Impact of climate and land use changes on soil erosion and sediment yield in Nan river basin, northern Thailand

Studyoffuturesoilerosionandsediment yield

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Abstract-The impacts of climate and land use changes on soil erosion and sediment in Nan river basin in north of Thailand were assessed using RUSLE, SDR and sediment transportation model. The results suggested that the changes in both climate and land use have significant impacts on both soil erosion and sediment. The increase of rainfall in near future directly affects surface runoff which is important factor related to soil erosion, and river discharge that controls the sediment flow in river. Land use change from forest to agriculture has a greater effect on soil erosion and sediment than that from one type of agriculture to another due to the reduction in plant cover. Furthermore, the severe scenarios in Nam Wa river basin which is branch of Nan river basin, illustrate how land use changes tend to affect soil erosion more than climate change, while climate change has a greater impact on sediment than land use change.This analysis can be useful in designing optimal land use that is effective for reducing soil erosion damages and decreasing sediment accumulation in the river including planning to mitigate the impact of climate change in the future.

Keywords- Climate change, land use change, soil erosion, sediment yield

INTRODUCTION

In the present, soil erosion and sediment are the important environmental issue in the developing country at present (Lslam *et al*., 2015). Soil erosion can lead to many environmental problems such as removals the topsoil and soil nutrient loss, flooding and water pollution. Moreover, soil erosion is the origins of the sediment in the river which is the main factors that makes the river shallow. The increase of sediment will decrease storage capacity of streams and cause flooding and increase the risk of flash flood (Daniel *et al*., 2015). It also causes further corrosion by deflecting the flow into the adjacent stream bank or even on neighboring land (The Department of Water and Environmental Regulation, 2017).

The key factors that can control the soil erosion and sediment yield are the climate and land use. In the present, climate and land use changes are the important problems of the world (Branes, 2017). Climate change is responsible for the variation of soil erosion due to the change in rainfall pattern include increase or decrease of strong rain, and high variability of rainfall (Ritter, 2012, Li and Fang, 2016, National Geographic, 2018). It can directly affect to the surface runoff, which is the important factors that related to the soil erosion in the part of detachment and movement which is the origins of the amount of sediment in the river (Coit, 2014, Roudier *et al*, 2014, Chang *et al*., 2017). In addition to climate change, land use change also affects the soil, water resource, and hydrology(Lawlera *et al*., 2013, Elmhagen *et al*., 2015, Paul and Rashid, 2017, NOAA, 2018). The deforestation leads to increases soil erosion, flooding, and landslides (Elliot, 1999, Wu, 2008, Mohammad and Adam, 2010, Plangoen *et al*., 2013, Yao *et al.*, 2016). Thus, it can be said that the climate change and land use change can control and have a significant impacts on the potential of soil erosion and the amount of sediment in the river. However, whether climate change or land use change has the greater effect on soil erosion and sediment are not clear. Moreover, from the past to present, the most researchers were interested in the factors that related to soil erosion which is the origins of sediment in the river and the impact of soil erosion on the environment. Nevertheless, the research about sediment, and the impact of climate and land use changes on sediment are not widespread, scarce and don’t get much attention due to the limitation of the measurement data that necessary for estimation (Karaburun, 2010). Thus, this study is interested to study the impact of climate and land use changes on both soil erosion and sediment in the river using the RUSLE and sediment model in Nan river basin which has some observation data and the potential of soil erosion and sediment yield become obvious recently.

DATA AND METHODS

To calculate soil erosion and sediment, we used Revised Universal Soil Loss Equation (RUSLE) which is the famous and suitable equation to estimate the impact of land use change to soil erosion (Leh *et al.,* 2013).In addition, we combined RUSLE with Sediment Delivery Ratio (SDR) and sediment transportation model to estimate the sediment in the catchment area.

