Evaluating the Impact of Land Use Change and Climate Change on Hydrological Services in Na Luang Sub-watershed, Nan Province, THAILAND

(Climate Change and Uncertainty in Hydrology and Meteorology)

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Abstract— Nowadays, deforestation under climate change of headwater in Nan province has been a big problem of land use change and encroachment area to expand the maize production area and contract farming such as rubber plantation. There were reducing the ability of soil water storage and affecting to increase runoff and sediment yield in a stream which is hydrological services from the watershed. Hence, hydrological services should be evaluating and forecast using SWAT model in forest and maize sub-watershed. This study divided into six scenarios including SC1: land use in 2016, SC2: Trend scenario, SC3: Sandbox scenario, and SC4–SC6 are land use change with RCP8.5. The results show the total forest area was 20% decreased during 2013–2016 and the maize area has been 40% increase. Water and sediment yield in sub-watershed show significant (NSE = 0.72) when compared with observed data. Both land use changes have a greater impact on annual runoff than sediment yield. Nevertheless, land use which has mostly forest cover still provide water use for agriculture in dry season rather than maize cover area. And this research it was cleared that the climate change had been affecting to hydrological services which provide from the watershed, especially the water timing. The results were obtained in this study can provide information for land use and water resource planning in small sub-watershed as well as soil and water conservation on highland.

Keywords— Land use change, climate change, hydrological services, Nan province, SWAT model

I. INTRODUCTION

Ecosystem services are the values and functions of ecosystems that conducive to human living and happiness were divided into 4 part i.e. provisioning service, regulating service, supporting service, and culture and recreation service. Nan province is the one of the head watersheds which provides water in Nan River. Nowadays, deforestation of the headwater in Nan province has been a big problem of land use change and encroachment area to expand the maize production area with contract farming such as para rubber plantation. Maize cropping area is the one of influenced leading cause to environmental degradation due to unsuitable land use planning. Their activities are affecting soil erosion, which is a worldwide problem directly to environmental sustainability [1]. Raindrop impact makes a large contribution to soil erosion by enhancing soil detachment and runoff disturbance [2]. When raindrops impact to the soil surface, the energy of it used to overcome the bonds holding particles in the soil surface. [3] Then, there were reducing the ability of soil water storage and affecting to increase runoff and sediment yield in the stream which is hydrological services from the watershed. Moreover, the environmental conditions are more drastically deteriorate due to the effect of climate change, there are affecting to flood in wet season and water shortage for agriculture activities during dry season. Therefore, this research has aim to evaluate and forecast the effect of land use change and climate change on hydrological services for determining land use guideline in Naluang sub-watershed using SWAT model.

II. METHODOLOGY

A. Study area

Naluang sub-watershed (Fig. 1) was located in Wiang Sa district, which area has 12.45 square kilometer. This research was conducted in two sub-watersheds, which was 2.51 square kilometer of forest sub-watershed and 4.27 square kilometer of maize sub-watershed. Geographic of Naluang sub-watershed most of the complex mountain and a little lowland. The average slope is more than 35%. The elevation between 210 to 1,980 meters. This area has one village is Pang mon which their uses water for consumption and agricultural activities from Naluang stream.

B. SWAT model input data

1) GIS data

1.1) DEM (resolution 20 x 20 m) from topographic map, map scale is 1:50,000 of The Royal Thai Survey Department.

1.2) Land use and soil series map and statistical data (scale of 1: 50,000) [4].

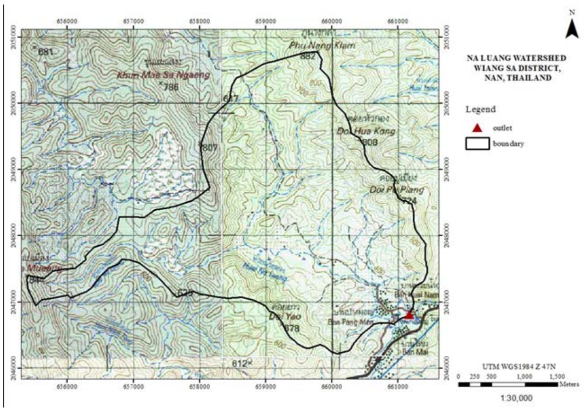


Fig. 1. Naluang sub-watershed, Wiang Sa district, Nan.

2) Statistical data

2.1) Daily and monthly climatic data i.e. rainfall amount, maximum and minimum temperature since 1994 to 2017 [5].

2.2) Daily runoff data of Naluang sub-watershed from the automatic water level station in two representative sub-watersheds, which is different land use patterns as deciduous forest and maize area.

