Effects of Climate Change and Land-use Change on Future Inflow to a Reservoir: A Case Study of Sirikit Dam, Upper Nan River Basin, Thailand

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ABSTRACT

Future changes of inflow to Sirikit reservoir in the Upper Nan River Basin as a result of future climate and land-use changes are predicted. Three regional climate models (RCMs) namely: ACCESS, CNRM and MPI with two Representative Concentration Pathways (RCP4.5 and RCP8.5) are used in projecting daily rainfall, maximum and minimum (extreme) temperatures for three-time periods: 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). The baseline period is from 1970-2010. The climate change projection is corrected using bias correction method with linear regression. The results show that seasonally the rainfalls in summer and winter have increasing trends for both RCPs. In rainy seasons, the rainfall has decreasing trends for both RCPs. The annual rainfall has increasing trends for RCP4.5, and decreasing trends for RCP8.5. For the annual extreme temperatures, the projections show clearly increasing trends of about 1^{o}C for RCP4.5 and 2.7 to 2.8^{o}C for RCP8.5. Generally, the projected rainfalls, extreme temperatures are in the same trends as in other researches in the same regions. A spatial dynamic model for land-use projection simulation FLUS is used to simulate and project land-use change for economic case studies and conservation case studies. In the economic case studies, the projected land-use shows the major increase in agricultural area of about 30% compared to 2016, while in conservation case studies, the largest increase is the forest area of about 27%. The inflow to the Sirikit reservoir is computed by using the hydrological model (HEC-HMS). The model is calibrated from 1999 to 2007 and validated from 2008 to 2017. The model is found to be accurate and acceptable for future projection of inflow to the dam. The future inflow is projected for both RCPs in 6 cases, i.e., cases 1 and 2 for climate change only, cases 3 and 4 for combined changes in climate and economic land-uses, and cases 5-6, for combined changes of climate and conservation land-uses respectively. Compared to the baseline, the changes of annual inflow discharge in 2080s due to climate change only are -0.11 % (RCP4.5) and -2.04% (RCP8.5); for climate change with economic land-use, they are 0.60% (RCP4.5) and -1.36% (RCP8.5); for climate change with conservation land-use, they are -1.05% (RCP4.5) and -3.07 % (RCP8.5) respectively. It is concluded that the changes of climate and land-uses are not significant under RCP4.5, hence the existing reservoir operation rules are applicable. But for RCP8.5, the change in annual inflow due to change in climate is more significant with an average decreasing trend; hence the reservoir operation should be adjusted to store more inflow in rainy seasons and release more outflow to downstream especially during drought periods in winter and summer. Further optimization studies on reservoir operation should be carried out for all the above case studies.

1. INTRODUCTION

Climate changes affect hydrological cycle and water resources management [14], [26]. They are caused by increase of anthropogenic greenhouse gas emissions around the world [15], [17], [25]. Records show an increase of 1.3% per year of greenhouse gas emissions during 1750 to 2010 and continue to increase to 43% in 2011[3], [5]. The reports from IPCC [2], [3] and [4] show

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an increase of 1.5 and 2°C on average temperature until the end of twenty-first century in Thailand [4]. The increased temperature and reduced precipitation have intensive damages to water resources and crop productivity in the future [5], [19], [26]. Consequently, climate change is a major challenge to achieve sustainable water resources management. Furthermore, urbanization, socio-economic and population growth have negatively affected water discharge volume in many large cities around the world [23], [24]. In climate change context, projected changes in rainfall in some regions may increase while they may decrease in the other regions. The change in rainfall is generally higher for Representative Concentration Pathway RCP8.5 than RCP4.5. However even in the same region, different models can give different projections. This is mainly because the current models still cannot represent all the atmospheric processes. Projected runoff will normally have a similar pattern to rainfall but sometime it may be influenced by other factors such as basin characteristics, local climatic conditions, and etc. For projected temperatures, most of the climate models clearly show a rising trend of extreme (maximum and minimum) temperatures in the future.

Many previous researches studied impact of future climate change projection on stream flow considering different greenhouse gas emission levels [12], [18], [16]. The future inflow discharge to the Bhumibol dam in the Ping River Basin and the Sirikit dam in the Nan River Basin in the central plain of Thailand [6] and the Ubolratana dam in the Pong River in the northeast of Thailand were predicted [16]. The prediction showed a reduction in the extreme temperatures and an increase in precipitation during the 21st century.The results indicated higher reservoir inflow and higher vulnerability in downstream floodplain areas. Tachikawa et al., 2013 [20] predicted that the future inflow to the Pasak dam reservoir will be reduced by 3.8% for the 2011-2040 period and by 3.5% at the end of twenty-first century respectively. This is due to decreasing of precipitation and increasing of evapotranspiration based on MPI-GCM3.1S. However, only the climate change was considered in both studies. Shrestha, 2018 [18] evaluated impacts of climate and land-use changes on hydrology and water quality. Approximately 19.5 and 24 % reduction in stream flow under RCP4.5 and 8.5 scenarios are predicted using the hydrological model (SWAT), linear bias correction method for climate projection and land-use change model (Dyna-CLUE). Many studies showed that the impact of future land-use change in runoff is usually not as significant as climate change. The effect of land-use change is mainly on evapotranspiration and is not significant unless there is a drastic change in land-use.

The global climate change results after downscaling are obtained by three regional climate models (RCMs): ACCESS-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM and MPI-ESM-LR-CSIRO-CCAM under RCP4.5 and 8.5. The precipitation and extreme temperatures are projected from the baseline period (1970-2010) for the three time-steps, i.e., 2020s (2011- 2040); 2050s (2041-2070) and 2080s (2071-2099).