Data

Climate data

We used the downscale monthly climate data in 1-arc minute resolution in1985-2004 and three climate models (CNRM-CM5, GFDL-ESM2M and IPSL-CM5A-LR) in 2080-2099 from Integrated study on Hydro-Meteorological Prediction and Adaptation to Climate Change in Thailand (IMPAC-T) Forcing Dataset.

Land use data

Land use data for Nan river basinin2000 (Figure 1a) and 2016 (Figure 1b) provided by the Land Development Department. Furthermore, the future land use was projected by the CLUE model (Conversion of Land Use and its Effects modelling framework), which was developed to simulate land use change using empirically quantified relationships between land use and its driving factors (Verburg, 2010, Verburg, 2015). In this study, we used the land use in 2016 as baseline data and topography data (slope, elevation and urban area) as a driving factor for the simulation of 2 scenarios future land use. First scenario, the forest area were converted into other types of land use by increase forest area approximate 5% of total area in 20 years. Second scenario, the forest area were decreased around 5% of total area and become to other types of land use such as field crop.

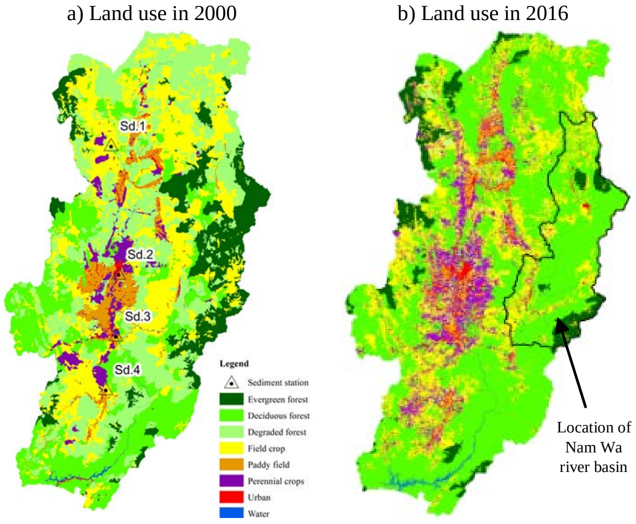
Methodology

Data preparation

We examined 8 normal cases and 3 extreme scenarios (Table I) to compare the impacts of land use and climate changes. For normal case studies, the following climate and land use data were considered 1) past data (hereafter, P; land use in 2000), current data (hereafter, C; climate in 1985–2004 and land use in 2016), and future data (hereafter F; climate in 2080–2099 and land use in the future (2036)).

The severe effects of climate change and land use changes were demonstrated in this study by examining two scenarios involving land use change and one involving climate change. In reality, however, it would be futile and unfeasible to reduce land use across the entire Nan river basin to a single land use type. The Nam Wa river basin, a branch of the Nan river basin, was therefore selected as a case study for this study.Location of Nam Wa river basin is shown in Figure 1b.

Both land use change scenarios were designed as follows: 1) the degraded forest and other agricultural terrain, such as paddy fields and perennial crops, in the Nam Wa river basin were converted to field crop, so that field crop accounted for around 50% of the total area, and 2) the entire Nam Wa river basin land cover type was changed to deciduous and evergreen forest based on past land use data (2000). These land use scenarios were calculated using climate data from 2004 from the IMPAC-T project. The climate change scenario was based on land use in 2016 and IMPAC-T project rainfall data from 2011, the year that saw Thailand's heaviest recorded rainfall. The results from the severe scenarios were compared with the result in 2004 from case C-C to analyze the impact of climate and land use changes. The detail of each case studies and extreme scenarios are shown in Table II.


a) Land use in 2000

b) Land use in 2016

Figure 1 Land use in Nan river basin and location of Nam Wa river basin

Table I Land use of Nan river basin

Year	Area (Km^2)			
Land use type	2000	2016	2036 (1)	2036 (2)
Evergreen forest	1429.8	721.5	734.3	681.9
Deciduous forest	2465.2	6853.2	7453.2	6289.7
Degraded forest	3794.5	160.4	0	71.7
Field crop	3224.1	2752.8	2242	3310.2
Paddy field	540	348.2	355.2	351.7
Perennial crops	400.1	862.1	900.5	894.5
Urban	95	214.3	220.4	315.1
Water	51.2	87.4	94.4	85.2
Total	12000	12000	12000	12000