C. Data analysis

1) SWAT model setup and run model

The first step of SWAT is generating sub-watershed by DEM of watershed. The streamline and outlet were created in the next step. The hydrological functions were determined based on hydrological response unit (HRUs), which represent the homogeneous combinations of soil types, land use types, and slope. The streamflow and water balance were calculated in warm-up period from 2010 to 2017. The sediment yield was calculated with MUSLE [6].

2) Model calibration and validation

This research using Sequential Uncertainty Fitting Program (SUFI-2) in the SWAT-CUP (SWAT calibration uncertainty procedures), this algorithm was used for calibration and sensitivity analysis for discharge outflow and sediment yield between observed daily and monthly data with output data from SWAT model. Streamflow will be calibrated at a daily time-step from January 2016 to December 2016. The model validation was set to run in 2017. Calibration SWAT model was adjusted parameter by Nash-Sutcliffe Efficient (NSE) and Coefficient of Determination (R^2), their values were closing 1 that shown simulation and observed data were satisfactory performance. The table I present the performance rating for NSE, as suggested by [7].

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	$NSE \leq 0.5$

3) Determining land use scenarios

According to land use analysis using overlay technique on GIS, which was considered in environmental impact from land use change and climate change. Six scenarios (Fig. 2) have been contributed for the hydrological services assessment in the watershed likely to exposed floods and soil erosion risk as followed,

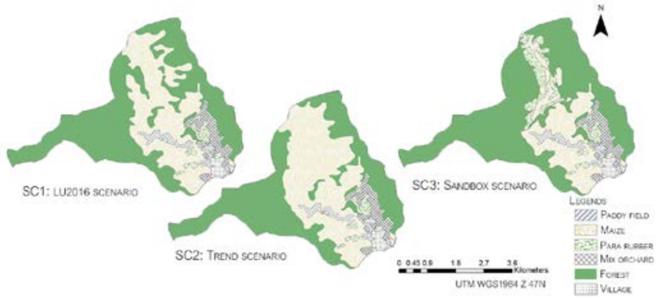


Fig. 2. Land use scenario in Naluang sub-watershed.

(SC1) LU2016 scenario; land use in year 2016 without soil and water conservation methods. There are 9 land use types i.e. dense deciduous forest, disturbed deciduous forest, teak plantation, para rubber, maize, paddy field, mix orchard, abandoned field crop and village. The highest proportion of deciduous forest was 53.69%, followed by maize was 34.52%.

(SC2) Trend scenario; land use land cover change from forest to maize was 40% (2013-2016) using transition matrix.

(SC3) Sandbox scenario; land use development in 72-18-10, which is a pilot project based on conserved forest area 100%. That's mean, to change the agricultural area which located in the conserved forest back to natural forest 72%, agro-forestry or economic forest was 18% and agricultural cropping was 10%.

(SC4) LU2016 with RCP 8.5 [8]

(SC5) Trend scenario with RCP 8.5

(SC6) Sandbox scenario with RCP 8.5

4) Forecasting water and sediment yield in each scenario

The simulation of runoff and sediment yield in the future were forecasted using SWAT model.

5) Determining the land use planning guideline

To determine the guideline of suitable and reasonable management approach in each scenario for supporting decision making of local people in land use planning as a land use map with hydrological information.

III. RESULTS AND DISCUSSION

Evaluating the impact of land use change and climate change on hydrological services, the results are as follows.

1) Model calibration

The different land use scenario reflects the hydrological service, including runoff and soil erosion, which come in water and sediment yield. Fig. 3 was illustrated the runoff calculated using the calibrated parameters (Table II) and the results from the SWAT model after calibrating the accuracy with measured runoff data in 2016 and 2017, showed the R^2 and NSE were 0.72 and 0.71 in the calibration period, the PBIAS was 6.2% in the calibration period. [7] suggested that model predictions having NSE values larger than 0.65 and 0.50, respectively are good or satisfactory. They also suggested that model predictions have PBIAS values ±10% and ±15% respectively, are very good or good. Therefore, based on these NSE and PBIAS values, it was concluded that the modified SWAT model can accurately simulate water and sediment yield as a significant part of the watershed.

TABLE II. SELECTED CALIBRATION PARAMETER FOR DAILY STREAMFLOW CALIBRATION IN SWAT MODEL.

Parameters	Description	Fitted value
CN2	Initial SCS runoff curve number	-1.88
Alpha_bf	Baseflow alpha factor	0.23
GW_Delay	Groundwater delay time	536.82
GWqmn	Threshold depth of water in the shallow	1.94
Sol_Z	Soil depth	2.49
Sol_AWC	Available water capacity of the soil layer	3.11
OV_N	Manning"n" value for overland flow	55

2) Influence of land use change on water and sediment yield.