The main objective of this study is to predict the future inflow to the Sirikit reservoir under climate change and land-use change projections. The climate change projection is analyzed considering average daily precipitation, extreme temperatures using the three RCMs under RCP4.5 and 8.5[18]. Moreover, land-use change projection is investigated on two case studies namely economic and conservation. The sub-objectives of this research are; (i) projecting future climate change using bias correction technique. (ii) predicting land-use change maps under historical and forest conservation trends. (iii) calibration and validation of precipitation-runoff model (HEC-HMS) on flow discharges. (iv) evaluating inflow discharge to the Sirikit reservoir with the predicted daily rainfall, daily extreme temperatures, and land-use types in each sub-basin.

2. STUDY AREA AND DATA COLLECTION

Study Area

The Upper Nan River Basin (U-NRB) is situated in the north of Thailand. The basin covers Nan and Uttaradit provinces as shown in Figure 1 [21], [24]. The Nan River drains into the central plain of Thailand and merges with the Ping, Wang and Yom rivers to become the Chao Phraya River at Nakhon Sawan province. It covers a drainage area of 13,130 km^2 [21] that include 65% (forest area), 31% (agricultural area) and 4% (water body and built-up area). Field crops and rice dominate productivity in agricultural sector. The ground elevation varies from 7 to 2,061 meters above mean sea level (MSL). The upper part of U-NRB originates the Nan river from Luang Prabang range located between Thailand-Lao PDR border. The middle part of U-NRB has a large agricultural and built-up area dominated with paddy filed and rubber tree plantation areas. The Sirikit Dam is a large earth dam with a capacity of 9,500 million m^3, 113.6 meters high, a crest width of 12 meters and crest elevation of +168 meters MSL. The dam is located in the lower part of U-NRB [21]. U-NRB has a tropical climate with three different seasons, i.e., summer from March to May, rainy season from June to October and winter season from November to February. The average annual rainfall, extreme temperatures are 1,371 mm, 36.6° and 15.3°C respectively.

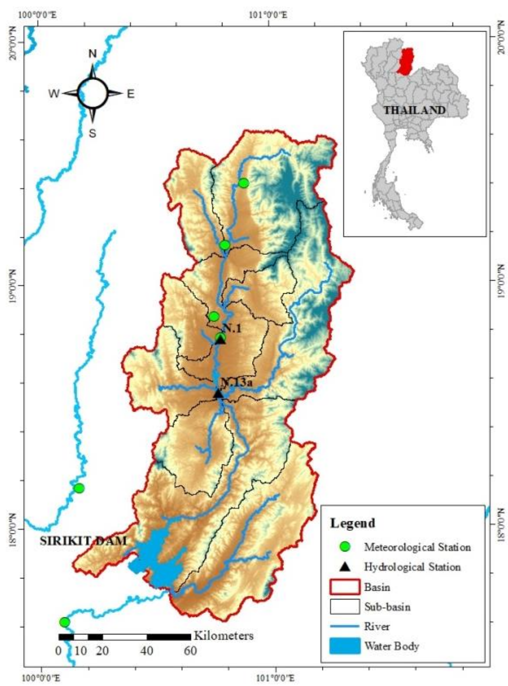


Fig.1. Study Area of Upper Nan River Basin (U-NRB), Thailand.

Data Collection

The main input data for climate change projection includes observed daily rainfall, extreme temperatures at 6 meteorological stations from 1970-2010 from the Thai Meteorological Department (TMD). Three RCMs, i.e., ACCESS, CNRM and MPI with high resolution (0.5^0/daily) under RCP4.5 and RCP8.5 in 1970-2100 are obtained from the Collaboration of the Australia Weather and Climate Research, the National Centre of Meteorological Research and European Network of Earth System Modelling, respectively. The historical land-use/cover maps of 2016 and 2019, DEM, soil map, the distance of water body, road and city from Land Development Department (LDD) are used for land-use change projection. In hydrological modelling, the observed daily streamflow discharge from 2 telemetering stations (N.1 and N13a) from 1999-2017 are gathered for model calibration and validation.

3. METHODOLOGY

The methodology can be described in four steps as follows: Step 1) climate bias correction and projection of daily precipitation, extreme temperatures. Step 2) evaluating future land-use changes under two hypotheses namely: economic scenario and conservation scenario. Step 3) gives calibration and validation of precipitation-runoff model. Step 4) provides prediction of impacts of changes in climate and land-uses on inflow to the Sirikit reservoir. In the first step, the linear bias correction and projection of climate parameters during 1970-2010 and 2011-2100, is based on linear regression method. The future time is divided into three time-periods, i.e., 2020s (2011-2040), 2050s (2041-2070) and 2070s (2071-2100). In the second step, a spatial dynamic modeling (FLUS model) is applied to project land-use maps from 2020-2100 under two schemes or scenarios, i.e., economic scheme and conservation scheme. Land-use maps in 2016 and 2019 are used to analyze the historical changing trend of land-use for the economic scheme. The conservation scheme is assumed according to the 20-year Thailand Government Strategy (2018-2037) on conserving and rehabilitating biological diversity to protect and increase forest area. The third step is the calibration and validation of the precipitation-runoff model (HEC-HMS) [22] for the observed and simulated daily discharges using statistical performance parameters namely Nash-Sutcliffe coefficient (NSE), the coefficient of determination (R^2), Normalized Root Mean Square Error (NRMSE) and Volume Ratio (Vr). The fourth step is the simulation of inflow to the Sirikit reservoir under future climate and land-use changes. Two case studies are taken into consideration. Case 1, which only climate change under RCP4.5 and RCP8.5 is considered. Case 2 in which both climate change and land-use changes with economic and conservation scenarios are considered for both RCPs.