Table II List of case studies

Normal case study		
Climate data **Land use**	***Current (1985-2004)***	***Future (2080-2099 from 3 GCM; IPSL, GFDL-ESM2M, and CNRM-CM5)***
2000 (Past)	Case C-P (Used to calibrated)	Case F-P
2016 (Current)	Case C-C	Case F-C
2036 (Future; increase forest area)	Case C-F (1)	Case F-F (1)
2036 (Future; decrease forest area)	Case C-F (2)	Case F-F (2)
Extreme scenario		
Scenario	***Land use***	***Rainfall data***
1	Field crop 50%	Rainfall in 2004 from IMPAC-T project
2	Forest area 100%	
3	Land use in 2016	Rainfall in 2011 from IMPAC-T project

Calibration of soil erosion and sediment model

Parameters of the RUSLE that related to land use island cover management factor or C-factor. The model can be calibrated by changing the values of the parameters based on land use type and evaluated using the Nash–Sutcliffe Efficiency Coefficient (NSE). When the NSEvalue is close to 1, both outcomes agree well; when the NSE value is closeto 0, the groups are poorly related (Suwanlertcharoen, 2011). Sediment data in 1989-2004 from four observation station of RID (Figure 1a) were used to calibrate and validate the sediment model and soil erosion data from April to October

1992 belonging to Nan watershed research station were used to calibrate soil erosion model.

RESULTSAND DISCUSSION

Results

Soil erosion and sediment yield of Nan river basin

We estimated soil erosion and sediment from Nan river basin in case C-P for calibration and validation the model. In case of sediment, evaluation of the accuracy and compatibility of the monthly results using measurements of Nan river basin and the model yielded, NSE values for case C-P at stations 1-3 of 0.72, 0.67 and 0.59, respectively. In case of validation, NSE values for case C-P at stations 1, 3 and 4 are 0.57, 0.75 and 0.44, respectively.Additionally, the evaluation of the accuracy by NSE show the soil erosion model is also well calibrated, NSE is 0.61. The NSE values indicate that the model is well calibrated and can be used for simulation in cases of land use change.

Impact of climate change on soil erosion and sediment yield

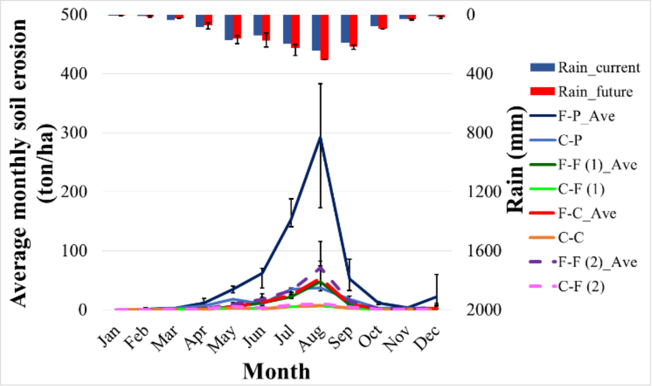
Considering the impact of climate change from the current to the future, the results show that the soil erosion from simulation has the similar tendency as R-factor value which depends on rainfall. The monthly soil erosion in April to December according to the future climate data (2080-2099), in cases F-P, F-C, F-F (1) and F-F (2), are higher than those for the current climate (1985-2004), including cases C-P, C-C, C-F (1) and C-F (2). There is little difference in the monthly soil erosion for January to March between current and projected climate data.However, the tendency of sediment is little difference with soil erosion due to the river discharge and the amount of sediment that flow through the river.The monthly sediment yields from January to May, based on projected future climate data (2080-2099) were lower than those based on climate data for the period 1985-2004 and the results for other months stand in contrast to this. (Figure 2).

