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

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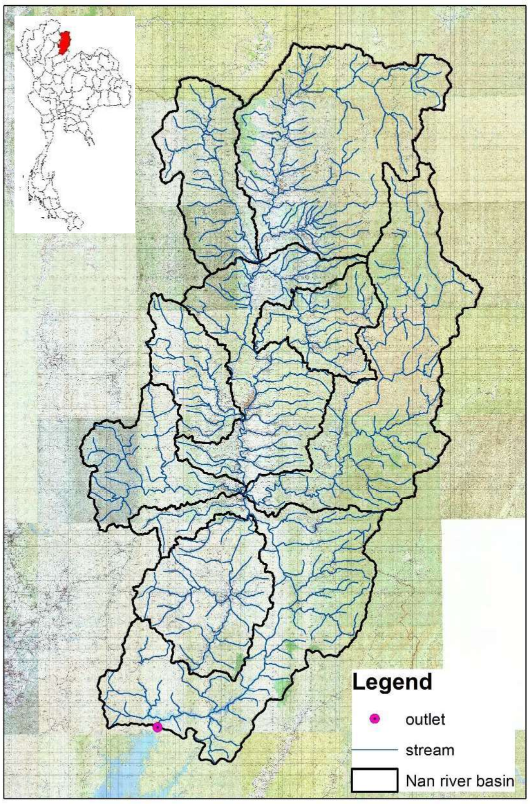
Land use and climate change

- **Land use change** → Forest to Agriculture
  - Increased runoff rate *(Elliot at el, 1999)*
  - Increased the risk of soil erosion
  - Increased sediment in the river *(Wu, 2008)*

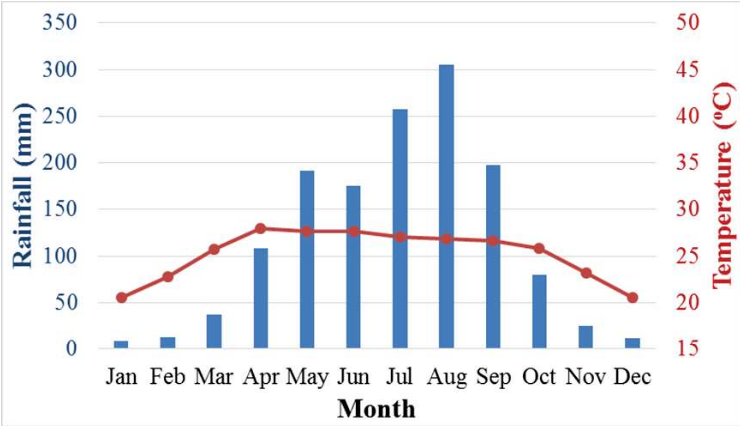
- **Climate change**
  - Intensity of rain can control surface runoff (Arnell, 2004)
  - Can control soil erosion rate and lead to increased sediment in the river (Jain and Kothyari, 2000)
- **Main objective of this study**
  - Examine and present the land use management and effect of climate change on soil erosion and sediment yield

Study area

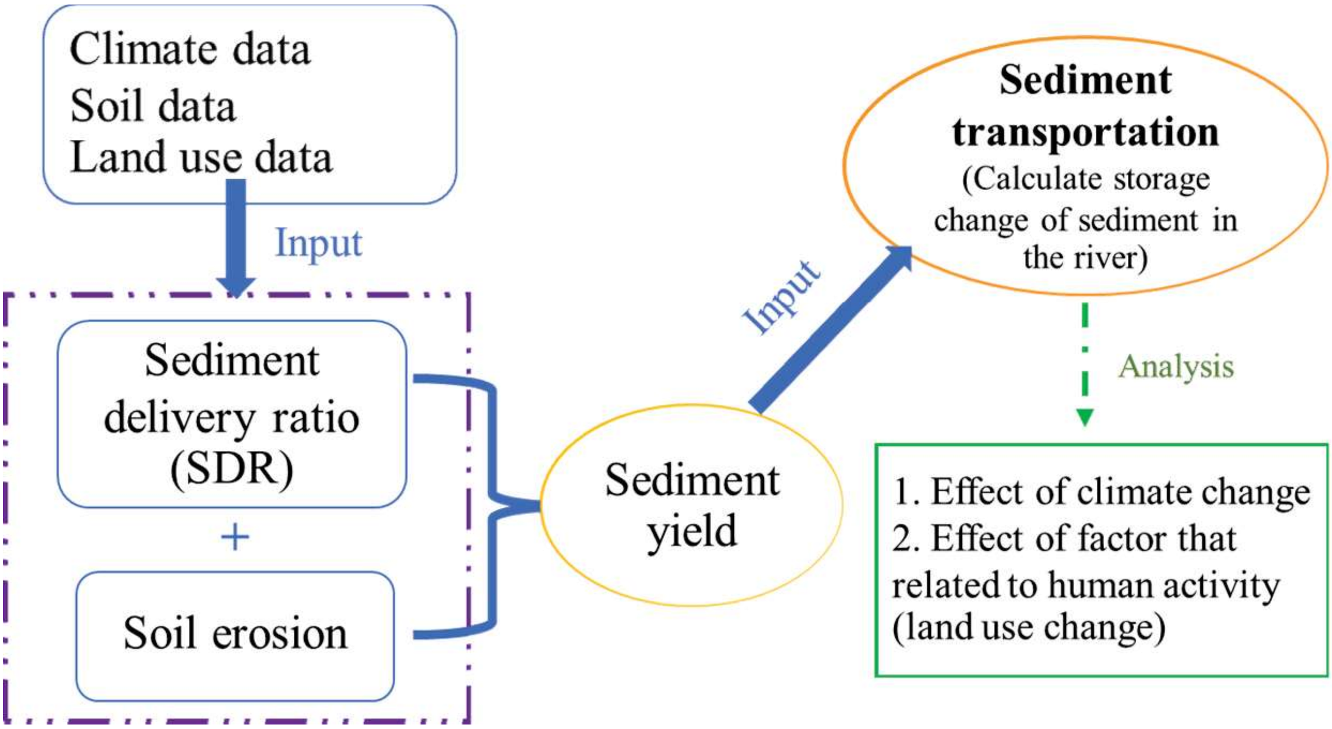
Nan river basin is the branch of Nan watershed. It located in the northern of Thailand.



