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Assessment of climate change impacts on drought severity using SPI and SDI over the Lower Nam Phong River Basin, Thailand

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Abstract

The Lower Nam Phong River Basin, which is located in Northeast Thailand, is impacted by drought, which is likely to increase in severity in the future. Since drought seriously affects human life and well-being, this assessment was focused on the impacts of climate change on drought severity in the Lower Nam Phong River Basin. Daily climate data, such as rainfall and temperatures, for 2020 to 2050 under emission scenario Representative Concentration Pathway (RCP8.5), were obtained from "HadGEM2-AO", downscaled by the Regional Climate Model version 4 (RegCM4), and bias-corrected via the Delta Change Method. Drought conditions were then classified based on the Standardized Precipitation Index (SPI) calculated from future daily rainfall, and the Streamflow Drought Index (SDI) derived from future daily discharge at each sub-basin outlet obtained from the Soil and Water Assessment Tool (SWAT) model simulations. At the E.22B gauging station, the SWAT performance was found to be satisfactory for all evaluation criteria, i.e. R^2 and NSE values were 0.86 and 0.74 for calibration (2005 – 2010), and 0.92 and 0.89 for validation (2011 – 2016), respectively. For drought risk assessment, the point-based SPI and SDI values at 3- and 6-month time scales were spatially interpolated using kriging to assess short-term drought conditions. Based on the SPI-6 during the mid-future period (2041 – 2050), the Lower Nam Phong River Basin would have the highest chance of drought with cumulative frequency of 90.7%, whereas based on SDI-6 the highest chance of drought would occur during the near-future period (2031 – 2040) with cumulative frequency of 97.5%. These findings imply that both SPI and SDI indices can be used as good alternatives for monitoring droughts in the Lower Nam Phong River Basin; however, validation is required to ensure forecast accuracy of droughts in the near- to mid-future time horizons.

Keywords: Climate change, Drought, SDI, SPI, Regional climate model, SWAT model

1. Introduction

Climate change is a serious threat to loss of life and human injury through pathways including intensifying of natural phenomena like flooding and drought. Through direct or indirect human interventions such as industrial development, pollution, transportation, and fossil energy use, possible future climate change impacts include rising temperature, rising concentrations of CO_2, changes in rainfall patterns (and distribution) and hydrological cycles, shifting of seasons, and increases in intensity and frequency of extreme weather events. [1-3]. In several countries including Thailand, droughts are exacerbating water scarcity and thereby adversely impacting people's livelihood and constraining economic growth. Two periods of prolonged droughts occur regularly in some parts of Thailand: 1) during the transition between winter to summer in which the amount of rainfall decreases from mid-October to mid-November in the northern, northeastern, central, and eastern regions; and 2) during the middle of rainy season (end of June to July) throughout all of Thailand [4-5].

The study area is the Lower Nam Phong River Basin, with its climate usually controlled by monsoon winds. Specifically, the Northeast monsoon causes cool and dry conditions between November and February, and a dry period occurs from March through May. The Southwest monsoon causes a wet season lasting from June to October. The average annual temperature is 26.8 °C, varying between 22.9 °C (in December) and 30.0 °C (in April) [6]. The mean annual rainfall is about 1,237.6 mm/year, in which the wettest month is September (224.9 mm) and the driest month is January (2.1 mm) [7]. This area is affected by climate change and drought conditions as a consequence of unseasonal rain and lengthy dry spells (normally occurring between June and July), together with the alteration of ecosystems, human community expansion, expansion of agricultural land (both irrigated and non-irrigated areas), as well as lacking potential water storage for household and

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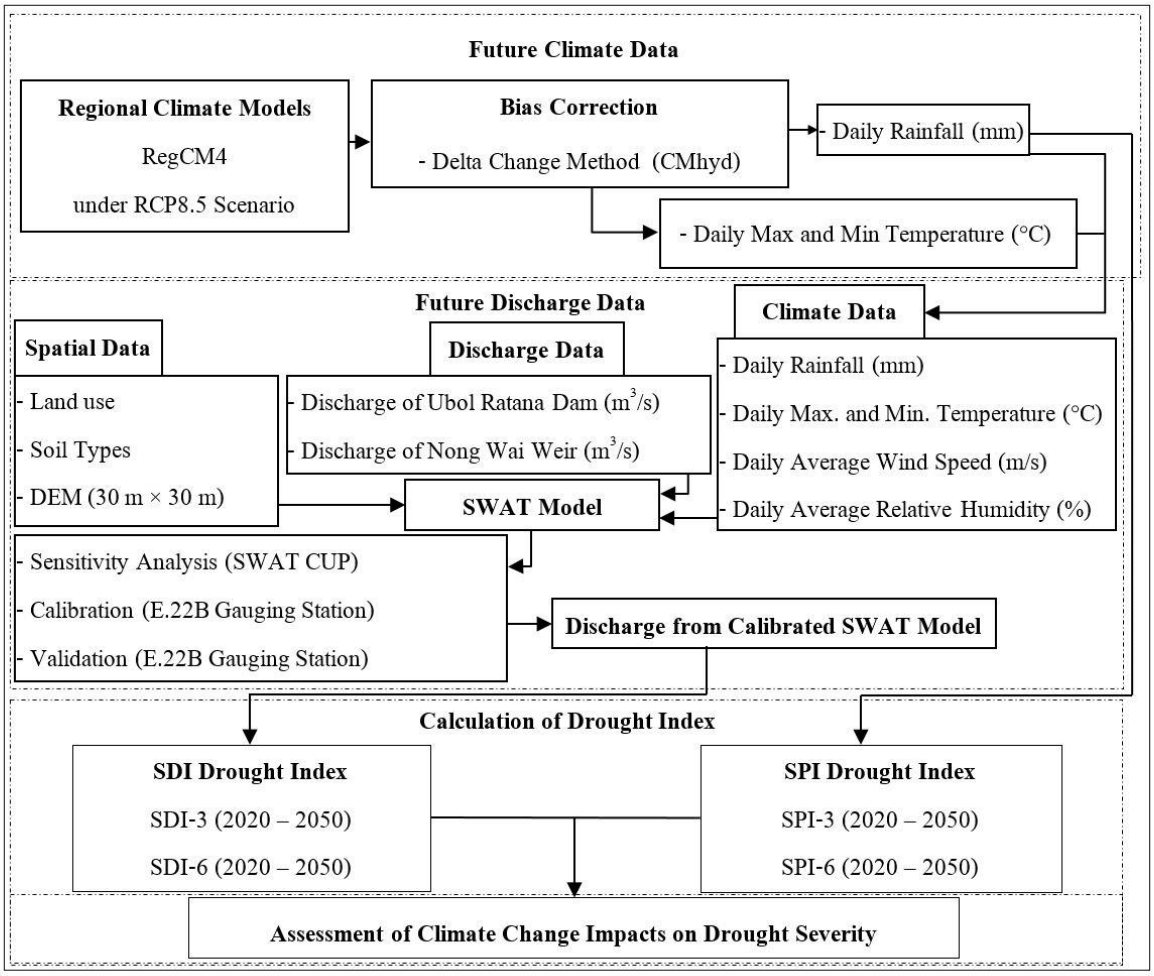

Figure 1 Detailed conceptual framework for assessing climate change impacts on drought severity in the Lower Nam Phong River Basin

industrial consumption within the Lower Nam Phong River Basin [8]. According to [9], drought mitigation measures were put in place for both irrigated and non-irrigated areas throughout the drought-affected areas in the Northeast of Thailand. A number of mitigation actions, including: (1) developing and implementing water consumption planning during the dry season, (2) increasing water storage capacity, (3) increasing the number of wells, (4) increasing public awareness and adaptive capacity of the affected areas, (5) supporting and mobilizing tools and equipment such as water pumps, water container, water trucks, etc., and (6) creating artificial rain, were adopted by the relevant government agencies and enterprises. According to the drought statistics for the Lower Nam Phong River Basin during 2017 – 2019 assessed by [10], it was found that in the year 2020, 17 and 19 districts are highly vulnerable to water scarcity for domestic and agricultural uses, respectively. Current drought risk assessments are carried out with historical statistics, in which drought-prone areas cannot clearly be identified for present and future conditions. To deal with the aforementioned drought-related risk in the study area, assessment of climate change impacts on drought severity in the Lower Nam Phong River Basin, Thailand was carried out. The indicator Standardized Precipitation Index (SPI) [11-12] was used to quantify the drought intensity based on bias-corrected daily Regional Climate Model (RCM) rainfall data under the RCP 8.5 climate change scenario, and the indicator Streamflow Drought Index (SDI) [13] was used to characterize the severity of hydrological droughts based on future daily discharge at the outlets of each sub-basin obtained from the Soil and Water Assessment Tool (SWAT) model simulations.