Bias Correction for Climate Data Projection

Bias correction is a technique to match simulated and observed data to increase precision and accuracy of simulated data [18]. Linear scaling is a perfect matching technic to correct values [1], [7], [11], [13]. The simulated climate characterizes with several intersections for different RCMs with 14 intersects for U-NRB are inaccurate and insufficient to use. Applying linear scaling technic, the historical and simulated rainfall from all RCPs are corrected and matched with the observed rainfall data using equations 1 and 2 (see below), and for simulated extreme temperatures using equations 3 and 4 (see below) to correct the simulated temperatures with the observed data [16], [18]. The accuracy of the results can be checked in terms of dispersion and central tendency of the corrected data by using standard deviation (SD) and mean. The final outputs are the corrected historical and future rainfall, extreme temperatures.

Temperature correction formulas:

$$T'_{his,d} = T_{his,d} + [\mu_m \cdot T_{obs,d} - \mu_m \cdot T_{his,d}] \tag{1}$$

$$T'_{sim,d} = T_{sim,d} + [\mu_m \cdot T_{obs,d} - \mu_m \cdot T_{his,d}] \tag{2}$$

Precipitation correction formulas:

$$P'_{his,d} = P_{his,d} \left[\frac{\mu_m \cdot P_{obs,d}}{\mu_m \cdot P_{his,d}}\right] \tag{3}$$

$$P'_{sim,d} = P_{sim,d}\left[\frac{\mu_m \cdot P_{obs,d}}{\mu_m \cdot P_{his,d}}\right] \tag{4}$$

*w*here, P is the rainfall, T is the temperature, d is the daily unit, μ_m is the monthly unit, obs is the observed data, his and sim are the historical and simulated data of RCMs and ' is the corrected value.

Land-use Modelling

Land-use Simulation Model (FLUS) is a dynamic model to predict multiple land-use changes under anthropogenic and environment effects. FLUS is a commercial model which is widely accepted for future land-use projection [8], [9], [10]. There are two components: multiple cellular automata (CA), allocation model and artificial neural network (ANN) [10]. The CA model is used to analyze spatial land-use pattern following land-use change and demand through past historical trend and anthropogenic impact [18]. ANN system defines the complex relationship for influent human-environment parameters which have driving forces to future land-use types.

The study used FLUS version 2.4 that simulates future land-use maps under economic and conservation pattern scenarios. Two hypothesized case studies are considered, i.e., economic case study and conservation case study. The economic case study is analyzed from land-use maps in 2016 and 2019 gathered from Land Development Department (LDD) to determine the land-use change projection from 2020 until 2100. Five-land-use types, i.e., agriculture, forest, miscellaneous, water body and built-up are analyzed for land-use change classification. The conservation scenario considered the Thai Government Strategy on forestation policy according to the Royal Forest Department. The plan is to increase the forest area from 9,953 in 2018 to 13,317 km^2 in 2024 for U-NRB with unchanged water body area. However, urbanization is one driver in increasing build-up and reducing agricultural areas.

The relevant human-environment parameters include DEM, slope, aspect, rainfall, soil, population density, and distance of road, city and waterbody maps with fine resolution coordination (90 m x 90 m). After inputting all data, the simulated land-use map in 2019 is calibrated against the observed land-use map in 2019 by using Kappa statistical parameter (K) in equation 5 below. The K value ranges 0 to 1 in which 1 represents strong agreement between both maps [18].

$$\mathrm{K} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} \tag{5}$$

where, Pr(a) is the observed relative agreement amongst all raters and Pr(e) is the probability or chance of agreement.

Hydrological Modelling

The hydrological model or rainfall-runoff model (HEC-HMS) [1] is a program to simulate complete hydrologic process to generate streamflow from rainfall in small-large watershed areas. The model can be separated into several watershed-meteorological components such as climate, water losses, direct runoff, base flow, river transfer and reservoir models. Moreover, this model can also analyze sediment transportation, water quality, evapotranspiration, soil accounting and erosion. The HEC-HMS version 4.3 is used in this study to simulate streamflow from rainfall under different climate and land-use scenarios.

All input parameters for the precipitation-runoff model (HEC-HMS) model is prepared by HEC-GeoHMS with ArcGIS program to delineate hydrological elements such as sub-basin, river network and basin characteristics. The model uses parameters from digital elevation model (DEM), land-use, land-cover and soil map [1]. With the basin parameters, the loss method is considered to delineate infiltration by analyzing SCS curve number. Impervious percentage from land-use type and soil maps each year, simple canopy, and surface equations are used to define water detention and surface storage, respectively. Clark unit hydrograph equation is used to simulate the river transform method that needs time of concentration and storage coefficient to input to model. The base flow method is applied using constant monthly flow data determined from measurement of stream flow discharge data. For meteorological parameters, Thiessen polygon modification is applied to define the weighting factor of each weather station in a sub-basin. Given daily precipitation, daily extreme temperatures of the period 1999 to 2017, the model are used to compute daily discharges. The model is calibrated from 1999 to 2007 and verified from 2008 to 2017, respectively. The accuracy of the model outputs are evaluated by using statistical performance indices. The model parameters are adjusted by trial and error until satisfactory agreement between the calculated and observed data is obtained at stations N.1 and N.13a. Then, the model is applied to predict future inflow to the Sirikit reservoir under the predetermined changes in climate and land-uses.

Evaluation of Future Inflow Discharge to Sirikit Dam Reservoiur Under Climate and Land-use Changes

The simulated flow discharge is investigated for several meteorological, watershed and hydrological parameters [1] considering bias correction for climate change and land-use change projection. The HEC-HMS model is used to predict future inflow discharge to the Sirikit reservoir for different cases of climate and land-use change projections. These cases include a) climate change parameters based on RCP4.5 and 8.5, b) both future climate and land-use parameters based on RCP4.5 and 8.5 with economic and conservation scenarios. The model computed the projected flows for the three time-periods, i.e., 2020s(2011-2040), 2050s(2041-2070) and 2080s(2071-2099) respectively.