Area	12,000 Km^2
Annual rainfall	1,371 mm
Air temperature	26.3 ^{O}C
Annual streamflow	344 mm/year



Methodology



Soil erosion

Calculate soil erosion using RUSLE equation

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

- ❖ *A* is average soil loss
- ❖ *R* is R-factor or rainfall erosivity factor
- ❖ K-factor is soil erodibility factor; The K-factor values were determined by LDD.
- ❖ L-factor and S-factor are the ratio of soil loss from field slope length and field slope gradient, respectively.
- ❖ C-factor is cover-management factor; this value set by LDD
- ❖ P-factor is support practice factor;

(By Renard et al., 1997)

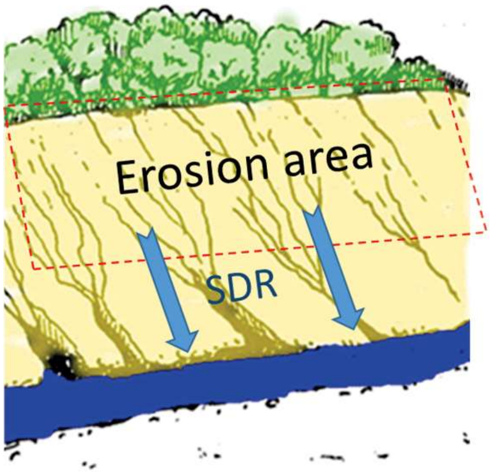
Sediment

✓ *Sediment yield*

$$Sediment\ yield = SDR * A$$

Where A is average soil erosion

SDR is Sediment delivery ratio



✓ *Sediment delivery ratio* *(By Arnold et al., 1996)*

$$SDR = \left(\frac{q_p}{r_p - [(R-Q)/DUR]}\right)^{0.56}$$

Where q_p is peak runoff, r_p is peak rainfall

R is rainfall, Q is runoff

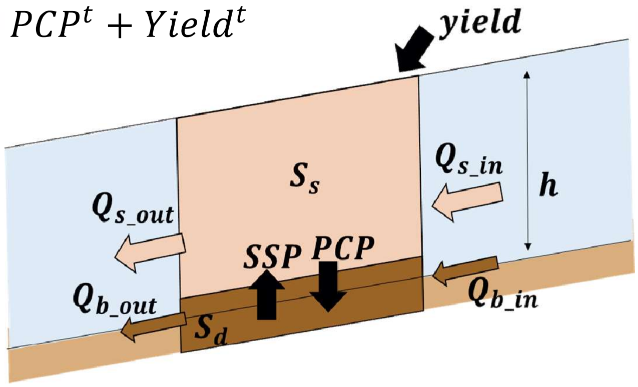
DUR is duration of rainfall event in hour $= 4.605(R/r_p)$

Arnold *et al.*, 1996; Ouyang *et al.*, 1997; Hatono, 2018

Sediment transportation

$$S_s = S_s^t + \sum_{k}^{upstream} Q_{s\_in}^t - Q_{s\_out}^t + SSP^t - PCP^t + Yield^t$$

$$S_d = S_d^t + \sum_{k}^{upstream} Q_{b\_in}^t - Q_{b\_out}^t + PCP^t - SSP^t$$



Where S_s is storage change of suspended sediment (m[3])

S_d is storage change of bedload sediment (m[3])

$Q_{s\_in}^t$ and $Q_{s\_out}^t$ are suspended sediment inflow and outflow

$Q_{b\_in}^t$ and $Q_{b\_out}^t$ are bedload sediment inflow and outflow

SSP is suspended sediment from bedload,

$Yield$ is sediment yield (m[3])

PCP is deposition of sediment

$$Q_{s\_out}^t = C \cdot Q_w$$

$$PCP = W_f CA$$

$$SSP = q_{su} A$$

Where C is suspended sediment concentration,

Q_w is river discharge (m^3/s),

W_f is setting velocity (m/s),

q_{su} is suspension velocity (m/s), and

A is area (m^2), respectively.

By Hatono, 2018

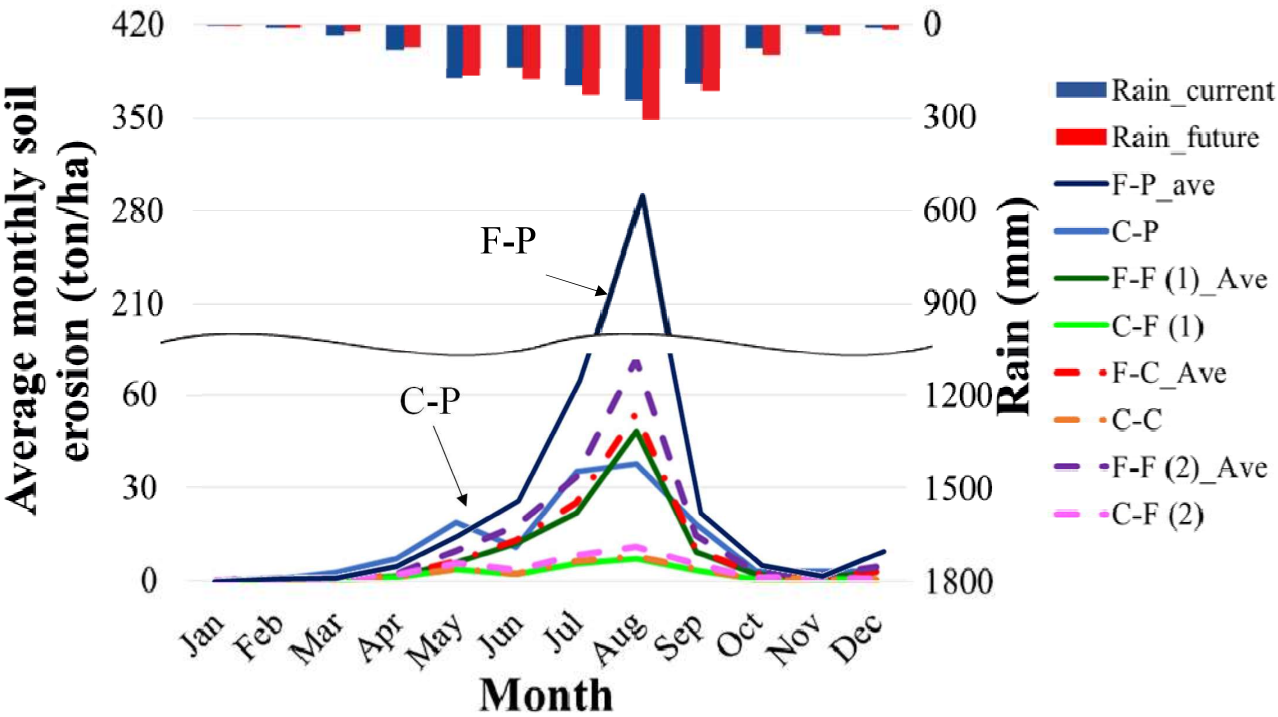
Data

	Year	Source
Climate data	1985-2004	From Impact-T project
	2080-2099	3 GCM from Impact-T project (IPSL, GFDL and CNRM)
Land use	2000	Land Development Department (LDD)
	2016	
	Future	CLUE model