Impact of land use change on soil erosion and sediment yield

The results indicate that the monthly soil erosion resulting from land use in the past (2000, case C-P and F-P) was highest due to the high field crop and degraded forest areas, while monthly soil erosion in the future in scenario 1 (2036, case C-F (1) and F-F (1)) was lowest, owing to increased deciduous forest area. These results were obtained using the land cover and C-factor value. The average C-factor value was highest in cases C-P and F-P.

In addition, the monthly sediment yield from land use in 2016 in case C-C and F-C, and the both land use scenario in the future, does not vary. The sediment from land use in the past (2000), are little higher than that from other cases only in August and September. These results obtain due to the land use type of each case study and river discharge (Figure 2).

a) Soil erosion



b) Sediment yield

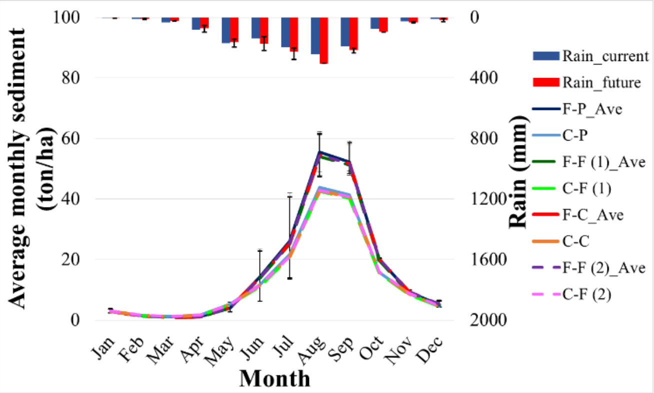


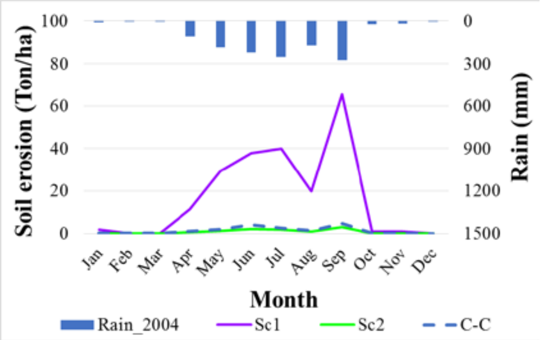
Figure 2 Average monthly soil erosion and sediment yield of Nan river basin

The extreme climate and land use changes scenario

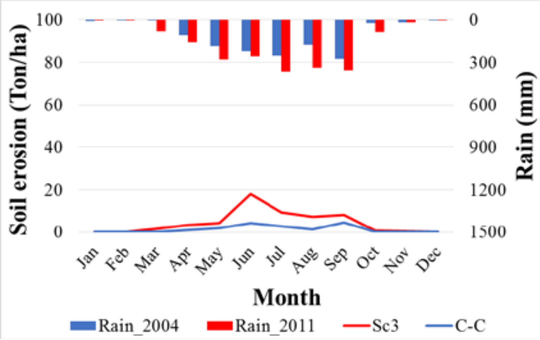
Analysis of the changes in land use illustrates that soil erosion and sediment clearly increased in the area where forest cover was converted to agricultural terrain. However, appropriate land use can help diminish the likelihood of soil erosion and sedimentation. For example, the results from scenario 1 (Sc1), in which field crops accounted for 50% of the total area, were highest in the land use change scenario, and also higher than the results from case C-C. Additionally, the results based on extreme rainfall in scenario 3 (Sc3) are incremental, but in the area covered with evergreen forest, the soil erosion and sedimentation level were lower than those in other areas. This is because forest area can protect the surface soil from the severe rainfall and relieve the impact of rainfall. As such, assiduous land use management can reduce the likelihood of soil erosion and sedimentation during extreme rainfall (Figure 3).