4. RESULTS AND DISCUSSIONS

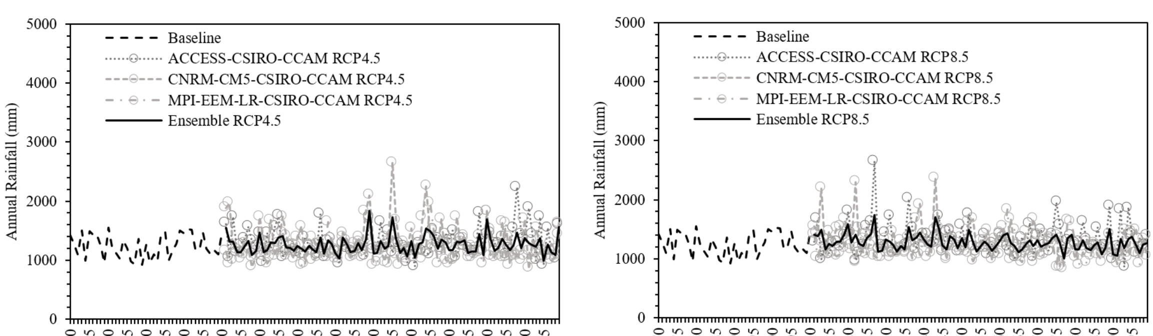
Climate Bias Correction and Projection

The future climate projection considers average daily precipitation, extreme temperatures of the three RMCs (ACCESS, CNRM, MPI) for RCP4.5 and 8.5. The bias correction–technique is applied to correct the projected rainfall and temperatures for comparison with the baseline rainfall and temperatures from 1970-2010 at 6 weather stations i.e., 330201, 331201, 331301, 331401, 331402 and 351201 as shown in Figure 1. Linear scaling formulas (equations 1-4) are used to project future climate change until the end of the twenty-first century in three-time-periods: 2020s, 2050s and 2080s. The standard deviation (SD) and mean are used to determine dispersion and central tendency of the simulated and observed climate characteristics of the baseline of ACCESS, CNRM and MPI as shown in Table 1.

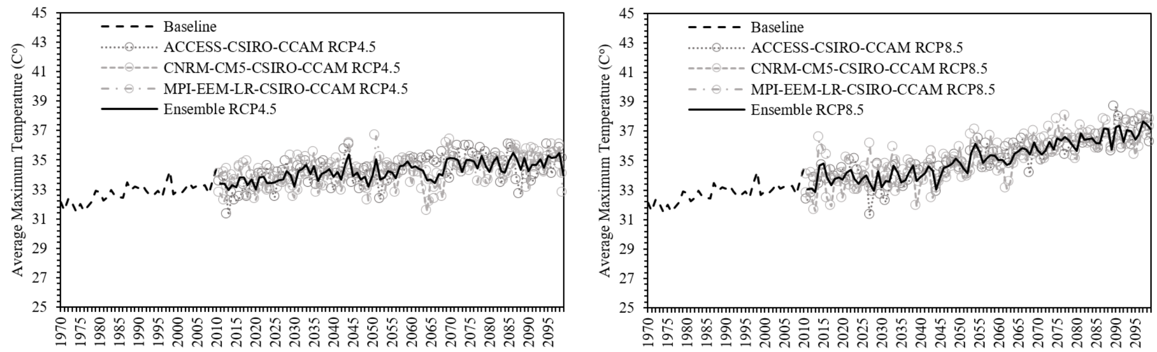
It is found that CNRM has the highest accuracy and precision on precipitation over ACCESS and MPI for both performance parameters. The stations 330201 and 351201 have lower SD values for all RCMs comparing to baseline. Additionally, the extreme temperatures of the three RCMs at all stations have values near the baseline data. This study uses the avarage daily climate data (precipitation, extreme temperatures) from three corrected RCMs with different RCPs to input into the hydrological model for projecting future stream flow. The accuracy of the projected data can be increased and the central tendency can be reduced by using the average method.

Table 1. Statistical Performance of Bias Correction Methods (ACCESS, CNRM and MPI) at 6 Weather Stations

