Climate Change and Land Use Change Effect on Water Accounting in Upper Nan Watershed

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***Abstract*—**This study assessed the effect of climate change and land use change on water accounting in the upper Nan watershed, Thailand, using the representative concentration pathway (RCP)4.5 scenario (SC1) and the RCP8.5 scenarios (SC2) of the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Two additional scenarios were based on the national park policy in Nan province, Thailand which aimed to increases forest area by 3% (SC3) and 10% (SC4). The soil and water assessment tool (SWAT) model was applied to simulate the streamflow using meteorological data over a 20 year period from 1998 to 2017. The results showed that the SWAT model produced an acceptable performance for calibration and validation, yielding Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2) values greater than 0.5. Under the extreme climate change scenario (SC2) water accounting decreased annually in both the wet and dry periods. Water accounting in the land use change scenarios in which forest area increased (3% and 10%) showed increases annually and in the dry period, but there was a decrease in the wet period. This result indicated that climate change and land use change influenced water accounting in the upper Nan watershed.

Keywords*—*water accounting, climate change, land use change, upper Nan watershed

I. INTRODUCTION

Climate change has caused the air temperature and rainfall intensity to change which in turn has affected the amount of rainfall and total streamflow [1] [2]. Many previous studies have assessed the impact of climate change on streamflow in watershed. These studies found that streamflow variability is closely associated with climate change. Moreover, land cover/land use (LULC) change has a continuous effect on the environment especially in the head water of a watershed with regard to quantity and timing. Therefore, many previous studies have investigated the combined effect of climate change and LULC change on hydrological [3] [4]. The two driving forces of climate change and land use change affect hydrological change in the watershed [5] [6].

The upper Nan watershed is an important head water area in the northern Thailand. It consists of steep mountains and hillsides making it extremely sensitive to change. Over an 8 years period (2009-2016), highland agricultural area increased 13.09% affecting the normal hydrological process that effect to bulk density has compacted, decreased soil infiltration and continuous effect on streamflow. These are the reason that hydrological has imbalanced by LULC and climate change. For example, Nan province experienced extreme flooding in August 2018.

Thus, it is crucial to assess the potential effect of climate change and land use change on water accounting spatially and temporally using the water accounting complement of Inflow, Outflow, and Depleted water [7] based on water balance to understand and drive adaptation in the future.

The Fifth Assessment Report (AR5) of the IPCC [8] is based on the Representative Concentration Pathway scenarios (RCPs; RCP8.5, RCPC6.0, RCP4.5, and RCP2.6 W/m^2 radiative forcing scenarios), which range from worse to optimistic emission scenarios, respectively. The RCPs impact on climate change is considered to include impacts caused by LULC.

The current study assessed the potential effect of climate change and LULC change on water accounting in the upper Nan watershed, Thailand. Factor considered in this study are summarized as follows:

1. LULC in the watershed as developed under the Doiphukha National Park policy, which increased the forest area by expropriating cleared land from formerly forested areas.

2. The soil and water assessment tool (SWAT), a distributed hydrological model was calibrated and validated automatically to simulate the streamflow in the watershed

II. STUDY AREA

The upper Nan watershed has an area of 3,459 km^2 in Nan province, Thailand (Fig.1), having elevation range from 220 to 1,923 m above sea level and an average slope of 32.3°. Most precipitation occurs from July to October in the watershed and the dry period extends from December to April. The annual average precipitation is approximately 1,500 mm with an annual average temperature of 25.9°C.