Case study

Climate / Land use	Current (1985-2004)	Future (2080-2099)
2000	C-P	F-P
2016	C-C	F-C
2036 (1) (Increase forest area)	C-F (1)	F-F (1)
2036 (2) (Decrease forest area)	C-F (2)	F-F (2)

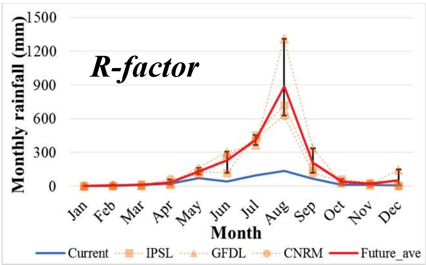
Impacts of climate changes on the soil erosion

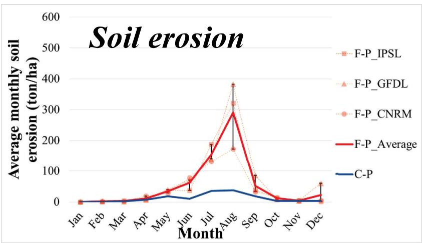


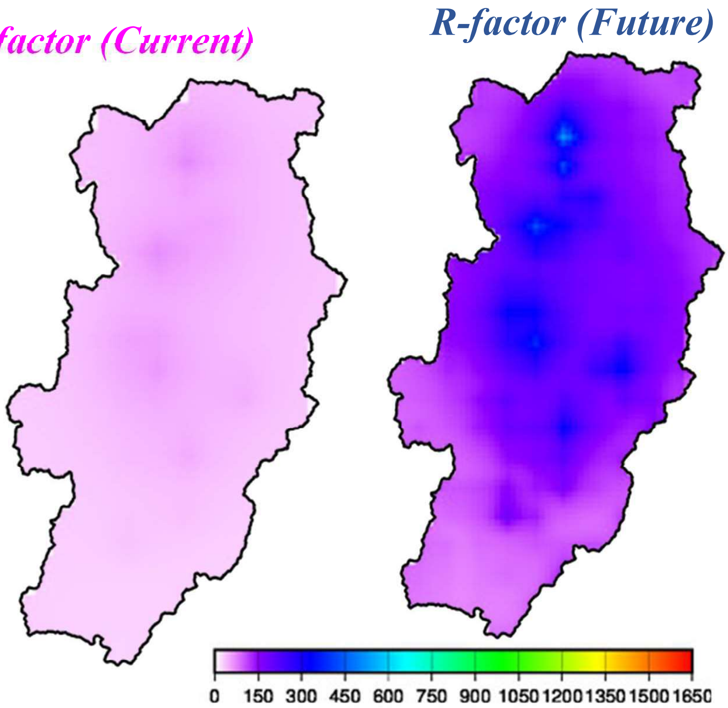
The monthly soil erosion from April to December from climate data in future are higher than that from climate data in the current.

Impacts of climate changes on the soil erosion

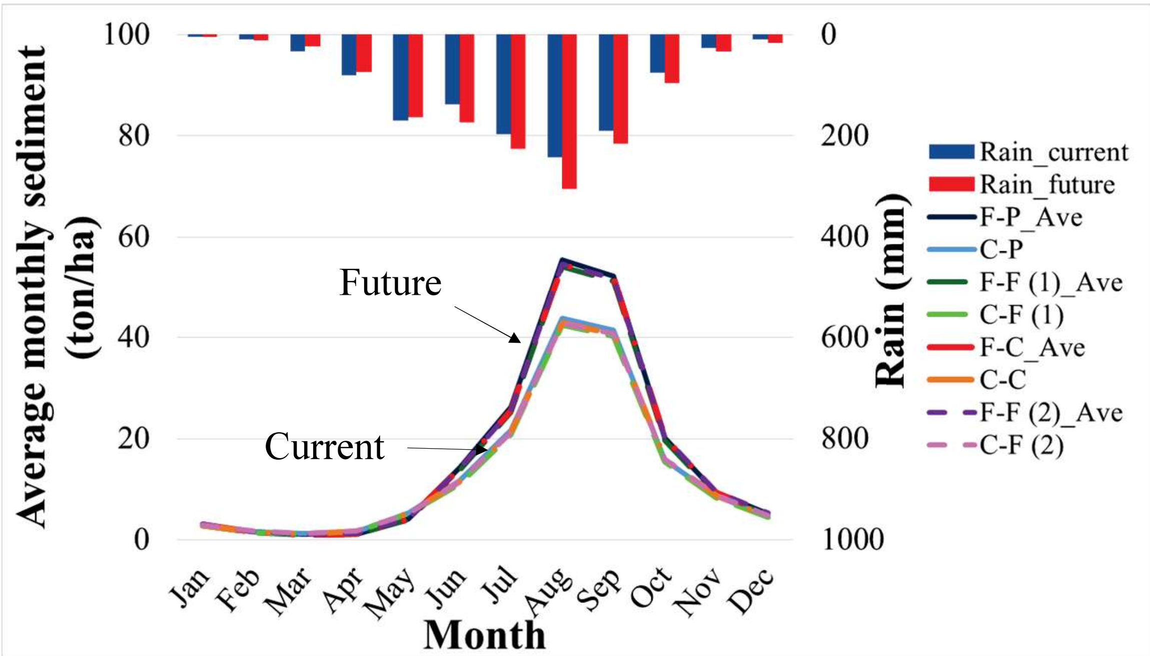
- The results obtained due to the variation of R-factor value which is related to rainfall.
- R-factor or rainfall and runoff factor can used to explained the effect of the raindrop, and reflect the amount and rate of runoff that related to rainfall.







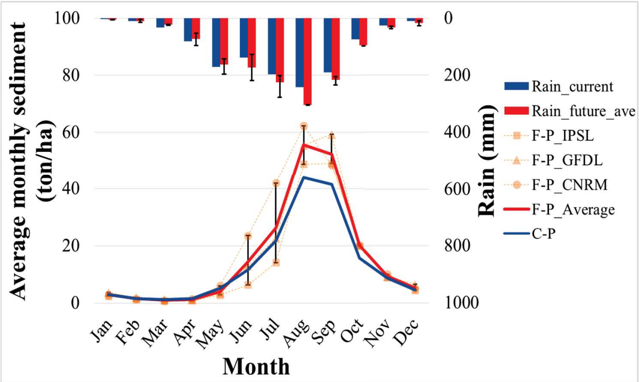
Impact of climate change on sediment



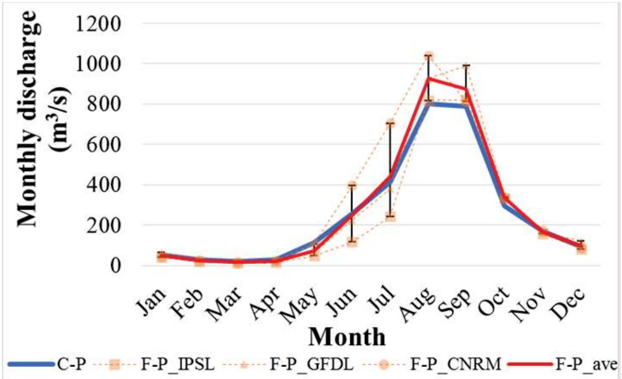
The monthly sediment from January to May, from the case of climate data in the future (2080-2099) are lower than the result from climate data in current (1985-2004).