LU2016 scenario had has the capacity to provided water yield from the watershed was 11 million cubic meter per year and the sediment yield was 365.50 ton per hectare per year, which was higher than the Trend scenario of 6 million cubic meters per year and 40.52 tons per hectare per year of sediment yield. The soil loss that was occurred every scenario is at a level where soil capability for agriculture is changing, which will effect on soil quality and crop yields over time as [9] has determined a very severe level could not exceed 3.2 tons per hectare per year. Sandbox scenario that was provided the water yield nearly Trend scenario, however, the sediment yields more than 2 times as table III and Fig. 4.

The monthly hydrology change (Fig. 4), it is found that the trend of water and sediment yield of LU2016 scenario depended on the rainfall influenced while the seasonal change has less influence to water yield in Trend scenario and was provide it less than LU2016 scenario because the maize cropping activity lasts 4 months per year.

Sediment yield was changed depending on the influence of rainfall. Trend scenario has a relatively low seasonal flow. It is lower than the LU2016 scenario because since the planting activity of maize is 4 months per year, after harvesting from November to December every year, farmers will abandon the crop area. During this period, the evapotranspiration from January to May was increased. Thus, the soil has a slightly absorbed rainfall capacity into the soil layer and the most of it will be evaporated back to the atmosphere that is affecting to less level of streamflow as the result of [10]. The sediment yield is reduced by the amount of water yield flowing into a stream. The Sandbox scenario was similar to the LU2016 scenario, as it has the forest which more efficiently to provide water yield and soil erosion control, however in rainy season. Sandbox scenario was provided more sediment yield than Trend scenario due to the rubber plantation, there is a gap between the canopies that is a cause of rainwater directly drop to the soil surface rather than the maize. So, soil erosion was transportation into the stream become more sediment yield.

Considering the water regulation of natural forest, it was provided 42-48% of rainfall and has been soil erosion control was 19-25% of the watershed as [11], which watershed with rainfall more than 500 millimeters per year and forest cover more than 36%, the function of the forest is a constantly rate. Hence, Sandbox scenario is the best preliminary land use planning that is suitable for land management to control the environmental impact effectively on highland.

3) Influence of land use and climate change on hydrological services.

According to the first result, this part was furthered the climate change with land use scenario and the results were shown as following,

Influence of RCP8.5 was affecting to temperature and rainfall will increase in the future. Fig. 4 was illustrated the water yield in SC4, SC5, and SC6 were similar trends. During dry season, it was found that no water in the stream since January to April because the land is very dry, when the raindrop to soil surface, rain is absorbed into the soil layer immediately meanwhile the water in soil cannot flow into the stream due to the adhesion bond between soil particles and water in the gap is more than gravity force. Subsequently, the soil is gradually saturation from below then it will begin to release water into stream since May and raising to peak in September before become below in October and also affecting to sediment yield which was occurred due to the flow rate in the stream. Consequently, climate change was non-significant (p-value = 0.1) effect on water and sediment yield, however, the flow period in SC4, SC5, and SC6 was 4 months lag time in dry season when compare with a normal year.

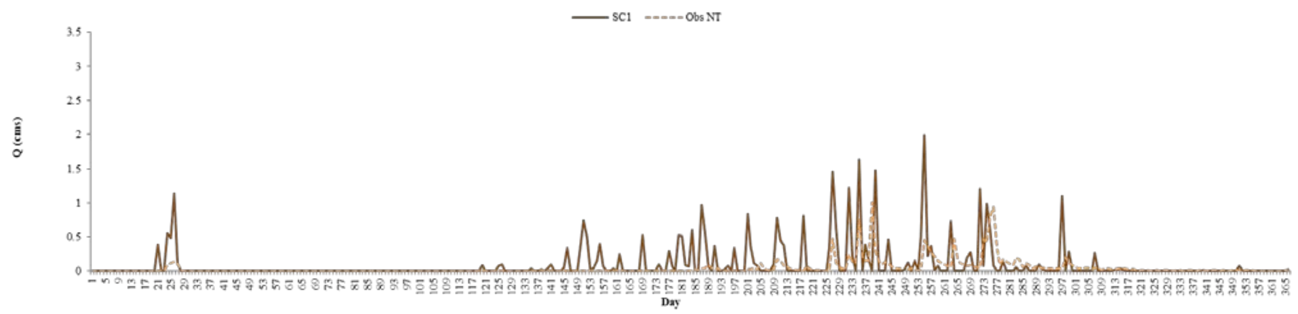
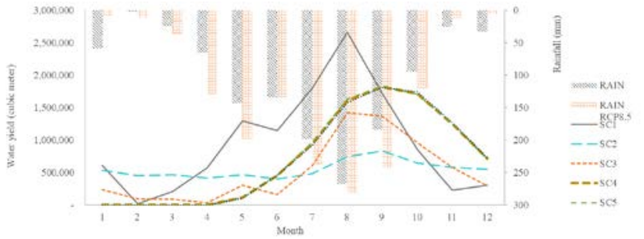