Capacity Building Program for New Researcher 2019 from National Research Council of Thailand (NRCT)

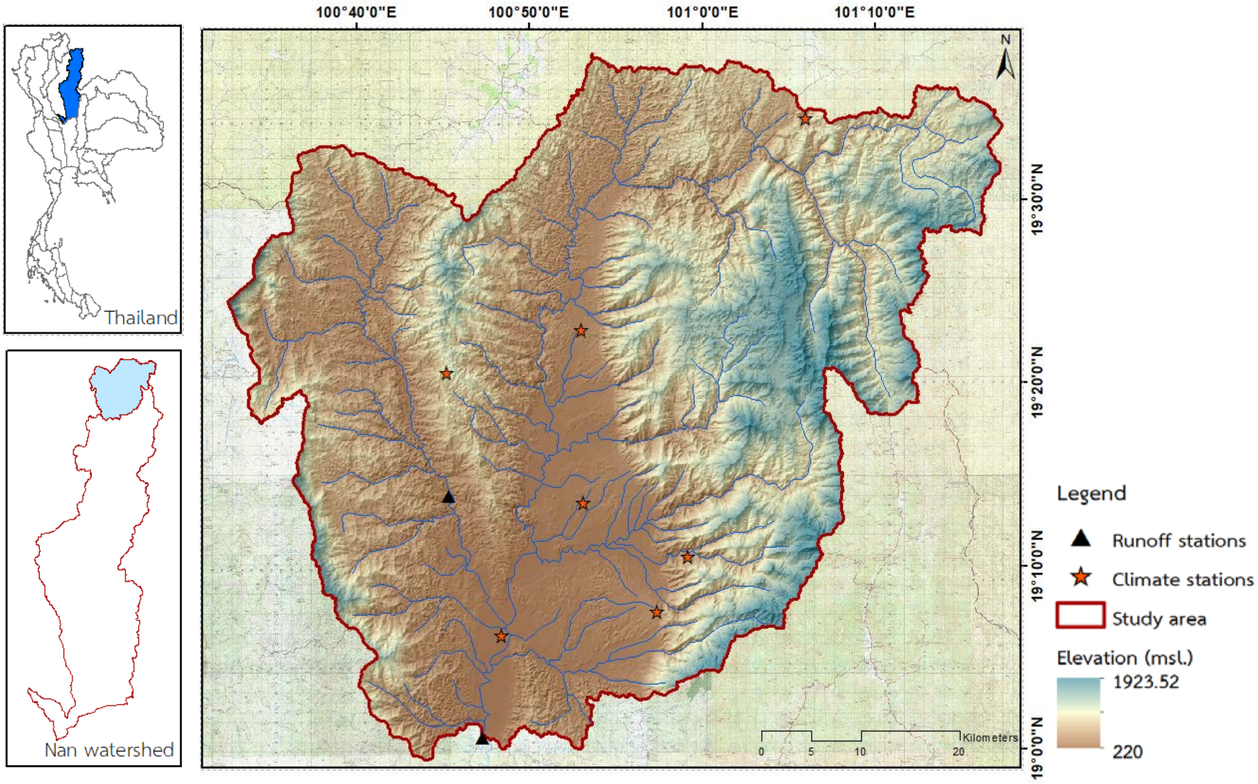


Fig.1 Digital elevation model and location of upper Nan watershed and associated, runoff-climate stations

III. METHOD

A. Data preapation

The following were used

1) Digital elevation model (DEM) with a 20 m grid interval

2) Soil group map at a scale of 1: 100,000

3) Land use map scale 1: 50,000 at 2016 provided by Land Development department.

4) Daily climate data (1998 to 2017) consisting of rainfall (mm), maximum temperature (□C), minimum temperature (□C), humidity (%), wind speed (m/s), and solar radiation (MJ/m^2)

5) Daily runoff data (1998 to 2017) at station N64 located in Thawangpha district, Nan province, Thailand.

B. Assessment of streamflow using the SWAT model

The steps in this section were:

1) Prepare input data to SWAT model (DEM, land use map, soil group map, and daily climate data 1998 to 2017)

2) Watershed delineation was determined using the DEM to analyze the physical aspects of the watershed area

3) Hydrologic response unit (HRU) analysis was based on land use map, soil group map, and slope with multiple HRUs

4) Prepare input table of climate data and SWAT model setup and run.