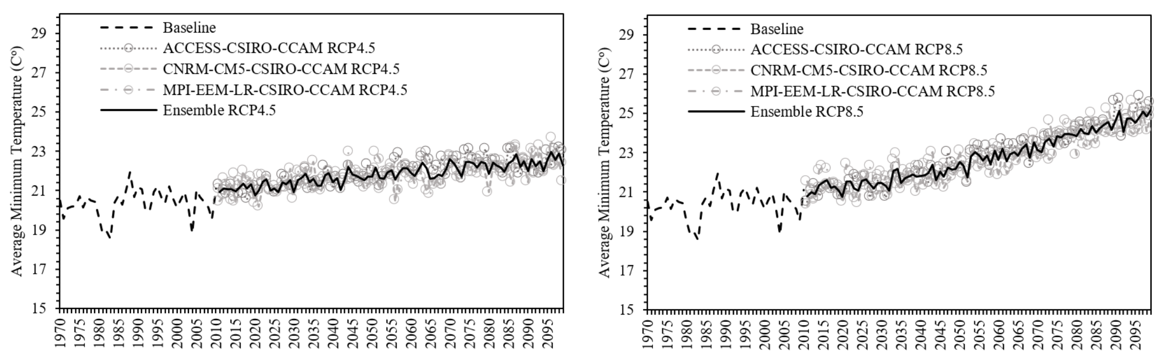
Station ID	330201		331201		331301		331401		331402		351201	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Rainfall, mm												
Baseline	3.04	9.62	3.44	9.94	3.44	9.92	3.89	10.93	4.91	12.23	3.88	11.53
ACCESS	3.12	7.37	3.56	8.53	3.58	8.73	4.09	10.48	4.81	10.65	3.85	7.270
CNRM	3.02	7.70	3.72	9.94	3.95	9.63	4.10	12.53	4.50	11.78	4.06	10.06
MPI	3.13	6.80	3.42	9.17	3.69	9.18	3.81	10.51	4.58	12.26	3.90	8.84
Maximum temperatures, degree Celsius												
Baseline	32.84	3.31	32.50	3.42	31.58	3.48	31.67	3.34	31.21	3.87	33.69	3.24
ACCESS	33.03	3.81	32.70	3.88	30.31	3.89	31.87	3.94	32.30	4.47	33.87	3.57
CNRM	33.01	3.78	32.68	3.86	30.25	3.87	31.84	3.91	31.36	3.87	33.87	3.52
MPI	33.04	3.61	32.70	3.83	30.29	3.80	31.86	3.88	31.32	3.69	33.88	3.66
Minimum temperatures, degree Celsius												
Baseline	21.25	4.11	20.23	4.43	19.39	4.58	19.80	4.71	19.61	4.16	22.03	3.45
ACCESS	21.45	4.02	20.41	4.35	18.65	4.09	19.98	4.59	20.53	4.35	22.23	3.49
CNRM	21.45	4.03	20.41	4.37	18.62	4.13	19.98	4.61	19.69	4.37	22.23	3.50
MPI	21.45	4.02	20.40	4.39	18.63	4.12	19.97	4.63	20.00	4.17	22.22	3.58



Projected Annual Rainfall under RCP4.5 and 8.5



Projected Average Maximum Temperature under RCP4.5 and 8.5



Projected Average Minimum Temperature under RCP4.5 and 8.5

Fig.2. Projected Average Rainfall, Maximum and Minimum Temperatures [(a), (b) and (c) Respectively] at Station 331201, Mueang Nan Province, Thailand.

The above mentioned three time-periods are called near future, middle future and far future respectively. The projection trends for precipitation, extreme temperatures at station 33120 (Mueang Nan, Nan province) are shown in Figure 2. The baseline of annual rainfall, extreme temperatures is 1,245.31 mm, 32.77^{o} and 20.36 ^{o}C, respectively, during 1970 to 2010.

Given the periods of summer (Mar-May), rainy (Jun-Oct) and winter (Nov-Feb), Table 2 shows that from 2020s to 2080s, the climate change increases rainfall in summer from 330 to 405 mm for RCP4.5 and 366 to 410 mm for RCP8.5. However, in rainy seasons, the rainfall reduces from 880 to 824 mm for RCP4.5 and 933 to 790 mm for RCP8.5. In winter, the rainfall increases from 28 to 38 mm for RCP4.5 and 24 to 38 mm for RCP8.5. For the annual rainfall under RCP4.5, its changes are from -0.143 mm/yr from the base period to 2020s, 1.3 mm/yr from 2020s to 2050s and -0.367 mm/yr from 2050s to 2080s. Its overall average change for the whole period is the increase of 0.263 mm/yr. For the annual rainfall under RCP8.5, its changes are 2.26 mm/yr from the base period to 2020s, -1.4 mm/yr from 2020s to 2050s and -1.47 mm/yr from 2050s to 2080s.The overall average change for the whole period is a decrease of -0.202 mm/yr.The trends of the projected rainfalls for RCP4.5 in this study are the same as in other researches such as [6], and [16].

For the extreme temperatures, they have average increasing trends of about 1^{o}C for RCP4.5 and about 2.7 to 2.8^{o}C for RCP8.5 respectively. Particularly, the maximum temperature increases from 33.76 to 34.80^{o}C for RCP4.5 and from 33.81 to 36.55^{o}C for RCP8.5. For the minimum temperature, it increases from 21.29 to 22.36^{o}C for RCP4.5 and from 21.40 to 24.20^{o}C for RCP8.5 respectively. The projected extreme temperatures show clearly the increasing trends as found in other researches in the same regions.

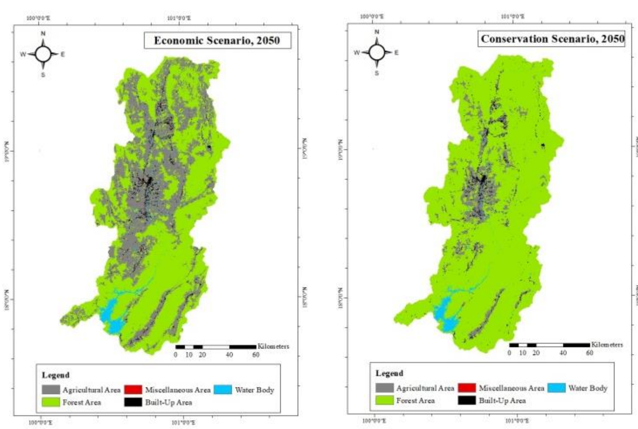
Projection on Future Land-use

The future land-use projection is simulated under two scenarios namely, economic and conservation. The past land-use changing trend is analyzed from past land-use maps in 2016 and 2019 considering future urbanization and population growths. By calibration, the projected land-use map on 2019 is compared and corrected with observed land-use maps based on Kappa statistical parameter (K). The study found that K is equal 0.92, which is very highly acceptable and sufficiently accurate to predict in the future. Forest conservation scenario assumed land-use demand and conversion sequence following the forestation plan of the Thai Government (2018-2037) to increase the forest area of U-NRB. The result of future land-use map for both scenarios are classified into five land-use types namely agricultural, forest, miscellaneous, build-up and water body area as shown in Figure 3.