2. Materials and methods

A detailed research conceptual framework for this in-depth drought impact assessment based on climate change in the Lower Nam Phong River Basin is shown in Figure 1.

2.1 The study area

This study focuses on the Lower Nam Phong River Basin, which is a tributary of the Chi River Basin, and is situated in the Northeast of Thailand. The river basin has a total area of 2,386 km^2 located in undulating terrain with altitude ranging from 150 m above mean sea level (m+MSL) to 500 m+MSL (see details in Figure 2). The Nam Phong River within the study area, which is the main river stretching approximately 136 km, originates from the Ubol Ratana Dam to the outlet of the river basin at the confluence with the Chi River.

2.2 Datasets

There are four main datasets used in the drought risk assessment that are described in detail below.

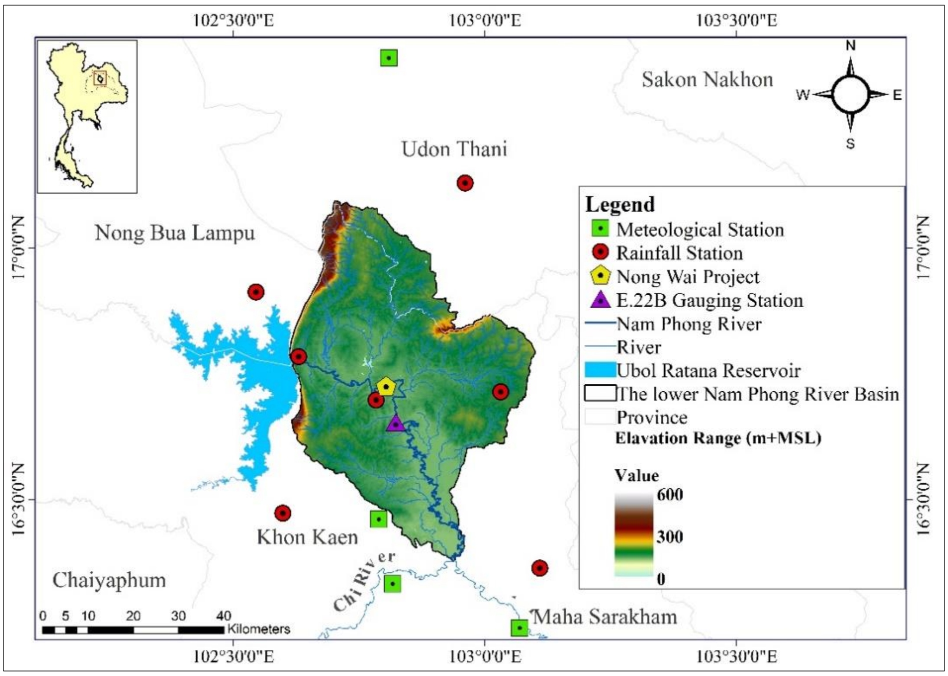

Figure 2 Location of the hydro-meteorological stations located in and around the Lower Nam Phong River Basin

2.2.1 Climate data

Climate data series used to assess the potential impacts of climate change on drought conditions in the Lower Nam Phong River Basin, were acquired from the Thai Meteorological Department (TMD) and the Royal Irrigation Department (RID), as well as climate model data reanalyses (note: reanalysis is a method using an atmospheric model for generating a high-quality climate data series, which are then corrected using historical observations collected from different sources, e.g., in situ, surface, satellite remote sensing, etc. [14]). In total, there are 11 climatological stations located in and around the river basin distributed over Khon Kaen, Maha Sarakham, Udon Thani, and Nong Bua Lamphu Provinces, in which the observed data, i.e. daily rainfall (mm), daily average relative humidity (%), daily average wind speed (m/s), and daily maximum and minimum temperatures (°C), are available from 1990 to 2016 (see Figure 2 for detailed locations).

2.2.2 Spatial data

Spatial data from the year 2015, such as Digital Elevation Model (DEM) with 30 m x 30 m grid resolution, soil types, and land use, were obtained from the Land Development Department (LDD) used in the preprocessing phase, and imported into the SWAT model through its interface.

2.2.3 Discharge data

Daily discharge data were used to calibrate and validate the SWAT model during the time period of interest from 2005 to 2016 (see Figure 2 for measurement locations). Based on the three different types of discharge data used in this study, the continuous daily time series were gathered from three different agencies, as described below:

- The released discharge from the Ubol Ratana Dam was obtained from the Northeast Hydro Power Plant, Electricity Generating Authority of Thailand (EGAT);
- The discharge through irrigation canals was provided by the Nong Wai Operation and Maintenance Project;
- The discharge at E.22B gauging station located at Ban Tha Mao, Nam Phong District, Khon Kaen Province, was acquired from RID.

2.2.4 Future climate data

The future predicted climate data used in this study were obtained from the data archive of the Intergovernmental Panel on Climate Change (IPCC) (Fifth Assessment Report, AR5). Daily climate data including rainfall (mm) and maximum and minimum temperatures (°C) were obtained from the Global Climate Model, called HadGEM2-AO. As noted by [15], the model simulations performed by the HadGEM2-AO were carried out for 72 years (1979 – 2050), including historical experiments (1979 – 2005) and future projections (2006 – 2050) with a set of four different scenarios called "Representative Concentration Pathways" (RCPs). The model outputs were then downscaled to a grid with 50 km resolution by the Regional Climate Model version 4 (RegCM4) over the COordinated Regional climate Downscaling EXperiment for East Asia (CORDEX-East Asia domain) [16], and bias-corrected via Delta Change Method. The high CO_2 emission scenario RCP8.5 was selected since global emissions are currently rising rapidly towards the upper bound of trajectory as stated by [17-18]. Therefore, the potentially severe climate impacts determined by this study could possibly lead to robust climate change mitigation policies for reducing global greenhouse gas emissions.

2.3 Generation of future climate data

In this study, a 27-year period (1990 to 2016) was used as a baseline for evaluating the regional climate model RegCM4 in reproducing the fundamental characteristics of daily rainfall and daily maximum and minimum temperatures for the Lower Nam Phong River Basin. To assess the RegCM4 performance, the Coefficient of

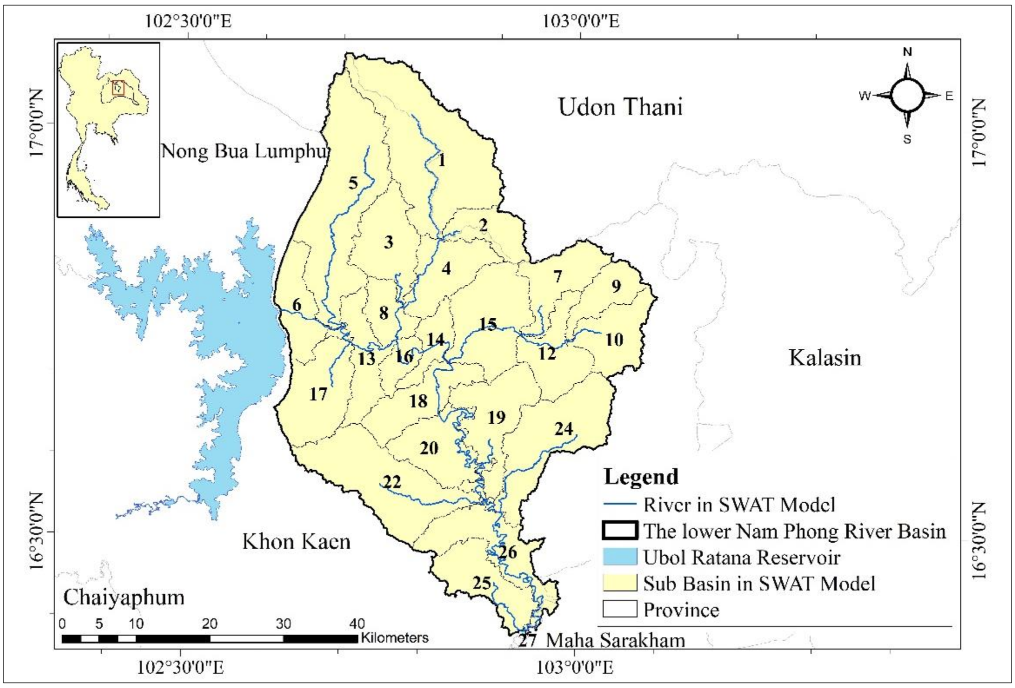

Figure 3 The SWAT delineated watershed, streams, and sub-basins of the Lower Nam Phong River Basin

Determination (R^2) was used to evaluate the goodness-of-fit between the observed monthly rainfall, maximum and minimum temperatures and bias-corrected RegCM4 simulation outputs between 2006 and 2016. The bias correction was performed at a daily scale using the nearest grid of the RegCM4 data by the Delta Change Method in the Climate Model data for hydrologic modeling program (CMhyd) [19], to account for mismatches between the historical observed and simulated RegCM4 data. The equations used for bias correction of selected climatic variables are shown in Equations 1 and 2 [20].

$$T_{fut,j,h}=T_{obs,j} + (\overline{T}_{fut,m,h} - \overline{T}_{cont,m}) \qquad (1)$$

Referring to Equation 1, $T_{fut,j,h}$ is the future temperature at day j and horizon h, $T_{obs,j}$ is the observed historical time series of temperature at day j, $\overline{T}_{fut,m,h}$ is the simulated future temperature at month m and horizon h, and $\overline{T}_{cont,m}$ is the simulated temperature at month m.