5) Calibration of SWAT model including adjustment of hydrological characteristic parameter using the Nash-Sutcliffe efficient (NSE) as in (1) and coefficient of determination (R^2) as in (2)

$$R^2 = \left[\frac{\sum_{i=1}^{n}(o_i - \bar{o})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(o_i - \bar{o})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right]^2 \qquad (1)$$

$$NSE = \frac{\sum_{i=1}^{n}(o_i - P_i)^2}{\sum_{i=1}^{n}(o_i - \bar{o})^2} \qquad (2)$$

Where O_i = Observed data

P_i = Simulated data

$\bar{o}$ = Average of observed data

$\bar{P}$ = Average of simulation data

Satisfactory performance is indicated by tgeR^2 and NSE values being close 1 which indicates the simulation and observe data were very similar. Table I presents the performance rating for NSE, as suggested by [9]

Table I. Performance rating for the recommended statistics.

Performance rating	NSE
Very good	$0.75 < NSE \leq 1.00$
Good	$0.65 < NSE \leq 0.75$
Satisfactory	$0.50 < NSE \leq 0.65$
Unsatisfactory	$NSE \leq 0.5$

C. Assessment of water accounting

Water accounting was assessed using the model and theory as follows:

1) Inflow (I) = precipitation from the SWAT model

2) Depleted water (DP) was separated into two processes:

a) Agricultural evapotranspiration using CROPWAT 8.0

b) Evapotranspiration of forest area base on the SWAT model

3) Outflow (O) = streamflow as assessed using SWAT model

4) Assessment of water accounting as in (3), where a negative value indicates a deficit and a surplus is indicated by a positive value.

$$\text{Water accounting} = I - O - DP \tag{3}$$

The resultant classification is shown in Table II

Table II. Water accounting classification of upper Nan watershed

Class	Value
Extreme deficit	<-170.0
Deficit	-170.0 to -50.1
Balance	-50 to 60.0
Surplus	60.1 to 200.0
Extreme surplus	> 200.0

5) Assessment of spatial water accounting using a Geographic Information System (GIS).

a) Combined the temporal water accounting and watershed map by join field tool.

b) Using feature to raster tool for create component of water accounting (inflow outflow and depleted water)

c) Calculated water accounting by Map algebra tool

d) Classification water accounting by reclassify tool followed Table II

D. Predicted water accounting under climate change and land use change in upper Nan watershed based on four different scenarios

1) Scenario 1 (SC1) involved moderate change in climate based on RCP4.5 which increased the average air temperature by 1.4 °C

2) Scenario 2 (SC2) involved extreme change in climate base on RCP8.5 which increased the average air temperature by 2 °C.

3) Scenario 3 (SC3) involved increased forest area (3%) based on the Doiphukha National Park policy which relied on expropriating cleared land from formerly forested areas during 2002 to 2014

4) Scenario 4 (SC4) involved increased forest area (10%) based on the Doiphukha National Park policy which relied on expropriating cleared land from formerly forested areas before 2002.

IV. RESULTS AND DISCUSSION

A. Calibration and validation model

Daily values of simulated streamflow were compared with actual observations to calibrate the SWAT model. The parameters used for the SWAT model simulation are given in Table III. The simulation values were slightly higher than the observed values (Fig. 2). In the calibration, the R^2 and NSE values were 0.86 and 0.74, respectively, while for validation, the R^2 and NSE values were 0.85 and 0.72, respectively. These results showed the calibration and validation models could describe streamflow in upper Nan watershed, as the R^2 and NSE were greater than 0.5 [7].

Table III. Sensitivity analysis parameters.

