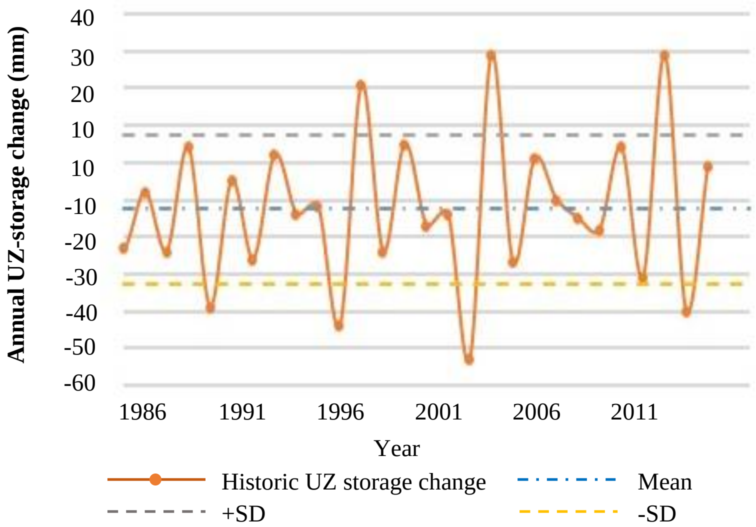

Figure 20 The annual UZ-Storage change for the historic period (1986-2015)

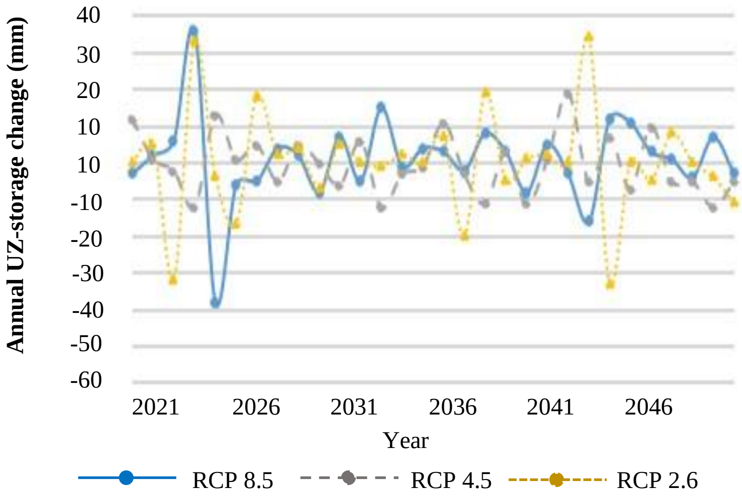

Figure 21 The annual UZ-Storage change for the RCPs scenario (2021-2050)

In the baseline period, the average annual amount of UZ-storage change valued -12.60 mm and future scenarios based on RCP8.5 valued from 0.90 mm, RCP4.5 valued -0.37 mm, and RCP2.6 valued 0.03 mm. The baseline UZ-Storage change and UZ-Storage change based on RCPs scenario were not significant changes. It can be safely said that climate change were not significantly influenced to UZ-Storage change.

The simulation of water in unsaturated zone was significantly influenced by soil properties. Soil properties (e.g. porosity, water holding capacity, and hydraulic conductivity) vary significantly with time because of vegetation growth [38]. In this study, the canopy followed vegetation dynamics by Leaf Area Index data so that feed the dynamic effect of vegetation because of vegetation growth.

Vegetation types also influence the soil moisture dynamics in calculation of water in unsaturated zone. The change of vegetation types in the study area could therefore give a conceivable adaptation measure towards anticipated changes in hydrological conditions [39].

3.7 Effect of climate change on saturated zone storage change

According to result of running MIKE SHE Model in Figure 22 and 23 saturated zone storage change (SZ-storage change) is a component of water balance which stores storage slowly. The minimum and maximum amount of SZ-storage change in historic period were -2 mm and 36 mm. Meanwhile the minimum and maximum amount of SZ-storage change in 30 years later with RCP8.5, RCP4.5, and RCP2.6 scenarios were -7 mm ─ 59 mm, -17 mm ─ 60 mm and -36 mm ─ 74 mm respectively. The average amount of SZ-storage change was 15.13 mm in baseline period. Meanwhile in future RCP8.5, RCP4.5 and RCP2.6 scenario, water will be stored into saturated zone around 22.33 mm, 15.97 mm and 18.83 mm respectively.