The future rainfall is calculated by multiplying the observed rainfall with the simulated rainfall as shown in Equation 2.

$$P_{fut,j,h} = P_{obs,j} \times \left(\frac{\overline{P}_{fut,m,h}}{\overline{P}_{cont,m}}\right) \qquad (2)$$

In Equation 2, $P_{fut,j,h}$ is the future rainfall at day j and horizon h, $P_{obs,j}$ is the observed historical time series of rainfall at day j, $\overline{P}_{fut,m,h}$ is the simulated future rainfall at month m and horizon h, and $\overline{P}_{cont,m}$ is the simulated rainfall at month m.

The RegCM4 was then used for climatic projection from 2017 to 2050 under scenario RCP8.5. The bias corrected RegCM4 outputs were then used to identify spatial and temporal patterns of drought phenomena in the Lower Nam Phong River Basin using the SPI index. The daily bias-corrected RegCM4 outputs were also used as inputs to the SWAT hydrological model for generating discharges under future climate change projections. Consequently, the SWAT simulated discharges for each sub-basin outlet were used to calculate the SDI for evaluating streamflow drought characteristics at various spatial and temporal scales in the Lower Nam Phong River Basin.

2.4 Assessment of future streamflow

Future streamflow variation under changing climate conditions in the Lower Nam Phong River Basin was assessed through SWAT simulation modeling, based on the three main required input data to be imported into SWAT: climate data, spatial data, and discharge data. Once the input layers and databases of SWAT hydrological model were set up, the Lower Nam Phong River Basin was then delineated and divided into 27 sub-basins (see Figure 3 for delineation results). The Hydrologic Response Units (HRUs) were also defined by lumping shared land use types, soil types, and slope characteristics together, dividing the Lower Nam Phong River Basin into 139 HRUs.

After preparation and implementation of the SWAT model, sensitivity analysis was then conducted by using the SWAT Calibration and Uncertainty Program (SWAT-CUP) based on the Latin Hypercube Global Sensitivity Analysis Method for identifying the most sensitive parameters which affect streamflow generation in SWAT. The parameters with highest absolute t-stat value and minimum p-value (close to zero) is considered and labeled high sensitivity compared to other parameters [21-22]. Using this method, the most sensitive parameters were determined, in which the number of parameters were reduced for SWAT model calibration and validation using SWAT-CUP. The calibration was performed based on the daily discharge recorded between 2005 and 2010 at the E.22B gauging station; the SWAT set up was then validated for the subsequent 6 years of data (2011 – 2016). To evaluate the SWAT model performance, the efficiency of each calibration and validation test was statistically evaluated through the use of the coefficient of determination (R^2) and the Nash-Sutcliffe Efficiency (NSE) between the observed and simulated values [23].

After rigorous calibration and validation, the SWAT calibrated model was applied to historic and future climate scenarios to generate future streamflow time series in the Lower Nam Phong River Basin using future projected climate data from RegCM4 under the RCP8.5 climate scenario, and predictions were made over the 2017 to 2050 time period using 1990 to 2016 as the control period.

2.5 Generation of spatiotemporal drought risk maps using SPI and SDI drought indices

To provide information about the spatial distribution of affected areas where severe drought occurred repeatedly in the Lower Nam Phong River Basin, drought risk maps were derived based on the magnitude and duration of future drought. For this purpose, the drought indicators SPI and SDI, were incorporated with the point-based areal interpolation approach in ArcGIS for spatial distribution patterns of meteorological and hydrological droughts under the RCP8.5 scenario between 2020 and 2050, which will be discussed in the following sections.

2.5.1 Calculation of SPI

To measure the impacts of drought on water resources availability, the SPI was used for quantifying the rainfall deficit for multiple time scales [11-12]. In this study, SPI-3 and SPI-6 were used to track the meteorological conditions in the Lower Nam Phong River Basin in response to rainfall anomalies on relatively short aggregated time scales, e.g., 3 and 6 months. SPI values were obtained by using the "SPI Generator" free software [24], which is based on the equation as follows [25] (note: see Table 1 for the description of meteorological drought based on the SPI criterion). The SPI is calculated by dividing the difference between normalized seasonal rainfall and its long-term seasonal mean by standard deviation as shown in Equation 3.

Table 1 Drought classification criteria based on the SPI and SDI indices [11, 26]

SPI and SDI values	Drought category
2.00 or more	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0.00 to 0.99	Mild wet
-0.99 to 0.00	Mild dry
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 or less	Extremely dry

$$\mathrm{SPI} = \frac{P_{ij} - P_{im}}{S} \tag{3}$$

From Equation 3, P_{ij} is the seasonal rainfall at the i^{th} rain gauge station and j^{th} observation, P_{im} is the long-term seasonal mean rainfall at the i^{th} rain gauge station, and S is the standard deviation.

2.5.2 Calculation of SDI

Hydrological drought frequency in the Lower Nam Phong River Basin was determined based on the SDI [13]. This drought index is calculated by dividing the cumulative streamflow anomaly of transformed data by the standard deviation of transformed data (see Equation 4). The description of hydrological drought based on the SDI criterion is illustrated in Table 1.

$$\mathrm{SDI}_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k} \tag{4}$$

As indicated in Equation 4, $\mathrm{SDI}_{i,k}$ is the Streamflow Drought Index for each reference period k of the i^{th} hydrological year, $V_{i,k}$ is the cumulative streamflow volume for the i^{th} hydrological year and the k^{th} reference period, $\overline{V}_k$ is the mean of cumulative streamflow volumes of reference period k, and S_k is the standard deviation of cumulative streamflow volumes of reference period k.

In this study, the SDI series with 3- and 6-month time scales (SDI-3 and SDI-6) were derived for 27 sub-basin outlets using the SWAT simulated daily discharge from 2017 to 2050. Using these values, the hydrological drought of the Lower Nam Phong River Basin was assessed.

2.5.3 Derivation of drought risk maps from drought indices

To represent drought exposure and vulnerability, the likelihood of drought impact occurrence can be presented in the forms of meteorological and hydrological drought indices (SPI and SDI, respectively), which were used to generate drought risk maps for the Lower Nam Phong River Basin. First, both SPI and SDI drought indices calculated at 3- and 6-month time scales under the RCP8.5 scenario between 2020 and 2050 were used to determine the cumulative frequencies of drought events (drought indices less than 0) based on the drought classification criteria indicated in Table 1 [27]. Possible drought periods were assessed for different time frames: near-future (2020 – 2030), mid-future (2031 – 2040), and far-future (2041 – 2050). To draw the drought risk maps, each point-based SPI and SDI values was averaged over time and area to find the mean SPI and SDI values. The possible drought periods (SPI and SDI values less than 0) with the highest cumulative frequencies were spatially interpolated using kriging in ArcGIS to assess the possible spatial extent of drought identified by the SPI and SDI between 2020 and 2050 in the Lower Nam Phong River Basin [28].

3. Results

The results obtained from the assessment of climate change impacts on drought severity over the Lower Nam Phong River Basin can be divided into 4 main parts with more details presented below.

3.1 Results on the prediction of future climate data

Prior to obtaining future climate data, the Coefficient of Determination (R^2) was calculated from the daily values of observed climate and bias-corrected data from 2006 – 2016. As suggested by [29], R^2 value of greater than 0.50 is regarded as acceptable for justifying whether the Delta Change Method can improve the quality of simulated climate data generated by RegCM4 under the RCP8.5 scenario (see Figures 4 and 5 for more details).