Rank	Name	Definition	Sensitivity	Process
1	CN2	SCS runoff curve number for moisture condition 2	-2	Runoff
2	ESCO	Soil evaporation compensation factor	0.7	Evaporation
3	SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	1.35	Soil

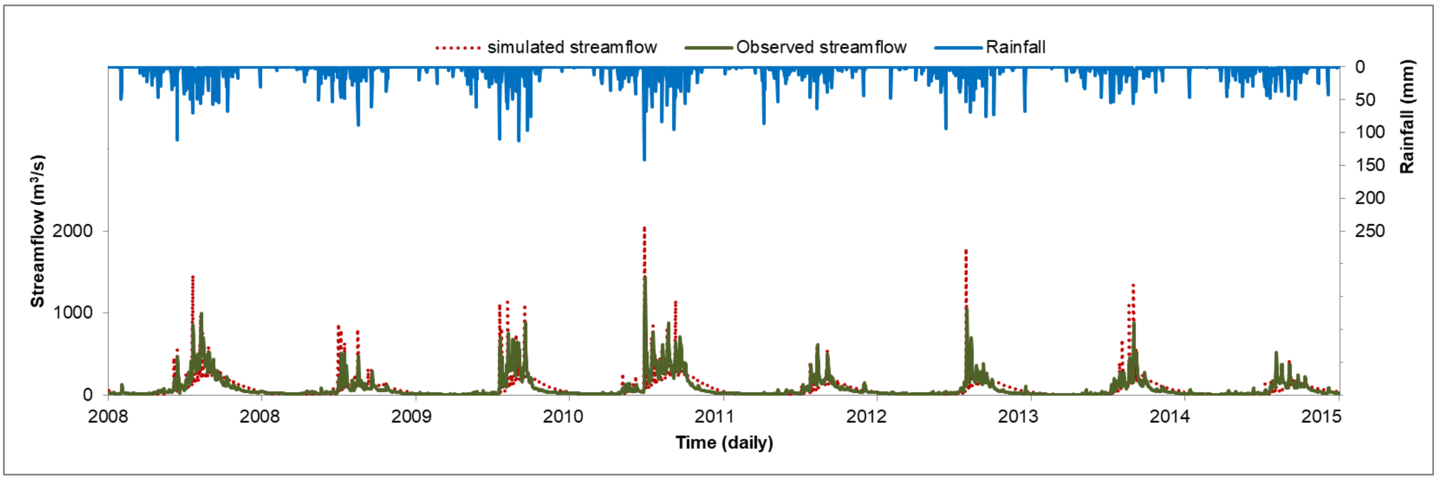


Fig. 2 Observed and simulated streamflow and corresponding daily rainfall in upper Nan watershed

B. The component of water accounting

1) The only Inflow (I) was precipitation in this area. In 2017 the total rainfall was with 1,358.6 mm which was higher than predicted under SC1 by about 4.6% due to the weak La Nina effect in 2017 [10]. In contrast, the SC2 predicted rainfall was 1,519.1 mm which was an increase of 11.8% over the actual 2017 amount (Table IV). SC3 and SC4 both had equivalent values for the rainfall as these scenarios were based on the average climate data (1998-2017).

Table IV Annual rainfall and variability (%) of average Inflow under climate and land use scenarios for the upper Nan watershed

complement	**Inflow under each scenarios**				
	2017	**SC1**	**SC2**	**SC3**	**SC4**
Annual rainfall (mm)	1,358.6	1,295.9	1,519.1	1,290.0	1,290.0
Variability (%)	-	-4.6	11.8	-5.1	-5.1

2) Depleted water (DP) was analyzed as either agricultural evapotranspiration or forest evapotranspiration (Table V)

The results showed that depleted water was highest due to swidden cultivation (308.9 mm) in 2017 and was maximum from August to September. Maize had the least evapotranspiration in 2017 (38.2 mm) with the maximum during the same period as for swidden cultivation. Paddy field (120.8 mm) maximum from September to November. On the other hand, perennial land (159.6 mm) was about the same each month. Forest evapotranspiration in deciduous forest was higher than in evergreen forest (191.3 and 106.5 mm, respectively)

Both agricultural and forest evapotranspiration under SC3 and SC4 showed similar trends in 2017 though maize was lower and swidden cultivation was higher. SC1 and SC2 had lower values in all of land use types.