Impact of climate change on sediment

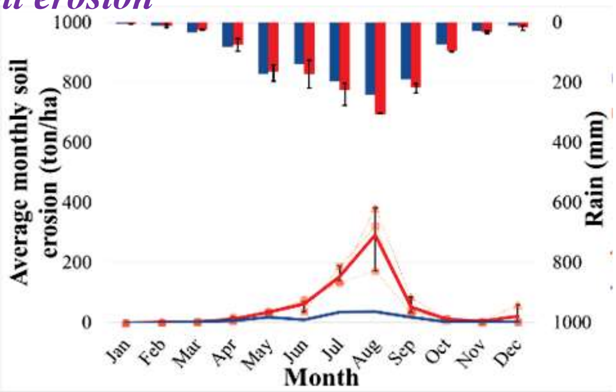
Sediment



River discharge

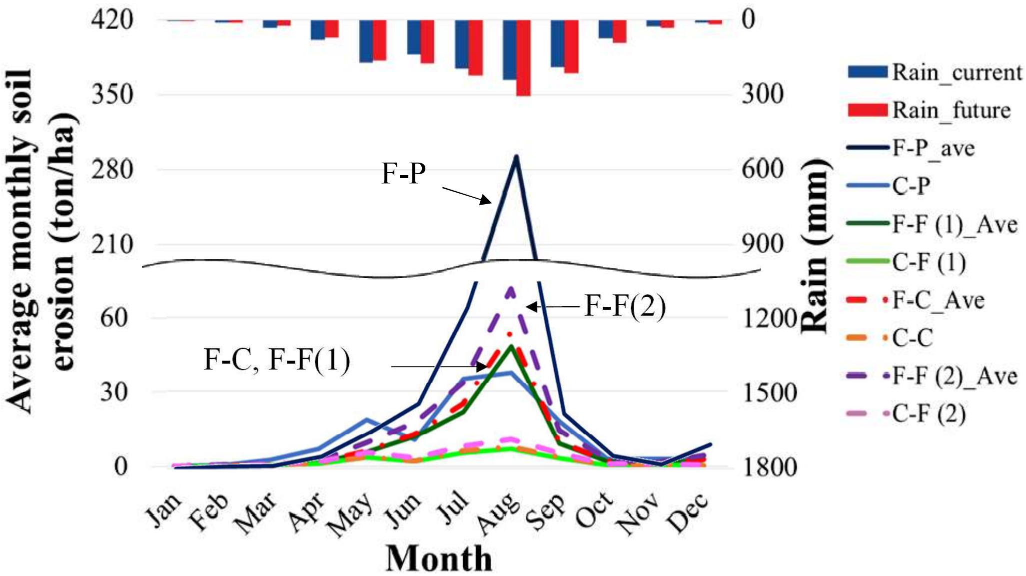


Soil erosion



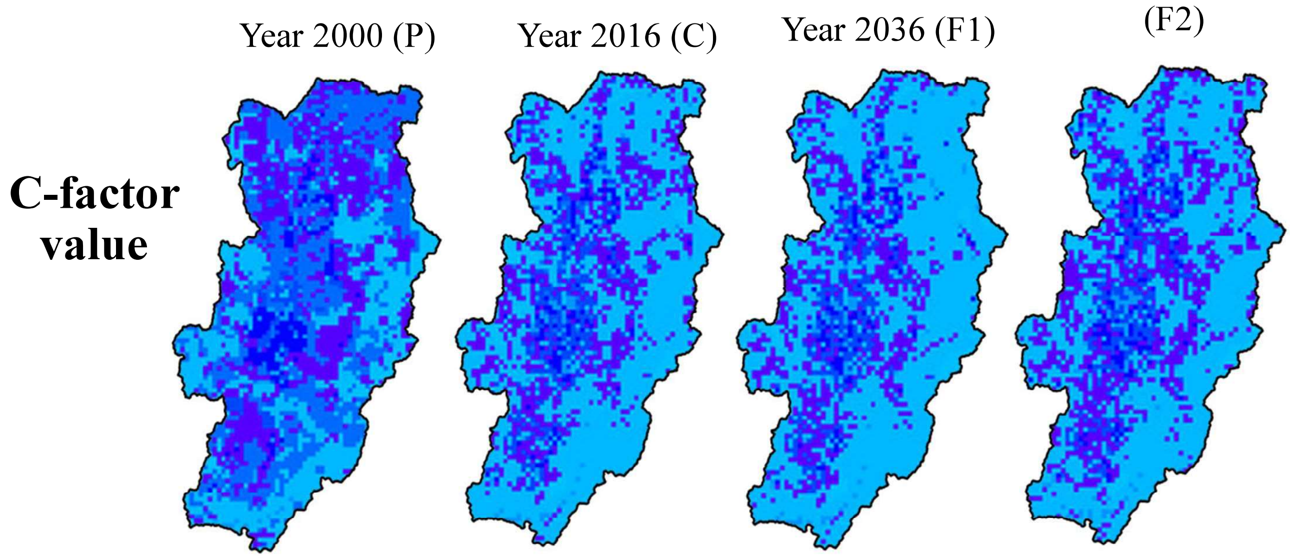
Sediment yield is influence by water flow and amount of sediment that flow with the water from upstream to downstream area more than soil erosion around the area.