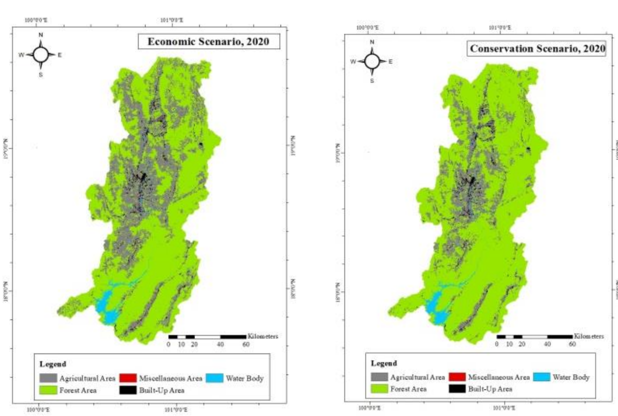
Table 2. Projection of Rainfall, Maximum and Minimum Temperatures of 2020s, 2050s and 2080s at Mueang Nan Meteorological Station 33120

Seasons	2020s		2050s		2080s	
RCP	4.5	8.5	4.5	8.5	4.5	8.5
Rainfall (mm)						
Summer	330	366	410	389	405	410
Rainy	880	933	842	865	824	790
Winter	28	24	27	27	38	38
Annual	1,240	1,324	1,279	1,282	1,268	1,238
Maximum Temperature (^{o}C)						
Annual	33.76	33.81	34.23	35.02	34.80	36.55
Minimum Temperature (^{o}C)						
Annual	21.29	21.40	21.88	22.57	22.36	24.20

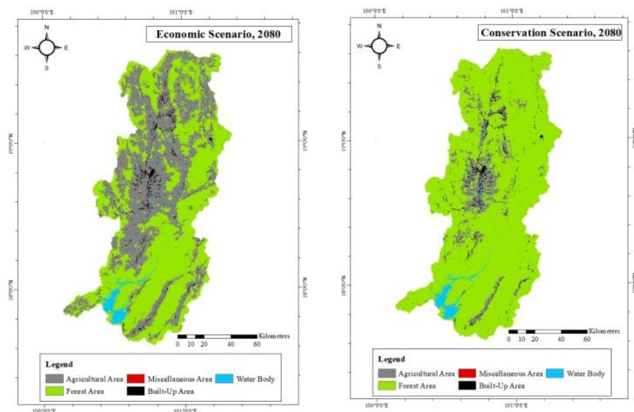
Figure 4 illustrates the land-use change in 2020s, 2050s and 2080s compared to the actual data in 2016.



(a) Predicted Land-use Map in 2050



(b) Predicted Land-use Map in 2020



(c) Predicted Land-use Map in 2080

Fig.3. Predicted Land-use Maps under Economic and Conservation Scenarios in 2020, 2050 and 2080

In the economic scenario, the projected land-use change is found to be 29.84% for agricultural area; -20.02% for forest area; -24.53% for miscellaneous area; 5.27% for built-up area; and 1.78% for water body area related with past land-use in 2016. The projected land-use change in conservation scenario is found to be -14.86% for agricultural area; 26.69% for forest area; -16.88% for miscellaneous area; 3.99% for built-up area; and 1.36% for water body area. Figure 4 shows no change in water body area and only slight change in the built-up area. The largest percentage changes are in agricultural area in the economic scenario and forest area in the conservation scenario.

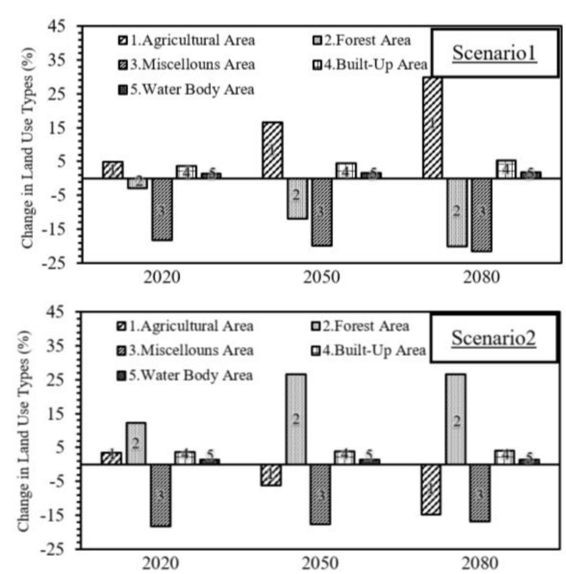


Fig.4. Absolute Change of Land-use Types for Economic and Conservation Scenarios on 2020s, 2050s and 2080s, respectively.

Hydrological Model Calibration and Validation

The projected discharges from HEC-HMS model is compared and corrected with observed discharge in two time periods 1999-2007 (calibration) and 2008-2017 (validation). The locations of the stations N.1 and N.13a are in the middle and lower parts of the study area upstream of the Sirikit reservoir. The statistical performance parameters namely, normalized root mean square error (NRMSE), coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Volume ratio (Vr) are used to evaluate for both calibration and validation. Those parameters can ensure the accuracy and reliability of this model for the future projection.