3) Outflow (O) consisted only of streamflow in this area. The trend was similar to that for rainfall because streamflow was influenced by rainfall [11][12] so that SC1 was the least in 2017, While streamflow was highest in SC2 (Fig. 3). Under SC1 and SC2, in the dry period from January to April there was no streamflow due to the increased temperature (2□C). In contrast, SC3 and SC4 had increased streamflow in the dry period (January to April) and decreased streamflow from September to November (Fig. 3). The extreme climate change resulted in the highest streamflow [13] and increased forest area increased the streamflow [14].

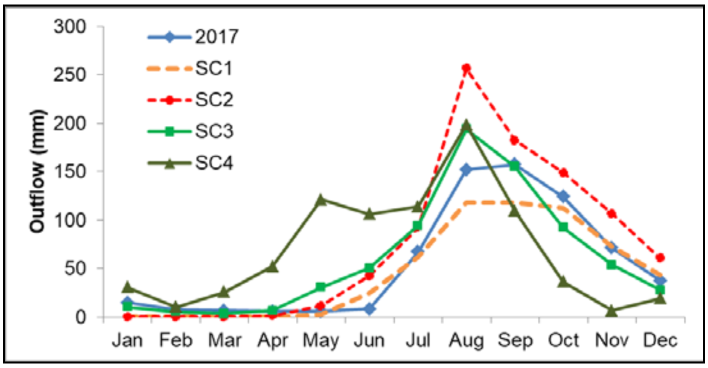


Fig. 3 Monthly Outflow under different land use change and climate change scenarios.

C. Water accounting assessment

Water accounting in 2017 indicated a deficit (Fig. 4) of -134 mm (Table VI). During the dry and wet periods, there was an extreme deficit and surplus of -273.4 and 139.2 mm, respectively. However, while there was high streamflow, the depleted water was higher so that water accounting was in deficit

Climate change affect annual water accounting resulting in an extreme deficit as in Table VI and Fig.4, in the dry and wet periods there was a deficit and balance, respectively in SC2. Annual water accounting in SC1 showed a deficit, but in the dry and wet periods there was a deficit and surplus, respectively.

Table V Annual average depleted water under different climate and land use scenarios in the upper Nan sub-watershed