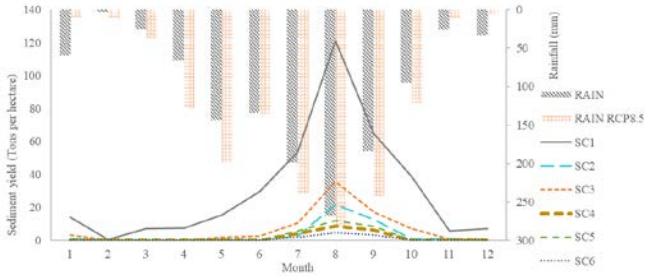
Fig. 3. Comparison of the observed and the calculated daily runoff of the Naluang sub-watershed.

TABLE III. COMPARISON WATER YIELD AND SEDIMENT YIELD IN EACH SCENARIO

Month	Rainfall (millimeters)		Water yield (million cubic meters)						Sediment yield (tons per hectare)					
	Normally	RCP 8.5	SC1	SC2	SC3	SC4	SC5	SC6	SC1	SC2	SC3	SC4	SC5	SC6
1	59.4	9.3	0.6	0.5	0.2	0.0	0.0	0.0	14.0	1.1	3.3	0.0	0.0	0.0
2	2.6	11.6	0.0	0.5	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
3	25.0	37.2	0.2	0.5	0.1	0.0	0.0	0.0	7.2	0.0	0.1	0.0	0.0	0.0
4	66.0	129.0	0.6	0.4	0.0	0.0	0.0	0.0	7.4	0.0	0.2	0.0	0.0	0.0
5	143.3	198.4	1.3	0.5	0.3	0.1	0.1	0.1	15.5	0.3	1.8	0.3	0.4	0.2
6	134.1	135.0	1.1	0.4	0.2	0.5	0.5	0.5	29.7	0.0	2.7	0.0	0.0	0.0
7	198.7	238.7	1.8	0.5	0.6	0.9	1.0	0.9	53.7	2.7	10.5	4.0	5.6	2.0
8	267.7	282.1	2.7	0.7	1.4	1.6	1.6	1.6	121.1	21.8	35.8	8.6	12.0	4.6
9	184.0	243.0	1.7	0.8	1.4	1.8	1.8	1.8	64.9	12.7	17.2	6.2	8.6	3.3
10	95.1	120.9	0.9	0.6	1.0	1.7	1.7	1.7	38.6	0.8	7.2	0.0	0.0	0.0
11	25.6	12.0	0.2	0.6	0.6	1.3	1.3	1.3	5.8	1.1	0.9	0.0	0.0	0.0
12	32.9	6.2	0.3	0.6	0.3	0.7	0.7	0.7	7.1	0.0	0.7	0.0	0.0	0.0
Total	1,234.5	1,423.4	11.4	6.6	6.2	8.6	8.7	8.6	365.5	40.5	80.1	19.2	26.6	10.0



(a)



(b)

Fig. 4. Water (a) and sediment yield (b) in SC1–SC6.

4) Water management guideline for highland watersheds under land use change and climate change

SC1 and SC3, the results were explained land use change had more influenced on water amount than timing because in SC3 that was 18% increased in the para rubber plantation, which was used water to grow more than another plant. Therefore, the problem of soil erosion should be considered rather than water management. This can be done as one sees by planting shrubs in the para rubber plantation to reduce the impact of soil detachment from a raindrop. And SC2 was shown the risk's opportunity to water shortage in dry season, as a hydrological characteristic in Fig. 4, soil and water conservation is must consider e.g. terracing for decrease the surface runoff in wet season, that can reduce the opportunities in water shortage during dry season.

For SC4, SC5, and SC6, the results are shown that there is no water flow in the stream during dry period. So, it is necessary to collect water at the end of the wet season e.g. to build a small pond nearly the agricultural area such as mix orchard and paddy field and so on. On the other hand, the crop calendar will be adjusted to a suitable time period with the water flow in the stream. Even though, maize cropping activities in this area are still largely unaffected by climate change, as the cropping period from June to December, which is enough water for growth and maintenance.

IV. CONCLUSION

A study of hydrological services was founded the natural forest still provided the water yield and had effectively soil erosion controlled, which was as close as possible to natural conditions. However, the overall scenario was shown trend scenario was likely to water shortage during dry season if there are no measures which reduce the surface runoff for increase the water retention. While the sandbox scenario is a land use planning that was supported the ecosystem to provided the hydrological services at an appropriate level for crop activities. Finally, this research is clear that climate change had been affecting to hydrological services, which provides from the watershed, especially the water timing.

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