Considering Figures 4 and 5, the R^2 was found to be higher than 0.50 in all cases, which suggests good agreement between the observed and future climate data generated by

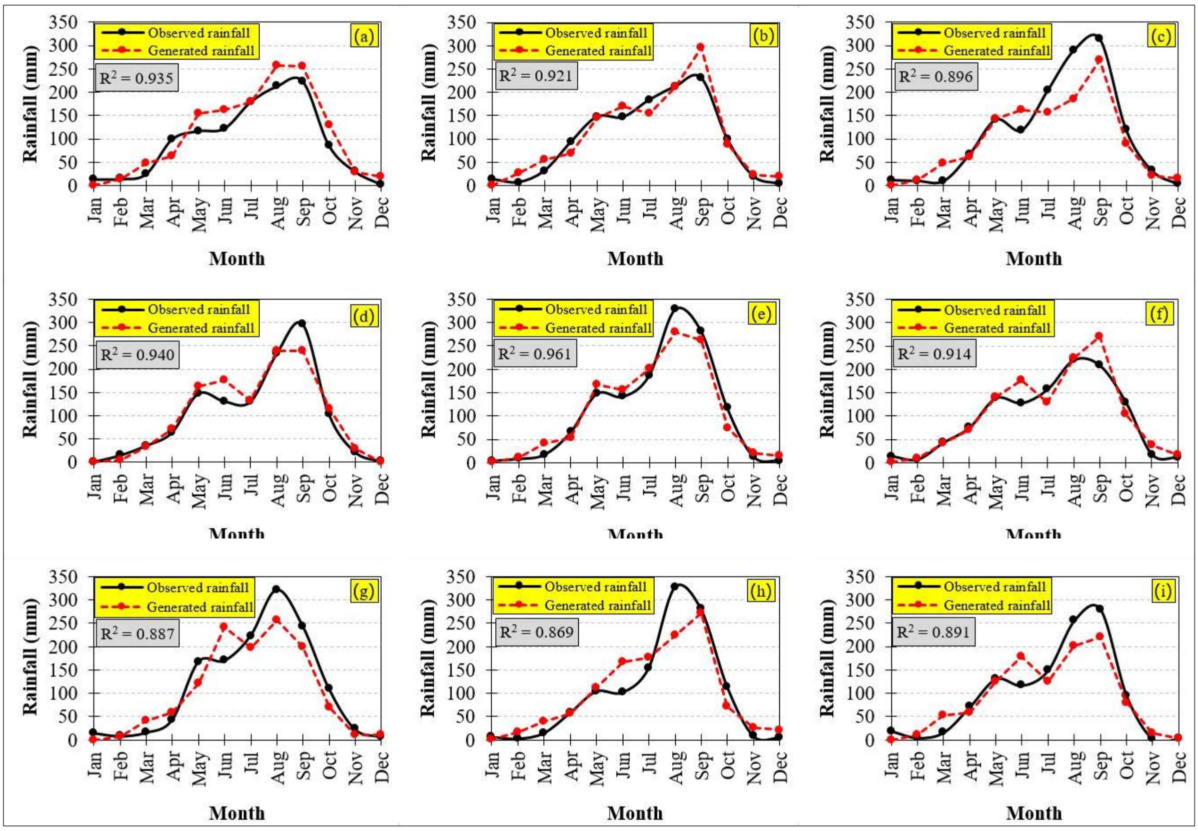

Figure 4 The comparison between observed and bias-corrected average monthly rainfall for 2006 – 2016 at: (a) station 140013, (b) station 140093, (c) station 140062, (d) station 140452, (e) station 140082, (f) station 140332, (g) station 680052, (h) station 750062, and (i) station 210072 (see Figure 2 for location of stations)

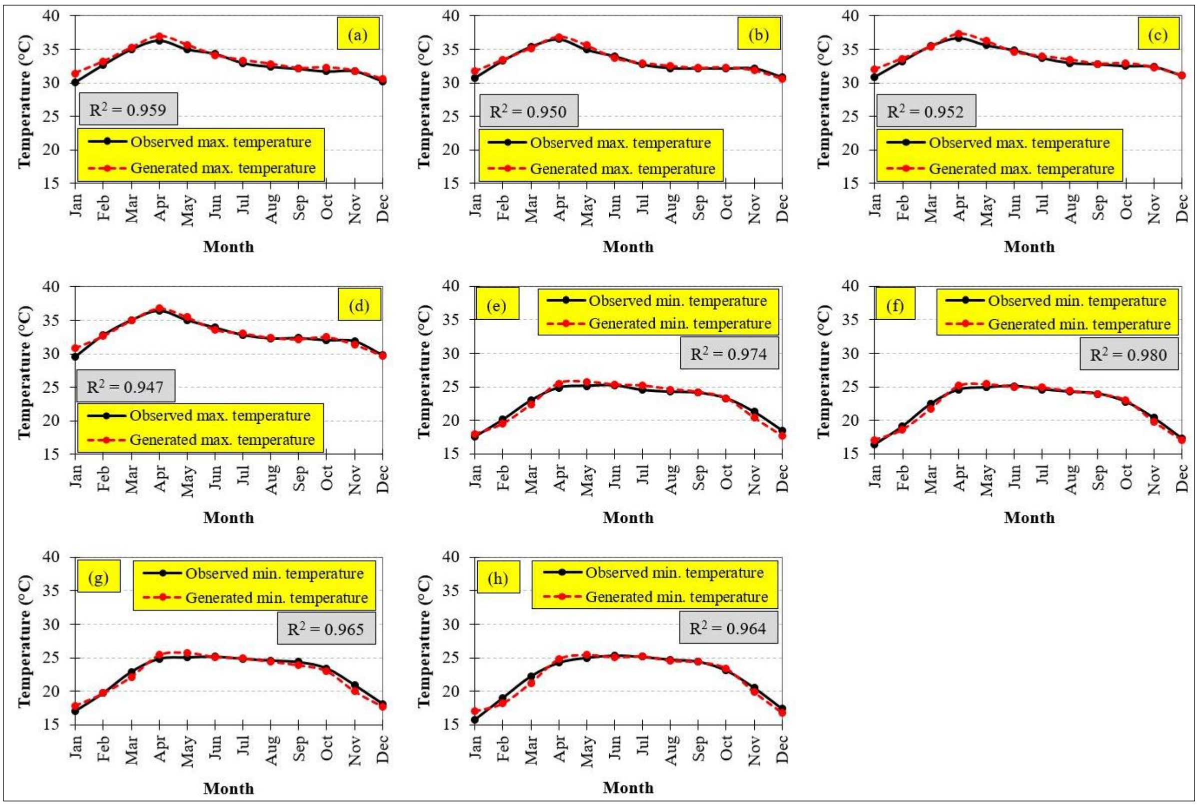

Figure 5 Comparison between observed and bias-corrected average monthly temperatures for 2006 – 2016 at: (a) station 140013, (b) station 140093, (c) station 210012, (d) station 680013 for average monthly maximum temperature; and (e) station 140013, (f) station 140093, (g) station 210012, (h) station 680013 for average monthly minimum temperature (see Figure 2 for location of stations)

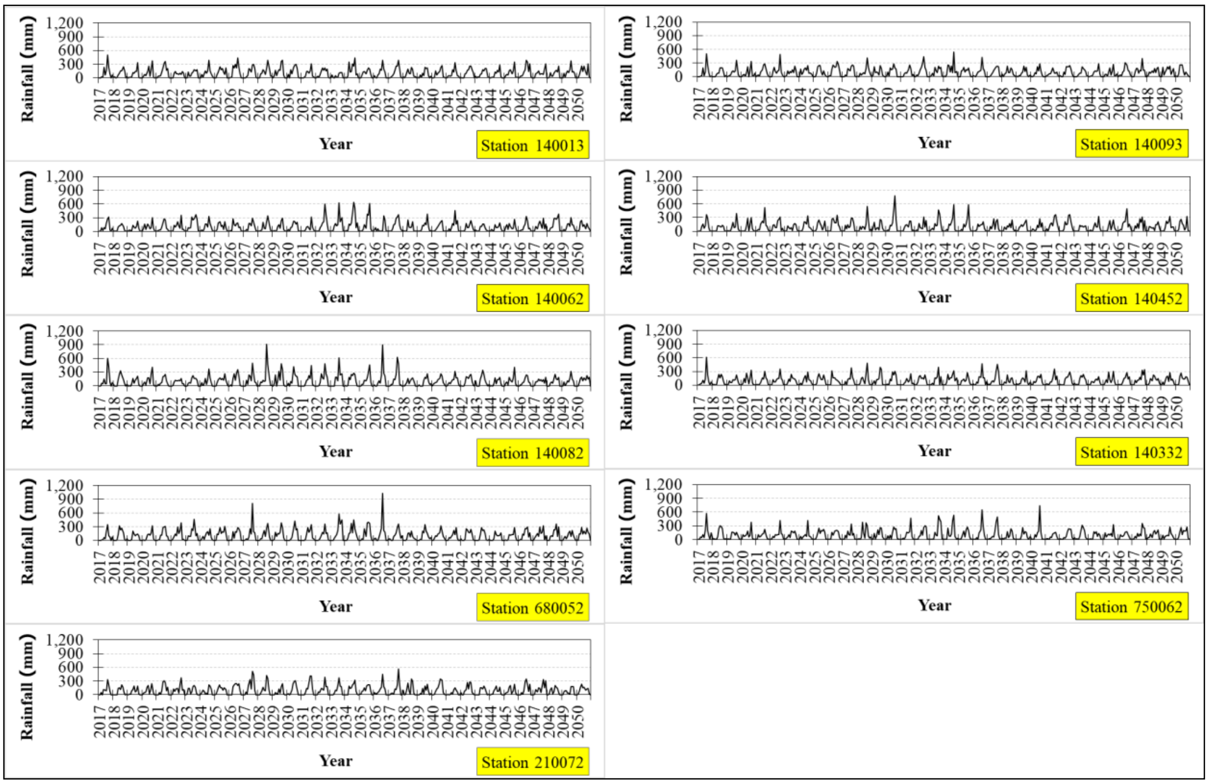

Figure 6 Future projected rainfall under the RCP8.5 scenario at different rainfall stations during the period 2017 to 2050 (see Figure 2 for location of stations)