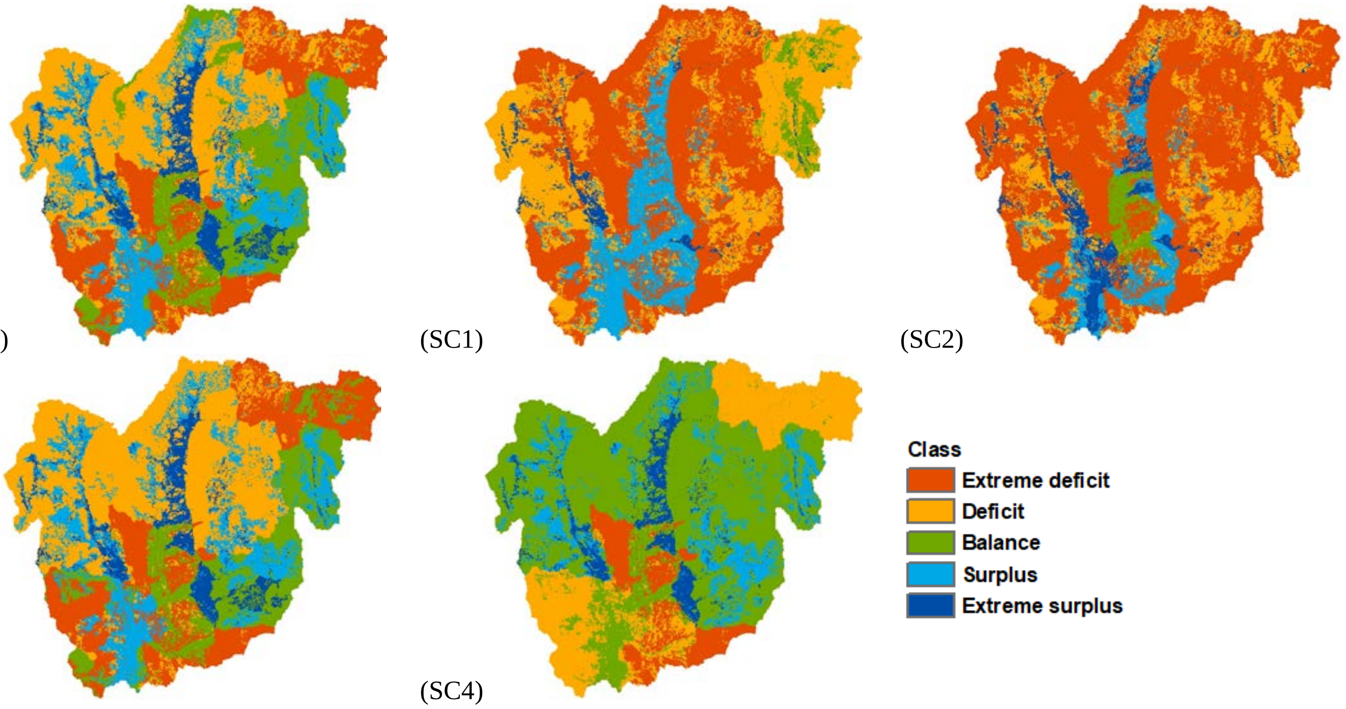
Land use	**Depleted water (mm)**							
	Area (km^2)	**2017**	**SC1**	**SC2**	**Area (km^2)**	**SC3**	**Area (km^2)**	**SC4**
Maize	140.4	38.2	53.7	53.1	125.2	34.1	111.5	30.3
Paddy field	151.9	120.8	115.8	119.4	147.2	117.1	139.1	110.7
Perennial land	212.0	159.6	143.1	144.6	202.4	152.4	84.2	63.4
Swidden cultivation	744.9	308.9	348.4	341.1	698.0	300.1	592.2	281.2
Deciduous forest	1,361.4	191.3	177.8	180.9	1,439.4	191.6	1,690.6	128.1
Evergreen forest	769.9	106.5	95.9	97.3	769.9	105.0	769.9	58.9

Forest area under the policy resulted in decreased water accounting in SC3 and SC4 (-94.1 and -68.5 mm, respectively) as show in Table VI. These were both in deficit on an annual basis (Fig.4), though both SC3 and SC4 had a deficit in dry period and a surplus in the wet period.

The classification of the water accounting was a specific class that could be used to explain water accounting in the upper Nan watershed only. These classifications will change depending on the complement of water accounting factor and each characteristic of the watershed but can be applied to determine present land use planning or in the future. If water accounting shows an extreme deficit then there will be a drought. In addition, an extreme surplus indicates flood.

Table VI Annual, wet period and dry period water accounting under climate change and land use change scenarios.

Period	**Water accounting (mm)**				
	2017	**SC1**	**SC2**	**SC3**	**SC4**
Dry	-273.4	-175.5	-271.2	-184.6	-119.5
Wet	139.2	73.2	33.8	90.5	50.9
Annual	-134.2	-102.4	-237.4	-94.1	-68.5


(2017) (SC1) (SC2)

(SC3) (SC4)

Fig. 4 Spatial distributions of water accounting under climate change and land use change.

V. CONCLUSION

The extreme climate change (SC2) scenario resulted in the baseline year of 2017 having a decreased water accounting on an annual basis and also for the wet and dry periods. Hence, increasing the uncertainty of climate change resulted in a corresponding severe drought.

Water accounting in forest land use change scenarios which (both 3% and 10%) base on 2017, produced an increase in annually and in the dry period, but a decreased in the wet period.

Thus, climate change had a negative effect on water accounting in all time periods studies, while land use had a positive effect on annually and in the dry period. In summary, climate change and land use change influenced to determining water accounting in the upper Nan watershed.

ACKNOWLEDGMENT

I would like to express my sincere appreciation to Dr. Venus Tuankrua and Assist. Prof. Dr. Piyapong Tongdeenok for their advice.

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