The average monthly results show that the soil erosion and sediment yield in Sc1 are higher than those in Sc2, due to the larger area of field crop. Additionally, with regard to climate change, the likelihood of soil erosion and sediment from Sc3 are overthree times and twice as high as that in case C-C, respectively. Particularly during the rainy season (mid-April to October), the soil erosion and sediment yield in Sc3 are significantly higher than that in case C-C due to the prolific rainfall. However, during the dry season (November to February), the results have the variation less than that in the rainy season.

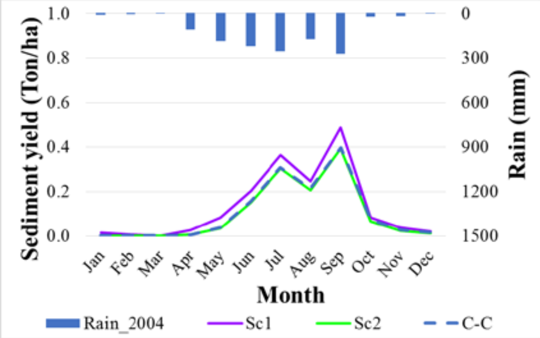
a) Soil erosion from severe land use change scenario



b) Soil erosion from severe climate change scenario



c) Sediment yield from severe land use change scenario



d) Sediment yield from severe climate change scenario

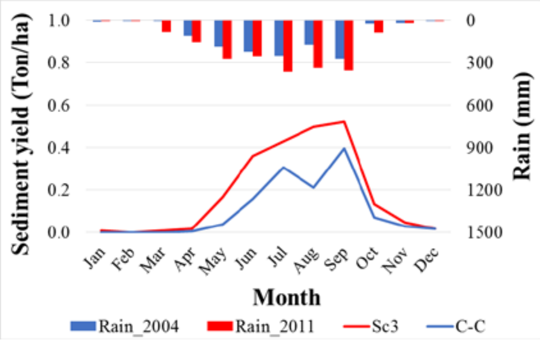


Figure 3 Average monthly soil erosion and sediment yield from severe scenarios in Nam Wa river basin

Discussion

Climate change on soil erosion and sediment yield

In case of climate change, the soil erosion were influenced by the change of rainfall from current to future that used to calculate R-factor in RUSLE. The rainfall and runoff factor or R-factor is the sum of individual storm erosivity. It can be used to explain the influence exerted by raindrops, reflecting the amount and rate of runoff associated with rainfall (Renard *et al*., 1997). The average annual R-factor of Nan river basin based on current (1985-2004) and future (2080-2099) rainfall data are 40.5 and 170 MJ·mm/ha·day, respectively. The average R-factor value calculated from projected future daily rainfall is higher than that calculated based on current daily rainfall, particularly from June to August, by approximately 320%by annual average.

The change of rainfall and the amount of soil erosion also can effect to the sediment yield. However, the tendency of sediment is little different with soil erosion due to the river discharge that can control the amount of sediment flow in the river. Therefore, the accumulation of sedimentof Nan river basin is influenced by the river discharge and sediment flow which flows through the river from the upstream area to the downstream more than the soil erosion around the area.

Land use change on soil erosion and sediment yield

In case of land use change, a key factor related to land use is the C-factor or crop management factor, which can determine the likelihood of soil erosion for each land use type. Agricultural land is at higher risk of soil erosion compared with degraded forest and forested areas. Therefore, the C-factor of agricultural land is higher than that of forested areas and has a significant effect on soil erosion.This is consistent with the results from this study which indicate that the potential of soil erosion of land use in the past is highest due to the maximum C-factor value fromthe expansion of degraded forest and field crop area, and the potential of soil erosion of land use in the future scenario 1 is lowest due to the least C-factor value of deciduous and evergreen forest area.