Table 2 Range of values for the eight most sensitive parameters for the SWAT model listed by name and input file type, definition, and the range of values that were selected for the model

No	Parameter description	Code	File	p-value	t-stat
1	SCS Curve Number	CN2	.mgt	1.71×10^{-134}	-30.389
2	Effective hydraulic conductivity in main channel	CH_K2	.rte	7.83×10^{-52}	16.338
3	Slope length for lateral subsurface flow	SLSOIL	.hru	1.26×10^{-39}	13.944
4	Soil evaporation compensation factor	ESCO	.hru	1.21×10^{-29}	-11.790
5	Baseflow alpha factor for bank storage	ALPHA_BNK	.rte	4.36×10^{-25}	-10.714
6	Average slope steepness	HRU_SLP	.hru	5.18×10^{-12}	-7.009
7	Saturated hydraulic conductivity of soil layer 1	SOL_K1	.sol	2.03×10^{-10}	-6.444
8	Groundwater revap coefficient	GW_REVAP	.gw	6.32×10^{-5}	4.022

RegCM4 under the RCP8.5 scenario for 2006 – 2016. The projected future daily climate datasets under the RCP8.5 scenario between 2017 and 2050 were then obtained to assess the probability of drought occurring in the Lower Nam Phong River Basin. By considering the projected rainfall under RCP8.5 shown in Figure 6, the future annual minimum and maximum rainfall were found to be approximately 487.0 mm/year in year 2033 at station 140013, and 2,341.0 mm/year in year 2034 at station 140062, respectively. In view of future mean annual rainfall in the Lower Nam Phong River Basin between 2017 and 2050, this prediction indicated the average amount of 1,191.1 mm/year, which is slightly lower than the present rainfall condition (1,237.6 mm/year as presented by [7]). Based on rainfall variability, possible anomalies in future mean annual rainfall may lead to drought occurrence in the study area especially during the dry season.

3.2 Results for future streamflow projections

After providing the future RCP8.5 projection of rainfall and maximum and minimum temperatures into the calibrated and validated SWAT model, the SWAT model was run to yield the projected future streamflow during the period 2017 – 2050.

3.2.1 Results of SWAT sensitivity analysis

The SWAT sensitivity analysis was performed to find the sensitive parameters when applying SWAT to the Lower Nam Phong River Basin. In detail, the only specific parameter was modified, whereas all other parameters were unchanged, to identify how the adjusted parameter affect streamflow simulation. Using the SWAT-CUP based Latin Hypercube Global Sensitivity Analysis Method, the listed parameters presented in Table 2 were selected based on their highest absolute t-stat values and the minimized p-values (close to zero), which will then be used in SWAT model calibration and validation processes.

Referring to Table 2, the SCS Curve Number (CN2) was found to be the most sensitive parameter with the highest absolute t-stat value of 30.389 and the lowest p-value of 1.71×10^{-134} for simulating the streamflow of the Lower Nam Phong River Basin. The Groundwater revap coefficient

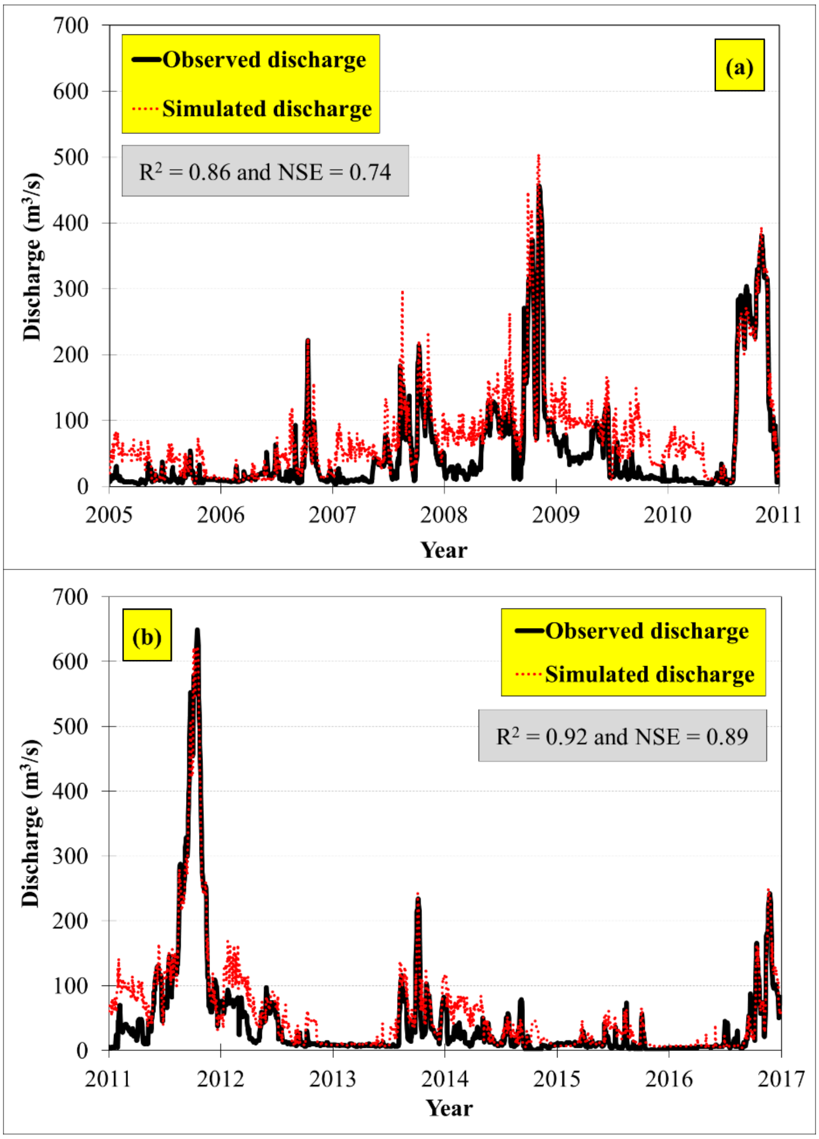

Figure 7 Comparison of SWAT simulated and observed daily discharges during: (a) the calibration period; and (b) the validation period at the E.22B gauging station

(GW_REVAP) was noted as the least sensitive parameter among the listed parameters with the absolute t-stat value and p-value of 4.022 and 6.32×10^{-5}, respectively. Three of the eight relatively sensitive parameters illustrated in Table 2, SCS Curve Number (CN2), Saturated hydraulic conductivity of soil layer 1 (SOL_K1), and Groundwater revap coefficient (GW_REVAP), were found to correspond to the sensitive parameters proposed by [4].

3.2.2 Results of calibration and validation of SWAT model

The SWAT model was manually calibrated using observed daily streamflow time series from the E.22B gauging station for 6 years (2005 – 2010) by adjusting the most sensitive parameters identified by sensitivity analysis. After that, the model was validated using data for the following 6 years (2011 – 2016). Statistical indicators (R^2 and NSE) [30-31], were used to evaluate the goodness-of-fit for simulated data to observed data. Figure 7 shows that the simulated results correspond well with observed time series in all the years as can be seen from the R^2 and NSE values equal to 0.86 and 0.74 for the calibration period, and 0.92 and 0.89 for the validation period, respectively. Based on these measures, the calibrated model performed reasonably well in calculating daily discharges in the Lower Nam Phong River Basin.

3.2.3 Assessment of future discharge under climate change impacts

Since the SWAT model is able to simulate streamflow with reasonable accuracy, the calibrated and validated SWAT model was then applied to future climate scenarios to generate streamflow for years 2017 – 2050. Future discharge under the RCP8.5 scenario, driven by the projected RegCM4 climate outputs, was calculated, as depicted in Figure 8. It was estimated that the highest future discharge at the E.22B gauging station will occur in the year 2035. The projected future daily discharge was then used to derive the SDI for the assessment of hydrological drought in the Lower Nam Phong River Basin.