Impacts of land use changes on the soil erosion



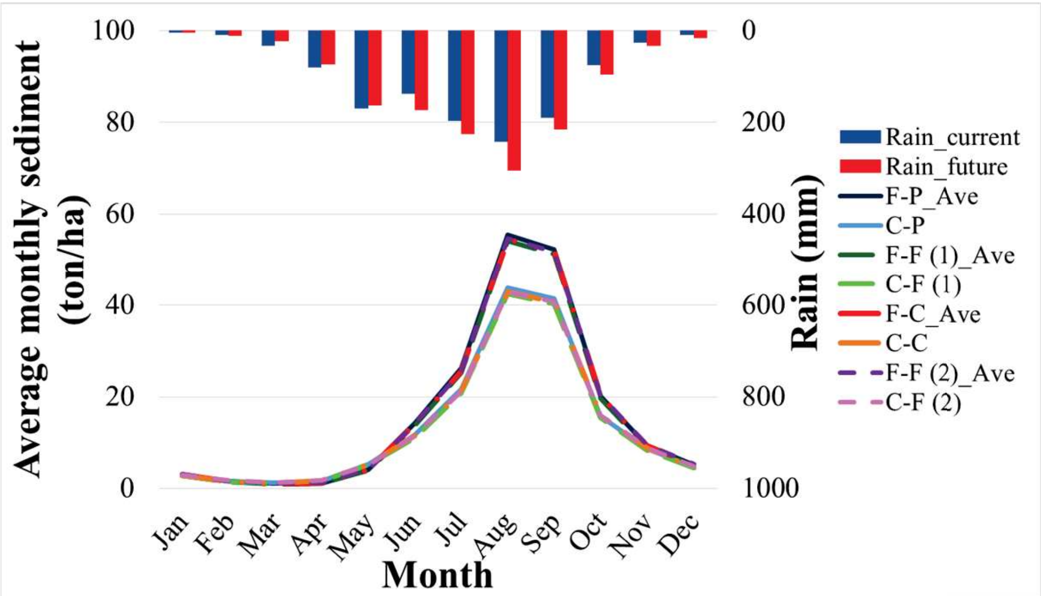
The monthly soil erosion of case C-P and F-P is highest due to the high field crop and degraded forest area and the monthly soil erosion of case C-F (1) and F-F (1)) is lowest due to the increase of deciduous forest

Impacts of land use changes on the soil erosion



- These result obtained due to the difference of land use type that cover and protect the surface soil from the impact of rain and slope.
- The factor that related to land use is land cover management factor (C-factor). This factor can explain the risk of soil erosion of each land use type and agricultural area has the potential of soil erosion more than forest area.

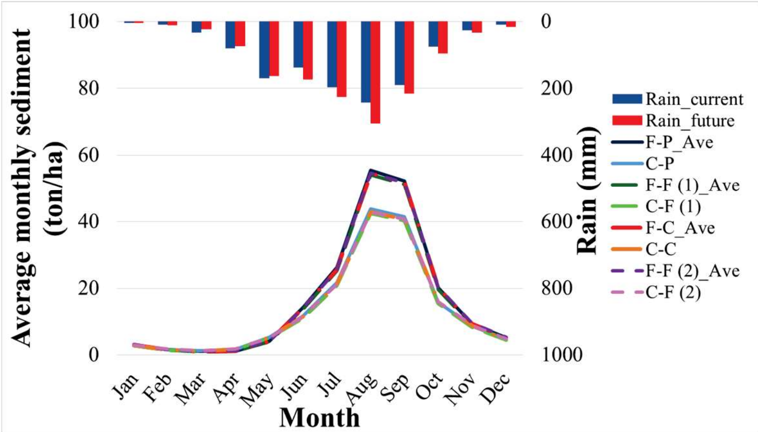
Impact of land use change on sediment



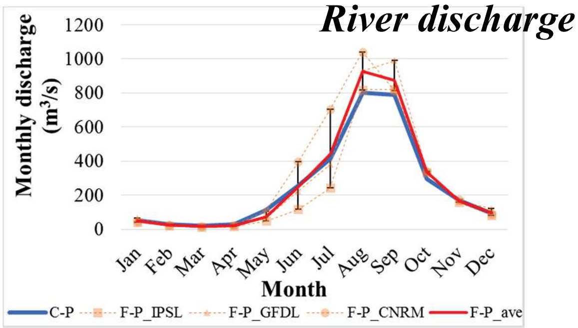
The results suggested that the sediment yield from every land use scenario are not different due to the slope and river discharge, which effect to sediment delivery ratio and sediment transportation.

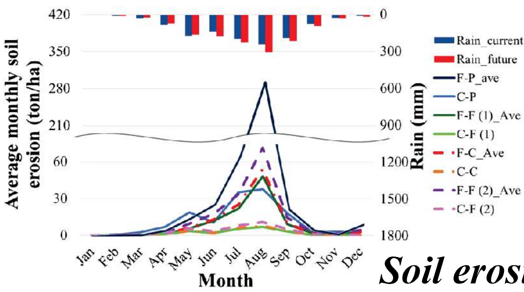
Impact of land use change on sediment

Sediment



River discharge

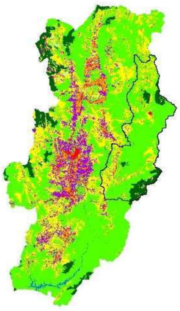




Soil erosion

The results present that the mostly of sediment are influenced by the river discharge which is the main factor that transports the sediment from the highland to the lowland, and the amount of sediment that flow with the water, more than the soil erosion around the area.

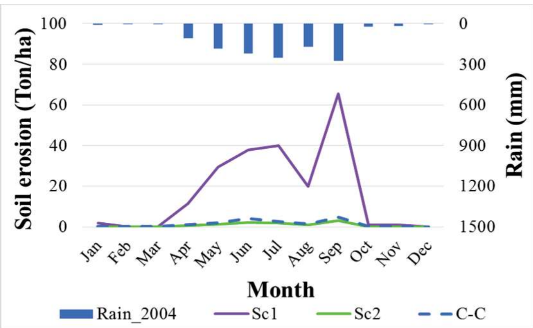
The extreme scenario in Nam Wa river basin



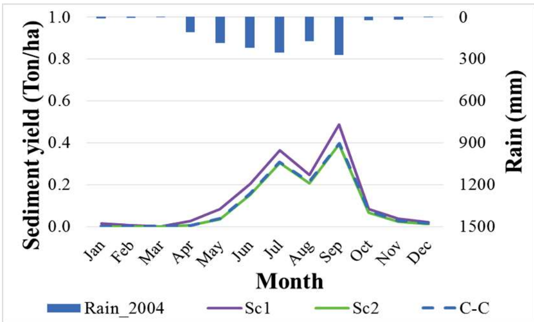
Scenario	Land use	Rainfall data
1	Field crop 50%	Rainfall in 2004 from IMPAC-T project
2	Forest area 100%	
3	Land use in 2016	Rainfall in 2011 from IMPAC-T project