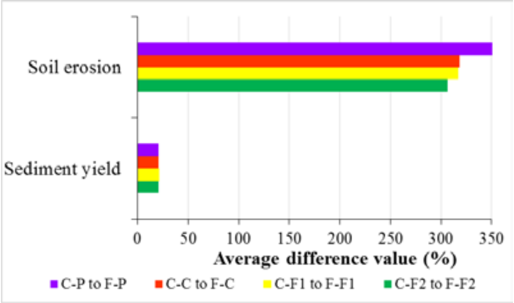
Furthermore, the sediment yield levels in all scenarios do not vary, as there is little difference in land use type and river discharge. The results suggest that the majority of sediment that accumulates in Nan river basin is more influenced by river discharge (which is the main transport medium for sediment travelling from highlands to lowlands), and the amount of sediment that is being transported, than by soil erosion in the vicinity.

The difference value and percentage change

In the normal case, the difference of each scenario shows that the results from climate change have larger changed more than the results from land use change. These results obtained due to the change of climate and land use from current to future. This study created land use in the future by increase and decrease forest area from the land use data in current approximately 5% of total area. Thus, the land use from the past to the future has average percentage change at least 5% while the climate change in this study has average percentage change 14% (the average change of rainfall approximately 14 mm.). That means, the percentage change of climate is greater than percentage change of land use. Therefore, the result of this study suggest that the impact of climate change is likely to effect on the soil erosion and sediment yield in Nan river basin more than the impact of land use change (Figure 4).

Moreover, the extreme scenario in the Nam Wa river basin, the results suggest that climate change is more likely than land use change to have a significant impact on sediment yield, but the opposite is the case with regard to soil erosion. Soil erosion can increase by up to more than 2,000% in response to changes in land use, whereby forest is replaced by field crop, while soil erosion will increase by approximately 235% under severe rainfall. Furthermore, the difference values and percentage changes indicate that the sediment yield varies more due to severe climate than to land use change, whereby forest is replaced by field crop or vice versa. The sediment yield increase exceeds 79% in the extreme rainfall scenario, while it is increased by approximately 31% in response to land use change, whereby forest is replaced by field crop.

Climate change



Land use change

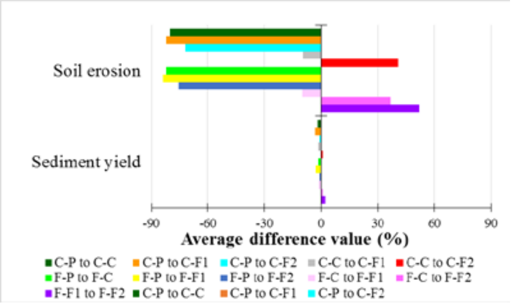


Figure 4 The average difference value of climate and land use change scenario

CONCLUSIONS

This study estimated soil erosion and sediment yield under combined cases of different years of boundary conditions, and try to show which factor affects soil erosion and sediment yield, climate change or land use change using the model that develop from RUSLE, SDR and sediment transport equation.

The impact of climate change shows that the monthly soil erosion are influenced by variations in the R-factor, which is associated with the rainfall. Increased or intensified rainfall can increase the R-factor, leading to the detachment of greater amounts of soil from the topsoil surface, in turn leading to increased soil erosion. Moreover, the level of sediment in the river depends on river discharge, which is the factor that has the greatest impact on sediment transportation, and is in turn influenced by rainfall.

Regarding land use change, the results suggest that the land use change whereby forest cover is replaced with agricultural land has a greater effect on soil erosion and sediment than does a change from one type of agriculture to another due to the difference of C-factor value. Additionally, the results from the extreme scenario suggest that suitable land use management can reduce the extent of soil erosion and sediment yield during extreme rainfall events.

The monthly percentage change from the extreme scenariosdemonstrate that land use change tends to be have a greater impact than climate change on soil erosion, while climate change has a greater impact than land use change on sediment yield.

This study examined how a keen and sensitive appreciation of the effects of land use change and climate change, under simulated sedimentation scenarios, can be beneficial in designing optimal land use strategies that are effective in reducing soil erosion damage and decreasing sediment accumulation in rivers, including planning to mitigate the future impact of climate change.

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