The SZ-storage changes from baseline condition to future scenarios were not significant than the other component of water resources. According to Figures 22 and 23 this finding is generally similar with previous results that has been conducted by the other researchers [40]. In their findings, they assessed climate change effects on groundwater resources and revealed that a low impact of climate change on groundwater resources in the study area.

That climate change does not impact on groundwater is not entirely corrected yet the climate may indirectly influence the water resource in saturated zone by reducing recharge, discharge or even impacting on the water quality [41]. Groundwater aquifers are recharged mainly by rainfall or through interaction with surface water bodies, the direct influence of climate change on rainfall and surface water ultimately affects groundwater systems [42].

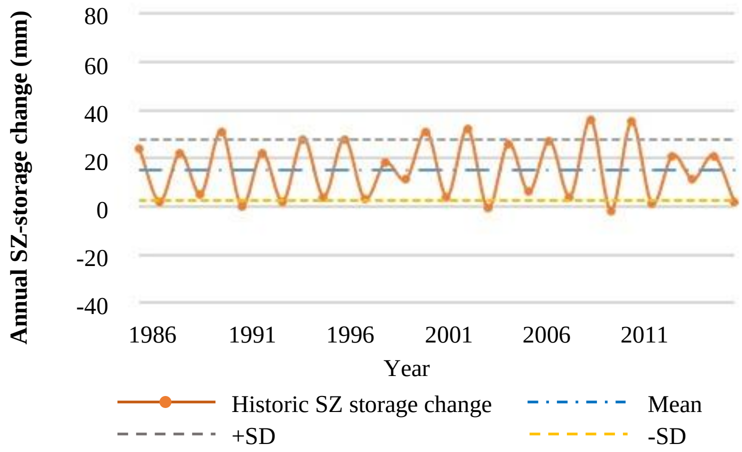

Figure 22 The annual SZ-Storage change for the historic period (1986-2015)

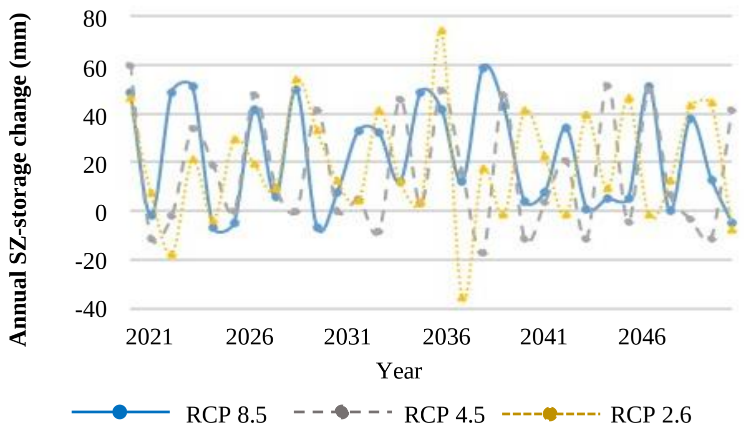

Figure 23 The annual SZ-Storage change for the RCPs scenario (2021-2050)

4. Conclusion

The focus objective of this study was to evaluate the effect of climate changes on water resources in Huai Luang Watershed, Thailand. MIKE SHE and MIKE 11 model was utilized to simulate all of water resources components. Those models were chosen over other models since it has a proven track record in a wide range. The MIKE SHE hydrological simulation model coupled with MIKE 11 has been reasonably calibrated and validated. Eventually, the results showed that in recent 30 years to 30 years later. It can be safely said that climate change was not significantly influenced to water in unsaturated zone and saturated zone. Changes in climate term can lead to larger relative impacts on OL-storage change compared to baseline data and all future scenarios. The increasing change of overland storage change in future projection was tied by the decrease of actual evapotranspiration.

5. Limitations of the study

The study in Huai Luang Watershed which relatively has large area has limited authors to extend running model for long term period (more than 30 years in past and 30 year in future scenario). A fully-distributed hydrological model will need higher capacity of laboratory computer. The authors believe that in near future the computer capacity is becoming higher and faster and the author can run long term period with this developed model to predict the water resource condition.

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