Table 3. Performance indicators of HEC-HMS hydrological model

Period	Duration	R^2	NRMSE (%)	NSE	V_r
Station N.1 (Mueang Nan, Nan province)					
Calibration	1999-2007	0.85	3.29	0.78	1.12
Validation	2008-2017	0.79	5.30	0.68	1.05
Station N.13a (Wiang Sa, Nan province)					
Calibration	1999-2007	0.80	6.16	0.75	1.17
Validation	2008-2017	0.77	6.85	0.67	1.22

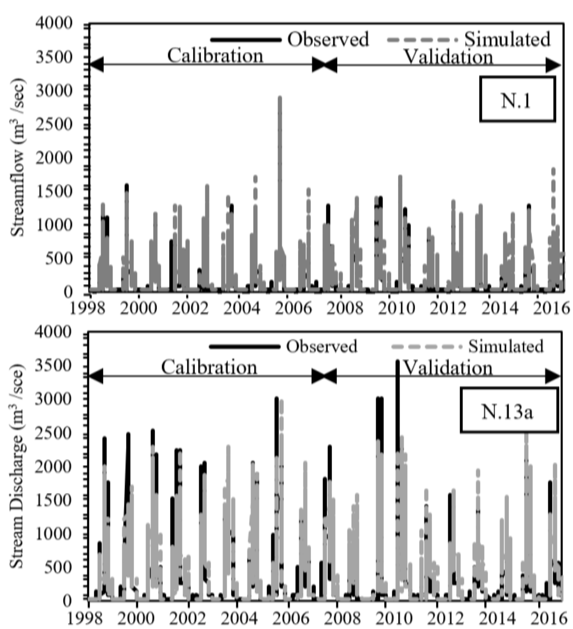


Fig.5 Calibration and Validation of HEC-HMS Model at Stations N.1 and N.13a, respectively.

The performance of HEC-HMS Model is shown in Table 3. The calibration is done by comparing the computed and observed daily discharges at both stations N.1 and N.13a. The comparison shows very good agreement with R^2 = 0.85, NRMSE = 3.29%, NSE = 0.78, Vr = 1.12 for station N.1 and R^2 = 0.80, NRMSE = 6.16%, NSE = 0.75, Vr = 1.17, for station N.13a.

The validation also shows a very good agreement at both stations with R^2 and NSE close to 1, and NRMSE less than 10%. It means that the model performance has a high accuracy on data dispersion and central tendency. Therefore, as shown in Figure 5, this model is capable to predict inflow to the Sirikit reservoir under various climate and land-use change scenarios.

Future Climate and Land-use Impacts on Inflow to Sirikit Reservoir

The changing on future rainfall and extreme temperatures lead to impacts to inflow discharge into the Sirikit reservoir. The projection of inflow for the 90 year period of the three time-periods, i.e., 2020s, 2050s and 2080s with middle and high greenhouse gas emission levels (RCP4.5 and 8.5) is done. It is found that the predicted precipitation has a slowly reducing trend and the temperatures have increasing trends. However, increasing in temperatures bring about higher evapotranspiration rate from surface water and plants. Land-use change and urbanization have influences on infilltration rate and percentage of impervious area of each sub-basin. The future inflow is projected for 6 case studies, i.e., cases 1 and 2 for determining climate change impact only (RCP4.5 and RCP8.5), cases 3-4 for determining the impact of the combined climate change and economic land-use changes, for RCP4.5 and RCP8.5 and cases 5-6, for determining the effects of the combined climate change and conservation land-use changes, for RCP4.5 and RCP8.5 respectively.

The predicted inflow to the Sirikit reservoir is analyzed considering the projected rainfall and temperatures in U-NRB as shown in Table 4. For the periods 2020s, 2050s and 2080s, cases 1 and 2 considered only climate change impact, the average annual inflow are 493.08, 498.30 and 494.15 CMS (case 1); 509.64, 495.94 and 484.59 CMS (case 2). For cases 3 to 6 the annual inflow are; 493.74, 500.16 and 497.64 CMS (case 3); 510.26, 497.57 and 487.95 CMS (case 4); 489.33, 493.65 and 489.49 CMS (case 5), and 505.44 490.84 and 479.49 CMS (case 6) respectively.

The baseline inflow discharge into the Sirikit Dam from 1970-2010 are 60.16 CMS for summer, 1,043.53 CMS for rainy, 128.01 CMS for winter, and 494.67 CMS for annual. By analyzing Table 4, the results show that the changes of annual discharge in 2080s compared to the baseline are approximately -0.11% (RCP4.5, case 1), -2.04 (RCP8.5, case 2), 0.60 (RCP4.5, case 3), -1.36 (RCP8.5, case 4), -1.05 (RCP4.5, case 5) and -3.07 % (RCP8.5, case 6). The following main points can be summarized. The changes in the annual inflow due to changes in climate and land-uses for RCP4.5 (cases 1, 3 and 5) for the time periods 2020s, 2050s and 2080s are not significant compared to the baseline period.

Table 4. Projected Average Inflow Discharge (CMS or m^3/s) and Absolute Change (%) in Comparison with Baseline data for Climate Change Only and Both Climate and Land-use Changes