Land use change

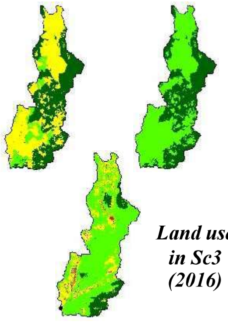
Soil erosion



Sediment

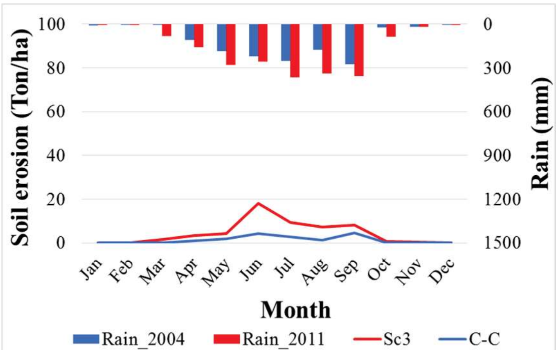


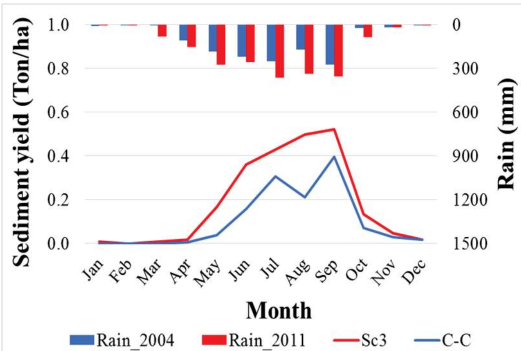
Land use in Sc1 *Land use in Sc2*



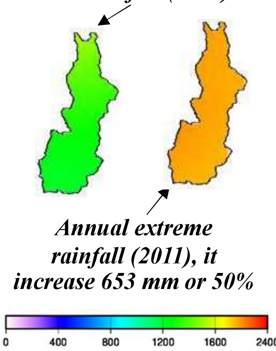
Land use in Sc3 (2016)

Climate change





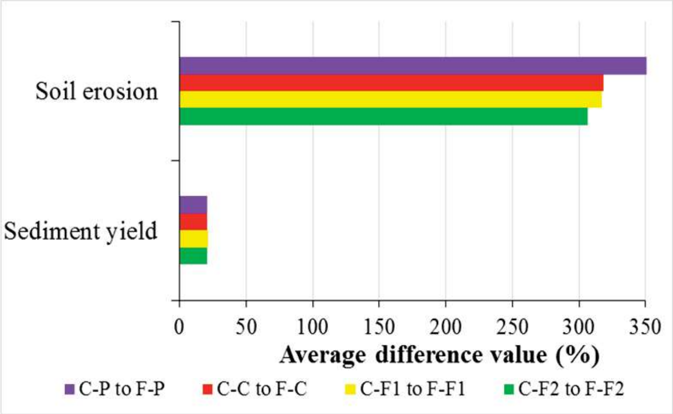
Annual normal rainfall (2004)



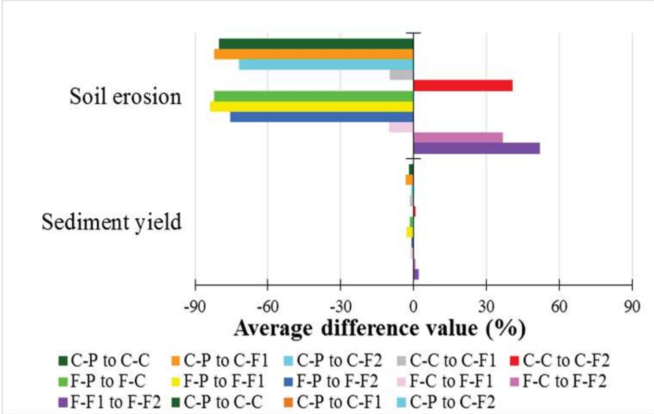
Annual extreme rainfall (2011), it increase 653 mm or 50%

Average % change

Climate change



Land use change



✓ For this river basin, the change on both of climate and land use have significant impact to both soil erosion and sediment in the river.

✓ However, climate change is likely to have a greater impact than land use change on both soil erosion and sediment.

Conclusion

- The impact of climate change tends to be effective on the soil erosion and sediment yield more than the impact of land use change.
- Furthermore, the severe scenarios suggest the land use change tends to be rather impact on soil erosion more than the climate change while the climate change has a significant impact to sediment than land use change.
- The monthly percentage change from the extreme scenarios demonstrate 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.

CLUE model

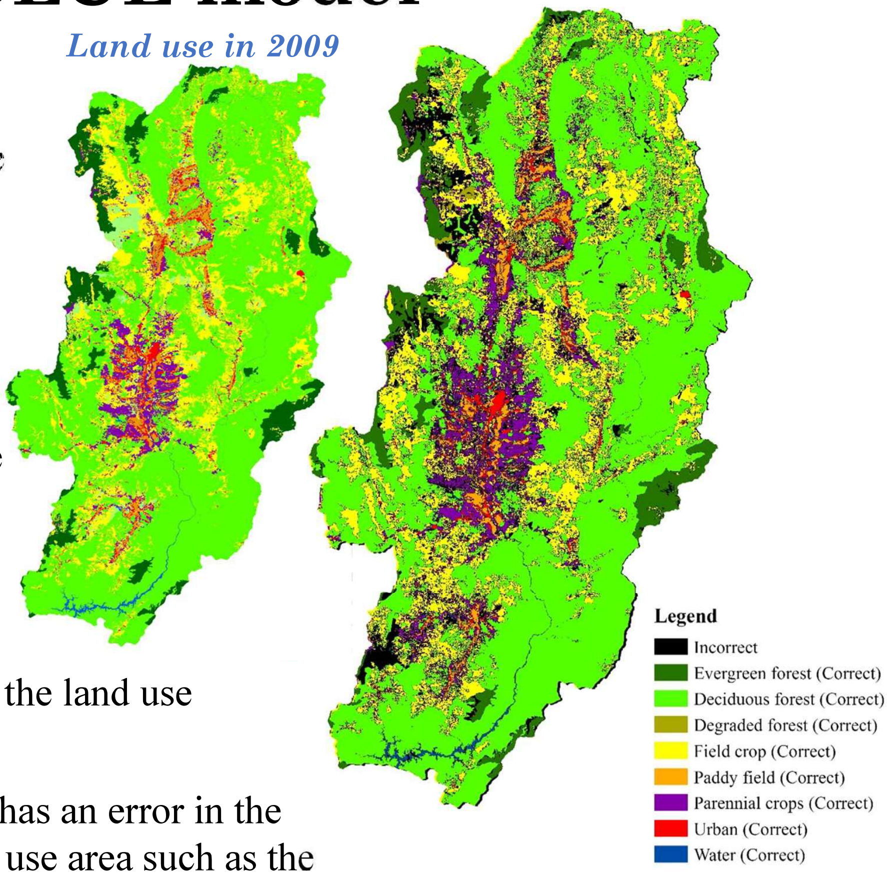
- The Conversion of Land Use and its Effects modelling framework (CLUE) was developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modelling of competition between land use types.