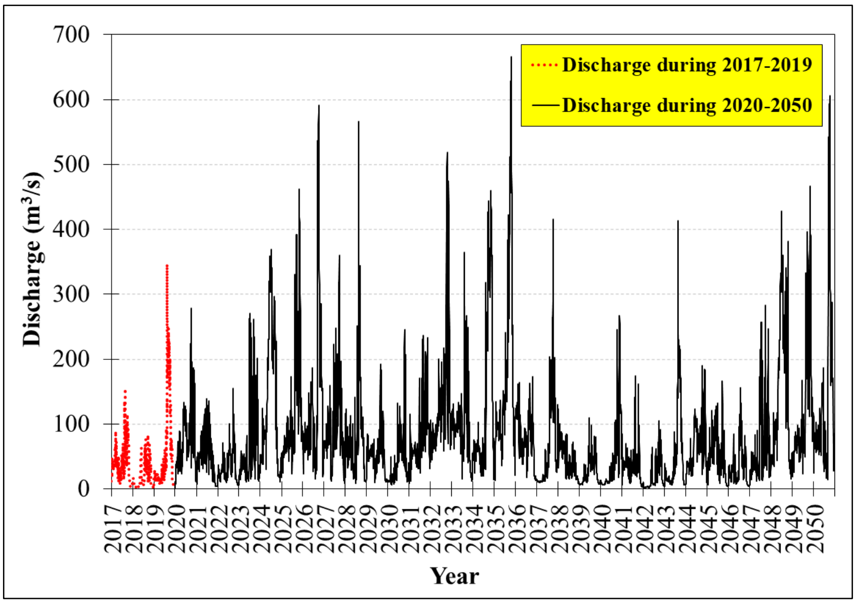

Figure 8 Current (2017 – 2019) and future discharge (2020 – 2050) under the RCP8.5 scenario at the E.22B gauging station

Table 3 The probability of drought occurrence based on SPI drought index under RCP8.5 for different periods (SPI < 0)

Drought index	Time period	Probability of drought occurrence
SPI-3	2020 – 2030	57.4
	2031 – 2040	76.9
	2041 – 2050	75.9
SPI-6	2020 – 2030	65.7
	2031 – 2040	80.6
	2041 – 2050	90.7

Table 4 The probability of drought occurrence based on SDI drought index under RCP8.5 for different periods (SDI < 0)

Drought index	Period	Probability of drought occurrence
SDI-3	2020 – 2030	76.9
	2031 – 2040	95.1
	2041 – 2050	87.3
SDI-6	2020 – 2030	80.9
	2031 – 2040	97.5
	2041 – 2050	87.3

3.3 Evaluation of SPI and SDI drought indices

SPI and SDI drought indices were calculated for certain locations on different monthly time scales. Specifically, the SPI values for 9 rainfall stations, (140013, 140093, 140062, 140452, 140082, 140332, 680052, 750062, and 210072) were computed for time scales of 3 and 6 months under the RCP8.5 scenario between 2020 and 2050. The cumulative frequencies of drought events (SPI values < 0) were determined (Table 3). The SPI with a longer time scale (SPI-6) shows droughts lasting longer and occurring more frequently for all periods in comparison to SPI-3, as illustrated in Table 3. Regarding the SDI index, hydrological drought was defined for 27 sub-basins for overlapping periods of 3 and 6 months under the RCP8.5 scenario between 2020 and 2050. The longer drought duration and more frequent drought occurrence were detected for longer time scales (SPI-6) compared with SPI-3 for all periods (Table 4).

3.4 Spatial distribution of drought severity using SPI and SDI indices

The severity of drought in the Lower Nam Phong River Basin was identified and mapped based on different meteorological and hydrological stations within and adjacent to the study area for the selected periods: near-future (2020 – 2030), mid-future (2031 – 2040), and far-future (2041 – 2050).

3.4.1 Mapping spatial distribution of SPI drought index

Output from the SPI Generator software was used as input to ArcGIS for generating drought severity maps for the Lower Nam Phong River Basin at 3 and 6-month time scales. The estimated SPI time series values at each rainfall station were interpolated by kriging interpolation technique in ArcGIS Spatial Analyst to create a surface from point locations, for better representation of drought distribution tendency over heterogeneous topographic terrain. Considering Table 3 and Figure 9, at a 3-month time scale (SPI-3) under RCP8.5, the period during 2031 – 2040 would have the highest probability of drought occurrence (76.9%). An SPI-3 extreme drought event is expected to occur in the western part of the Lower Nam Phong River Basin covering Ban Dong, Thung Pong, and some parts of Na Kham and Khuean Ubol Ratana Sub-districts, whereas the vast majority of the areas from the mid- to downstream areas are likely to face severe drought condition, similar to the results from [32]. For SPI-6, the highest probability of drought occurrence would occur during 2041 – 2050 and was found to be 90.7% (Table 3). Considering Figure 10, the SPI-6 severe drought event is likely to affect some parts of Ban Dong, Na Kham, and Khuean Ubol Ratana Sub-districts (western part), and some parts of Ban Fang, Nong No, Nong Ko, and Huai Chot Sub-districts located on the eastern side, whereas moderate drought is expected in the remaining areas of the river basin. These findings, especially the area covered by moderate drought, is comparable to the results found in [28].

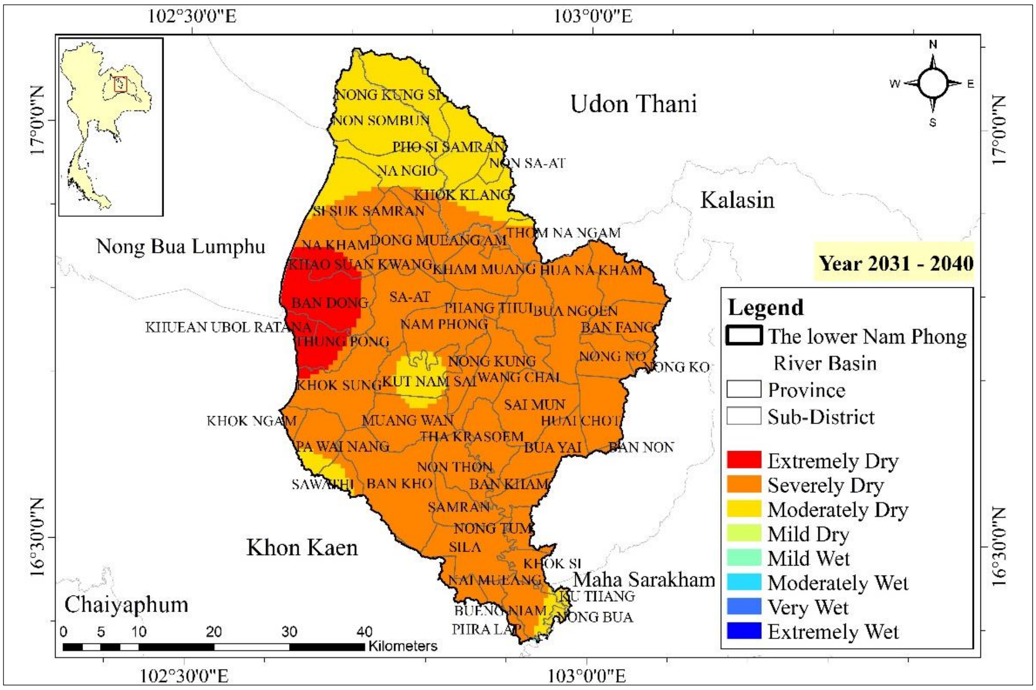

Figure 9 The spatial distribution of drought occurrence probability of SPI-3 under RCP8.5 between 2031 and 2040

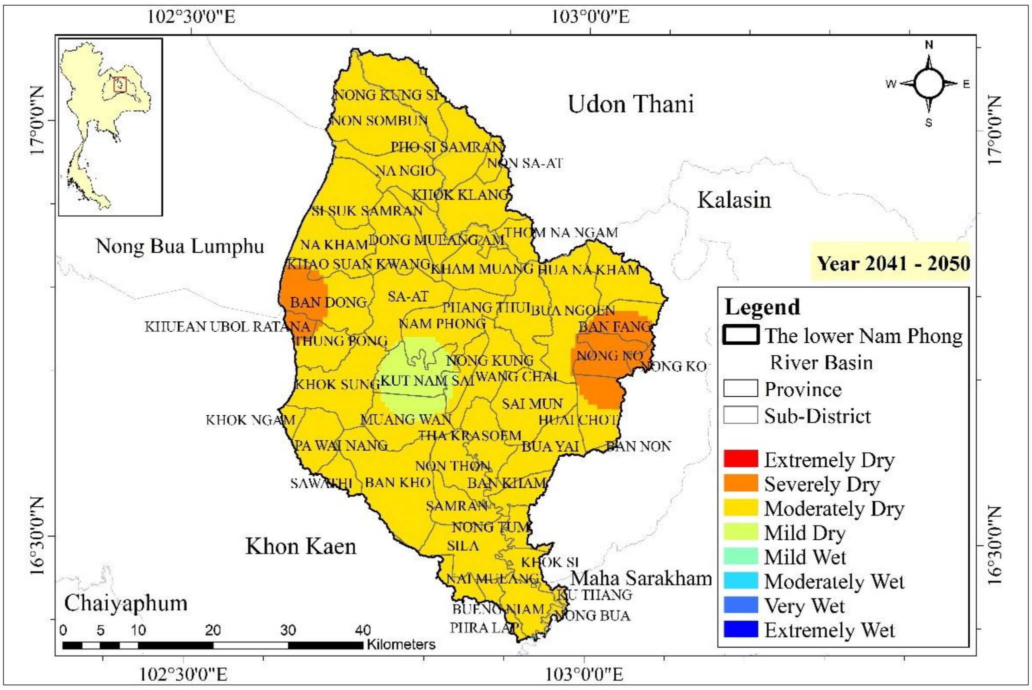

Figure 10 The spatial distribution of drought occurrence probability of SPI-6 under RCP8.5 between 2041 and 2050