Seasons	Only Climate Change		Climate and Land-use Changes			
	RCP4.5 Case 1	RCP8.5 Case 2	Scenario 1		Scenario 2	
			RCP4.5 Case 3	RCP8.5 Case 4	RCP4.5 Case 5	RCP8.5 Case 6
Baseline (1970-2010)	Baseline average inflow for summer (Mar-May) = 60.16, rainy (Jun-Oct) = 1043.53, winter (Nov-Feb) = 128.01 and annual (Jan-Dec) = 494.67 CMS respectively.					
2020s (2011-2040)						
Summer	52(-12.27)	53(-11.06)	52(-12.23)	53(-10.96)	52(-12.28)	53(-11.36)
Rainy	1,041(-0.24)	1,083(3.83)	1,042(-0.09)	1,084(3.97)	1,032(-1.10)	1,073(2.88)
Winter	132(3.15)	127(-0.25)	132(3.15)	127(-0.24)	132(3.13)	127(-0.26)
Annual	493(-0.32)	509(3.03)	493(-0.19)	510(3.15)	489(-1.08)	505(2.18)
2050s (2041-2070)						
Summer	66(10.51)	55(-7.67)	67(11.52)	56(-7.27)	65(8.60)	54(-8.86)
Rainy	1,049(0.52)	1,052(0.86)	1,053(0.91)	1,056(1.22)	1,038(-0.47)	1,040(-0.27)
Winter	127(-0.60)	124(-3.13)	127(-0.60)	124(-3.13)	127(-0.62)	124(-3.16)
Annual	498(0.73)	495(0.26)	500(1.11)	497(0.59)	493(-0.21)	491(-0.77)
2080s (2071-2099)						
Summer	61(2.49)	58(-3.54)	63(4.98)	59(-1.78)	60(0.42)	57(-4.76)
Rainy	1,043(0.01)	1,019(-2.34)	1,051(0.72)	1,026(-1.63)	1,033(-0.99)	1,007(-3.46)
Winter	125(-2.13)	130(1.63)	125(-2.17)	130(1.64)	125(-2.20)	130(1.61)
Annual	494(-0.11)	484(-2.04)	497(0.60)	488(-1.36)	489(-1.05)	479(-3.07)

For RCP8.5, the annual inflow change due to climate change only (case 2) compared to baseline is more significant than RCP4.5 that is 3.03% in 2020s, 0.26 % in 2050s and -2.04% in 2080s. In the case of climate change and economic land-use changes (case 4), the changes in annual inflow are 3.15, 0.59 and -1.36% respectively; for climate change with conservation land-use scenario (case 6), the changes are 2.18, -0.77 and -3.07% respectively. In all, we can conclude that: (1) the climate change effect under RCP8.5 on the annual inflow is much more significant than that of RCP4.5, (2) the climate change reduces the annual inflow from 2020s to 2080s, (3) the climate change and both land-use changes reduce the annual reservoir inflow with time, (4) the economic land use change has less effect in reducing inflow than the conservation land-use change.

The changes in inflow in summer, rainy and winter for RCP8.5 for the time steps 2020s, 2050s and 2080s compared to the baseline are shown in Table 4. Case 2 refers to climate change only; case 4 refers to climate change and economic land-use change and case 6 refers to climate change and conservation land-use change. The main part of the inflow occurs in rainy seasons which decrease with time from 2020s to 2080s due to climate change and both land use change scenarios. The effects of climate change and both land-use change scenarios on reservoir annual inflow are the same as in rainy seasons. The trend of reduction of reservoir inflow will have impacts on reservoir operation and water management in the downstream area of the Sirikit reservoir especially during the drought periods in winter and summer.

5. CONCLUSIONS

The projected inflows to the Sirikit reservoir under future changes in climate and land-uses are determined. The future climate projection is investigated using linear bias correction method to correct daily rainfall, extreme temperatures from three RCMs with two greenhouse gas emission cases (RCP4.5 and 8.5). The land-use projection is analyzed using past land-use data in 2016 and 2019 and forest conservation in developing the economic and conservation scenarios. The FLUS model is applied to predict land-use maps until 2080s. The reservoir inflow is simulated using rainfall to streamflow data and the hydrological model (HEC-HMS). All of projected climate, land-use and stream flow discharge are calibrated and validated successfully based on statistical performance indicators. The HEC-HMS model is found to have high accuracy and is acceptable for future projection of inflow to the Sirikit Dam.

It is found that from baseline to 2020s, 2050s and 2080s, the future climate change impact will increase the extreme temperatures by about 1°C for RCP4.5 and about 2.7-2.8°C for RCP8.5. For rainfall, the projected seasonal rainfall fluctuates with increasing trends in summer and winter for both RCPs. While in rainy seasons, it fluctuates with decreasing trends for both RCPs. The changes in annual rainfall under RCP4.5 are -0.143 mm/yr for the baseline period to 2020s, 1.3 mm/yr for 2020s to 2050s and -0.367 mm/yr for 2050s to 2080s. Its overall average change from the baseline to 2080s is the increase of 0.263 mm/yr. For the annual rainfall with RCP8.5, the changes are 2.26 mm/yr for the baseline period to 2020s, -1.4 mm/yr for 2020s to 2050s and -1.47 mm/yr for 2050s to 2080s.The overall average change for the whole period is a decrease of -0.202 mm/yr.The trends of the projected rainfalls are the same as in other researches in the same and nearby regions, such as [6] and [16].

For the periods from 2020s to 2080s, the effect of climate change in reservoir inflow due to RCP4.5 is practically insignificant and hence the existing reservoir operation rules are applicable. But under RCP8.5, the change of annual inflow due to climate change is more significant with a decreasing trend; the current reservoir operation should be revised to keep more water in the storage in rainy seasons and release more outflow for downstream uses in winter and summer. Considering the effect of changes in climate and economic land-uses, the change in annual inflow is found to be insignificant for RCP4.5, hence the current operation rules are still applicable. For RCP8.5, the trend of annual inflow is decreasing more significantly over a long term. The current reservoir operation rule should be revised to keep more water storage in rainy seasons and release more outflow for downstream uses in winters and summers. The reservoir operation should keep more water than the case of change in only due to more reduction of inflow. Considering the effect of climate change and land-use change under conservation scenario, the change in annual inflow is found to be insignificant for RCP4.5, hence the same operation rules are applicable. For RCP8.5, the reduction of annual inflow in the case of conservation scenario is more significant than the economic scenario; hence the reservoir operation should keep even more water in rainy seasons. More water should be stored in the reservoir than at present especially in rainy seasons and the reservoir should release more water for downstream uses in winters and summers during drought periods. Further reservoir operation studies should be carried out to find the optimum reservoir operation rules in all cases.

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