- Create land use map in the future from land use in 2016
  - Scenario 1: Increase forest area around 5% of total area and decrease agriculture area within 20 years
  - Scenario 2: Decrease forest area around 5% (convert to agricultural area)

Accuracy of CLUE model

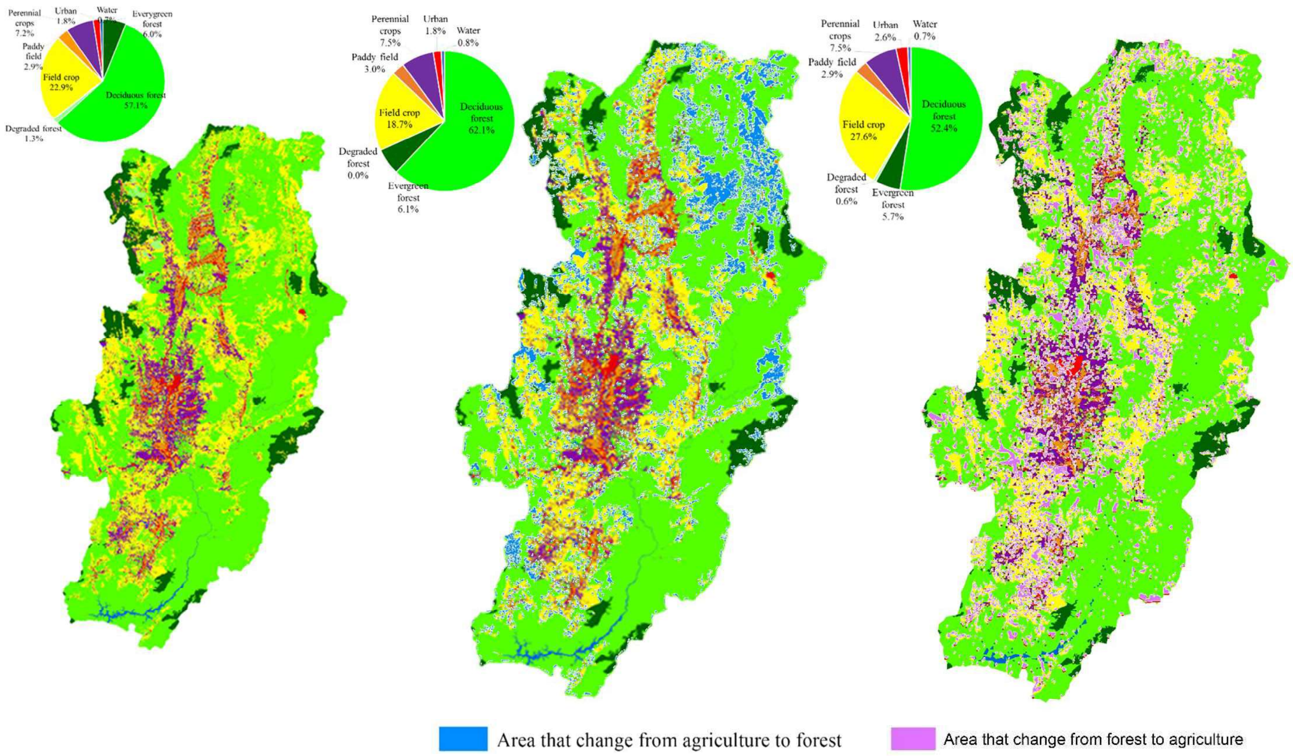
Land use in 2009

- ✓ Check the accuracy of the model by create the land use in 2016 base on land use in 2009 from LDD and compare the result in 2016 from CLUE model and the data from LDD.
- ✓ The results show the change of the main land use such as deciduous forest and field crop from the simulation of CLUE model are nearby the change of land use from the land use change data of LDD.
- ✓ However, the CLUE model has an error in the simulation of the small land use area such as the water area.



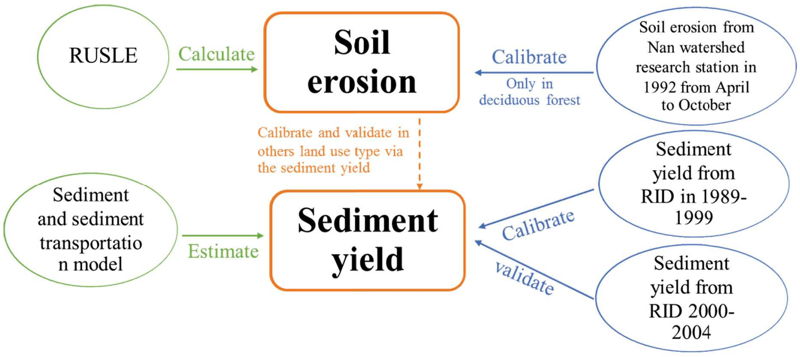
Land use

2016 ***2036 (scenario 1)*** ***2036 (scenario 2)***



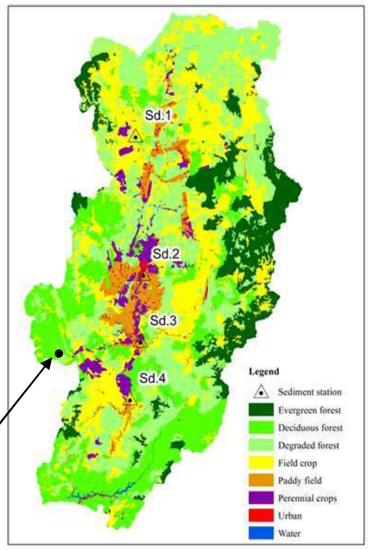
Calibrate the soil erosion and sediment model

- Calibrate soil erosion by observation data from Nan watershed research station with simulation from April to October, 1992



- Calibrated and validated sediment yield simulated by model using climate data in 1989-2004 and land use data in 2000 by observation data of 4 stations from RID.

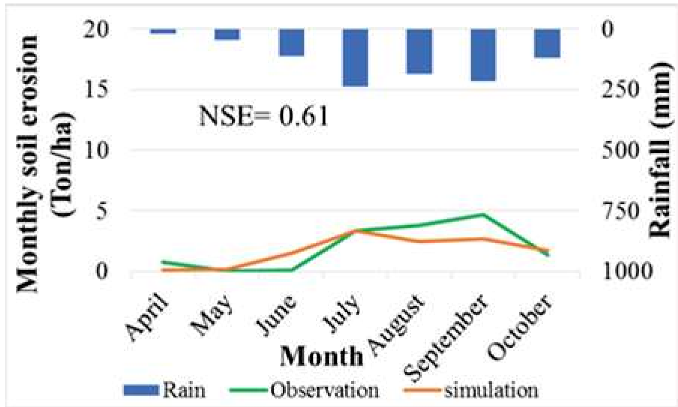
- Calibration by modified the C-factor value in Soil erosion model and parameters in SDR and sediment transportation model.