When comparing Figures 9 and 10, it is evident that extreme drought severity shown by SPI-3 is likely to propagate westwards, whereas the extreme drought is not detected throughout the river basin for SPI-6. The central through lower areas would experience severe drought under SPI-3, in which some parts of the western and eastern regions are expected to be hit severely based on SPI-6. Lastly, under SPI-3, there are some potential spots of moderate drought in the upper areas and some parts of the central and lower areas of the river basin, whereas moderate drought under SPI-6 is expected throughout most areas.

3.4.2 Mapping spatial distribution of SDI drought index

Extreme drought events are expected to expand spatially, especially in the eastern part of the Lower Nam Phong River Basin, including Phang Thui, Bua Ngoen, Hua Na Kham, Ban Fang, and Nong No Sub-districts, whereas some parts of

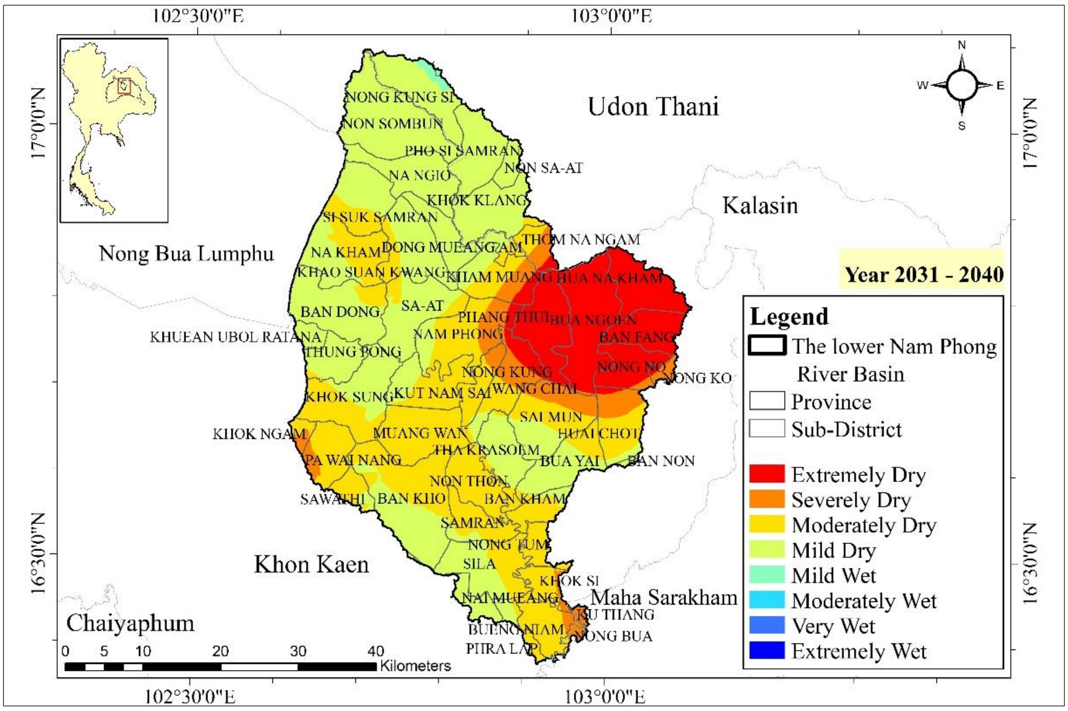

Figure 11 The spatial distribution of drought occurrence probability of SDI-3 under RCP8.5 during 2031 to 2040.

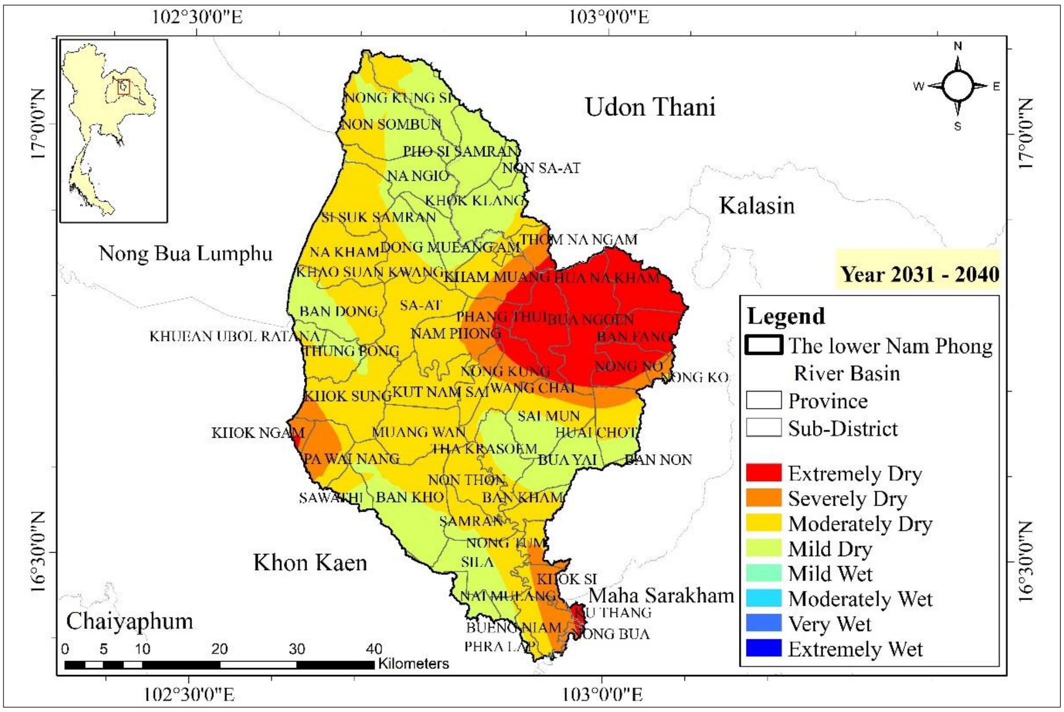

Figure 12 The spatial distribution of drought occurrence probability of SDI-6 under RCP8.5 during 2031 to 2040

Nong Ko, Huai Chot, Sai Mun, Nong Kung, Nong Kung, Nam Phong, Kham Muang, Thom Na Ngam, Khok Ngam, Pa Wai Nang, Khok Si, Ku Thang, and Nong Bua Sub-districts are expected to be threatened by severe drought (Figure 11). For the six-month scale (SDI-6), the 97.5% probability of occurrence of dry spells is the highest for 2031 – 2040 (Table 4). Based on generated spatial drought extent (Figure 12), the drought spatial pattern is similar to the case of SDI-3 with extreme and severe drought concentrated over eastern areas and extending along the western (some parts of Khok Sung, Khok Ngam, Pa Wai Nang Sub-districts) and southeastern edges of the river basin (some parts of Nong Tum, and Bueng Niam Sub-districts) with severe drought conditions. For both SDI-3 and SDI-6, the findings, which demonstrate that extreme drought is expected to intensify over the eastern region, align with the results in [33].

Figures 11 and 12 suggest that extreme drought would occur in eastern areas for both SDI-3 and SDI-6. Both SDI-3 and SDI-6 also show that severe drought would take place in the eastern and lower parts of the river basin. Furthermore, the SDI-3 moderate drought condition is likely to spread from central to lower areas, while it would expand from the upper to the lower end for SDI-6.

4. Conclusions

The importance of this study lies in forecasting climate change impacts on drought severity in the Lower Nam Phong River Basin, Thailand, during the period from 2020 to 2050, through SPI and SDI drought indices. First, a SWAT model was calibrated (years 2005 – 2010) and validated (years 2011 – 2016) with reasonable accuracy (R^2 and NSE > 0.50), based on the eight most sensitive parameters. Subsequently, the RegCM4 simulation outputs, including monthly rainfall, and monthly maximum and minimum temperatures during 2006 – 2016, were bias-corrected by the Delta Change Method in the CMhyd tool with acceptable R^2 (> 0.50). The RegCM4 output was then used for climatic projection under the RCP8.5 scenario for 2017 to 2050. Thereafter, the calibrated SWAT model was used to predict future streamflow under the RCP8.5 scenario for 2017 to 2050 by using the projected RegCM4 future climate data. Next, the SPI and SDI drought indices were calculated for 3- and 6-month time scales using RegCM4 future daily rainfall and future daily discharges for each sub-basin outlet obtained from SWAT. Finally, the interpolated SPI spatial distribution maps were created based on the probability of drought occurrence.