Nan watershed research station

Calibration and Validation

Land cover	C-factor value	
	Before calibrate	After calibrate
Field crop	0.34	0.42
Deciduous forest	0.019	0.015
Deforestation	0.25	0.15
Paddy field	0.28	0.30
Perennial crop	0.15	0.20
Urban	0	0.08



Parameter	Value		Model
	Before calibrate	After calibrate	
Rain intensity (mm/hr)	20	11	SDR
Peak rainfall (mm)	1450	1650	
Parameter of setting velocity	1	0.6	Sediment transportation
Depth to bedload	2	5	
Size distribution ratio	1	0.1	
Parameter of detachment velocity	1	0.8	

Soil erosion

- Accuracy of soil erosion by soil erosion data from Nan watershed research station (blue line) and soil erosion from the model (rad line)
- NSE = 0.61

Calibration and Validation

Calibrated and validated sediment simulated by model with observation data of 4 stations from Royal Irrigation Department

No.	Name	NSE	Duration
1	Sd.1	0.72	1998-2000
2	Sd.2	0.67	1989-1993
3	Sd.3	0.59	1995-2000

No.	Name	NSE	Duration
1	Sd.1	0.57	2001-2004
2	Sd.3	0.75	2001-2004
3	Sd.4	0.44	2000-2004

This calibration shows that the NSE value represented the sediment model has the accuracy in a good level and can be used to estimate storage of sediment in the future

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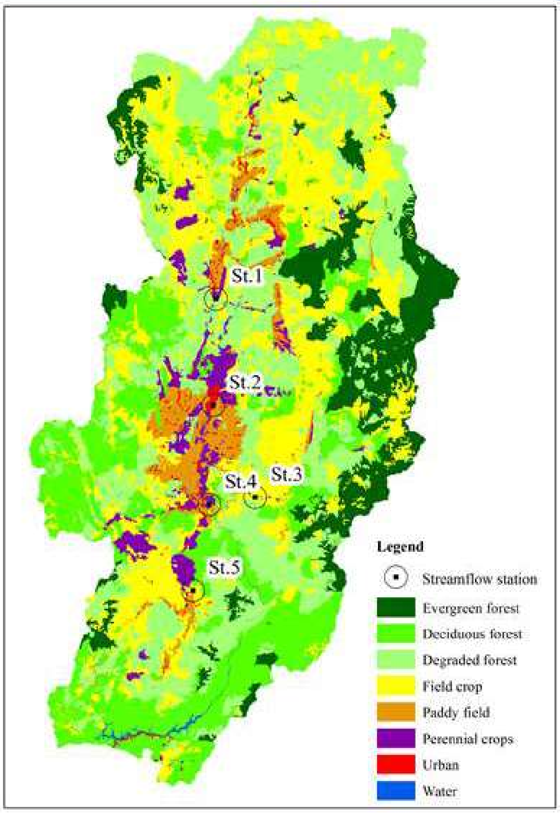
Calibrate H08 model (River discharge)

- Calibrated river discharge simulated by model using climate data in 1985-2004 and land use data in 2000 by observation data of 5 stations from Royal Irrigation Department and inflow of Sirikit reservior.
- Calibration by change the value of parameters in H08 model which related to land use.

  SD: soil depth
  CD: bulk transfer coefficient
  Tau: time constant for daily maximum subsurface runoff
  Gamma: shape parameter which relationship with subsurface flow.



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Hanasaki et al., 2014

Calibrate H08 model

Land use	Parameter		Land use	Parameter	
Paddy field	Soil Depth (m)	1.5	Forest	Soil Depth (m)	1.7
	CD	0.0005		CD	0.001
	GAMMA	1.8		GAMMA	1.7
	TAU (day)	110		TAU (day)	140
Field crop	Soil Depth (m)	2.0	Urban	Soil Depth (m)	1.5
	CD	0.00045		CD	0.0006
	GAMMA	1.5		GAMMA	1.7
	TAU (day)	120		TAU (day)	100
Perennial Crops	Soil Depth (m)	2.3			
	CD	0.0045			
	GAMMA	1.7			
	TAU (day)	120			

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Calibrate and validate river discharge

Calibrate: River discharge between observed data and simulation from climate data in 1984-2004 and land use in 2000

No.	Name	NSE	Duration
1	St.2	0.69	1985-1994
2	St.4	0.81	1988-1994
3	Sirikit reservoir	0.61	1985-1994

No.	Name	NSE	Duration
1	St.1	0.82	1995-2004
2	St.2	0.67	1995-2004
3	St.3	0.72	1993-2002
4	St.4	0.72	1995-2004
5	St.5	0.79	1995-2004
6	Sirikit reservoir	0.71	1995-2004

Validated: River discharge simulated by model using climate data in 1995-2004 and land use data in 2000 by observation data of 5 stations from Royal Irrigation Department and inflow of Sirikit reservoir from EGAT.

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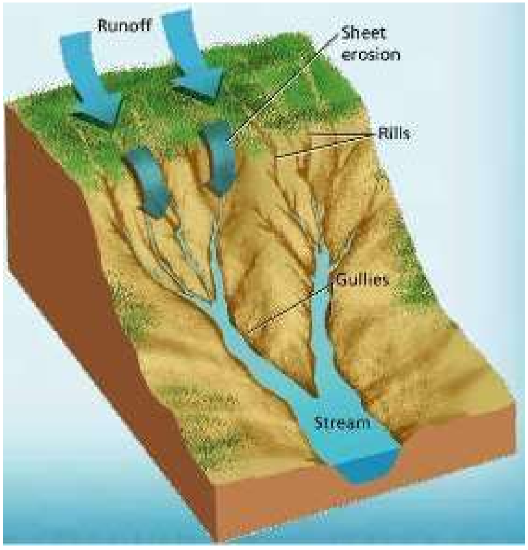
Soil erosion and sediment

- Soil erosion consists of a series of natural processes that move earth and rock material. The land surface is worn away through the detachment and transport of soil and rock by moving water, wind, and other geologic agents. Although erosion is a natural process, disturbance of the land surface by human has greatly increased this erosion rate. *(USDA, 1998)*



Soil erosion and sediment

- Sediment delivery ratio (SDR) represents the efficiency of the watershed in moving soil particles from areas of erosion to the point where sediment yield is measured. *(USDA, 1998), (LU et al., 2006), (Santos et al, 2017)*

- Sediment Yield (SY) can be defined as the amount of sediment reaching or passing a point of interest in a given period of time *(White, 2005)* or total quantity of sediment *(MacGregor, 2011)*