Important findings from this study reveal that based on SPI-3 under the RCP8.5 scenario from 2031 to 2040, the western part of the Lower Nam Phong River Basin (i.e. Ban Dong, Thung Pong, and some parts of Na Kham and Khuean Ubol Ratana Sub-districts) could be affected by extreme drought conditions, whereas the other areas (mid- to downstream) would face severe drought conditions. For SPI-6 under the RCP8.5 scenario from 2041 to 2050, severe drought conditions are expected in both eastern (some parts of Ban Fang, Nong No, Nong Ko, and Huai Chot Sub-districts) and western areas (some parts of Ban Dong, Na Kham, and Khuean Ubol Ratana Sub-districts), whereas moderate drought would be anticipated throughout the remaining areas. In terms of SDI at a 3-month time scale under the RCP8.5 scenario from 2031 to 2040, the eastern areas, including Phang Thui, Bua Ngoen, Hua Na Kham, Ban Fang, and Nong No Sub-districts, would be prone to extreme and severe droughts (covering some parts of Nong Ko, Huai Chot, Sai Mun, Nong Kung, Nong Kung, Nam Phong, Kham Muang, Thom Na Ngam, Khok Ngam, Pa Wai Nang, Khok Si, Ku Thang, and Nong Bua Sub-districts). Considering SDI-6 from 2031 to 2040, the eastern and some western areas, including some parts of Khok Sung, Khok Ngam, Pa Wai Nang Sub-districts, and southeastern edges covering some parts of Nong Tum, and Bueng Niam Sub-districts would be expected to be vulnerable to extreme and severe drought conditions.

The spatial distributions of both SPI and SDI can identify localities in the Lower Nam Phong River Basin subject to the impacts of severe drought and climate change. Recommended actions for developing policies, monitoring systems, mitigation strategies, and preparedness and action plans for drought risk management in the Lower Nam Phong River Basin can be developed based on this information for improved response and resilient outcomes in the future in the face of climate change and drought impacts.

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6. References

[1] Intergovernmental Panel on Climate Change. The physical science basis: contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, United Kingdom: Cambridge University Press; 2013.

[2] Thailand Science Research and Innovation. Thailand's second assessment report on climate change. Bangkok, Thailand: Thailand Science Research and Innovation; 2016.

[3] U.S. Agency for International Development (USAID). A review of downscaling methods for climate change projections: African and Latin American Resilience to Climate Change (ARCC). Washington: USAID; 2014.

[4] Wongsasri S. Water quantity and quality assessment for Lower Phong Basin by SWAT Model [Dissertation]. Khon Kaen, Thailand: Khon Kaen University; 2012.

[5] Thai Meteorological Department. Drought [Internet]. 2017 [cited 2018 Jun 5]. Available from: https://www.tmd.go.th/info/info.php?FileID=71.

[6] Secretariat Office of the Chi River Basin Committee. Management of the Chi River Basin. Khon Kaen, Thailand: Water Resources Regional Office 4, Department of Water Resources, Ministry of Natural Resources and Environment; 2012.

[7] Kuntiyawichai K, Sri-Amporn W, Pruthong C. Quantifying consequences of land use and rainfall changes on maximum flood peak in the Lower Nam Phong River Basin. Adv Mater Res. 2014;(931-932):791-6.

[8] Hydro Informatic Institute. Data collection and analysis of 25 basin in Thailand (Chi River Basin) and flood-drought simulation. Bangkok, Thailand: Hydro Informatic Institute; 2012.

[9] Pholpuech, S. Basic information on drought. Bangkok, Thailand: The Secretariat of the House of Representatives Printing Office; 2005.

[10] Disaster Prevention and Mitigation Provincial Office (Khon Kaen, Thailand). Strategy for Disaster risk management of Khon Kaen. Khon Kaen, Thailand: Disaster Prevention and Mitigation Provincial Office; 2019.

[11] McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration times scales. 8th Conference on Applied Climatology; 1993 Jan 17-22; Anaheim, California. USA: American Meteorological Society; 1993. p. 179-84.

[12] Aghelpour P, Bahrami-Pichaghchi H, Kisi O. Comparison of three different bio-inspired algorithms to improve ability of neuro fuzzy approach in

prediction of agricultural drought, based on three different indexes. Comput Electron Agr. 2020;170:1-12.

[13] Nalbantis I, Tsakiris G. Assessment of a hydrological drought revisited. Water Resour Manag. 2009;23:881-97.

[14] Reanalyses. Reanalysis. [Internet]. 2010 [cited 2020 Mar 6]. Available from: https://reanalyses.org/reanalysesorg-home-page.

[15] Oh SG, Park JH, Lee SH, Suh MS. Assessment of the RegCM4 over East Asia and future precipitation change adapted to the RCP scenarios. J Geophys Res Atmos. 2014;119:2913-27.

[16] National Institute of Meteorological Sciences. Participating models [Internet]. 2018 [cited 2019 May 6]. Available from: http://cordex-ea.climate.go.kr/cordex/participatingModel.do?fbclid=IwAR2pkZyvFGudZFdDwf1-6NeH0II5g_GUgljbfia6fNGKAb8kfQqdJY5DAhU.

[17] Peters GP, Andrew RM, Boden T, Canadell JG, Ciais P, Quéré CL, et al. The challenge to keep global warming below 2 degrees C. Nat Clim Change. 2013;3:4-6.

[18] Leng G, Hall J. Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. Sci Total Environ. 2019;654:811-21.

[19] Rathjens H, Bieger K, Srinivasan R, Chaubey I, Arnold JG. CMhyd user manual: documentation for preparing simulated climate change data for hydrologic impact studies. Texas: SWAT; 2016.

[20] Minville M, Brissette F, Leconte R. Uncertainty of the impact of climate change on the hydrology of a Nordic Watershed. J Hydrol. 2008;358:70-83.

[21] Hongsawong P, Samsalee R, Sittichok K. The study of parameter sensitivity of SWAT Model for runoff simulation in Maeklong River Basin [Internet]. Thailand: Department of Irrigation Engineering, Kamphaensaen Kasetsart University; 2016 [cited 2018 Jun 9]. Available from: http://irre.ku.ac.th/project/pdf/255906.pdf.

[22] Abbaspour KC, Ashraf VS, Srinivasan R. A guideline for successful calibration and uncertainty analysis for soil and water assessment: a review of papers from the 2016 international SWAT Conference. Water. 2018;6:1-18.

[23] Yuttaphan A, Baimuang S. Bias correction technique for meteorological data of climate model output under the scenario focus on regional economic development (A2). Naresuan Univ Eng J. 2014;8:34-9.

[24] National Drought Mitigation Center-UNL. SPI Generator free software, version release date 6 September 2018 [Internet]. 2018 [cited 2019 Apr 18]. Available from: https://drought.unl.edu/droughtmonitoring/SPI/SPIProgram.aspx.

[25] Dalezios NR, Tarquis AM, Eslamian S. Drought. In: Dalezios NR. Droughts. Dalezios NR, editor. Environmental hazards methodologies for risk assessment and management. London, UK: International Water Association Publishing; 2017. p. 177-210.

[26] Hong X, Guo S, Zhou Y, Xiong L. Uncertainties in assessing hydrological drought using streamflow drought Index for the upper Yangtze River Basin. Stoch Environ Res Risk Assess. 2014;29:1235-47.

[27] Khaewsuriyan A. Statistical downscaling model for evaluating climate change impacts on rainfall in Chi and Mun River Basin [Dissertation]. Pathumthani, Thailand: Thammasat University; 2008.

[28] Chomtha T. A study of meteorological drought index model for drought areas in Northeastern Thailand. Bangkok, Thailand: Meteorological Department; 2006.

[29] Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE. 2007;50:885-900.

[30] Krause P, Boyle DP, Base F. Comparison of different efficiency criteria for hydrological model assessment. Adv Geosci. 2005;5:89-97.

[31] Nash JE, Sutcliffe JV. River flow forecasting through conceptual models: part I. A discussion of principles. J Hydrol. 1970;10:282-90.

[32] Dau QV, Kuntiyawichai K, Suryadi FX. Drought severity assessment in the Lower Nam Phong River Basin, Thailand. Songklanakarin J Sci Tech. 2018;40:985-92.

[33] Department of Disaster Prevention and Mitigation. Analysis of drought risk area in Northeastern Thailand. Bangkok, Thailand: Department of Disaster Prevention and Mitigation; 2007.