The simulation of watershed-scale effectiveness of agricultural best management practices in a drinking water resource area of Beijing, China

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2016-07-28

CONTENT

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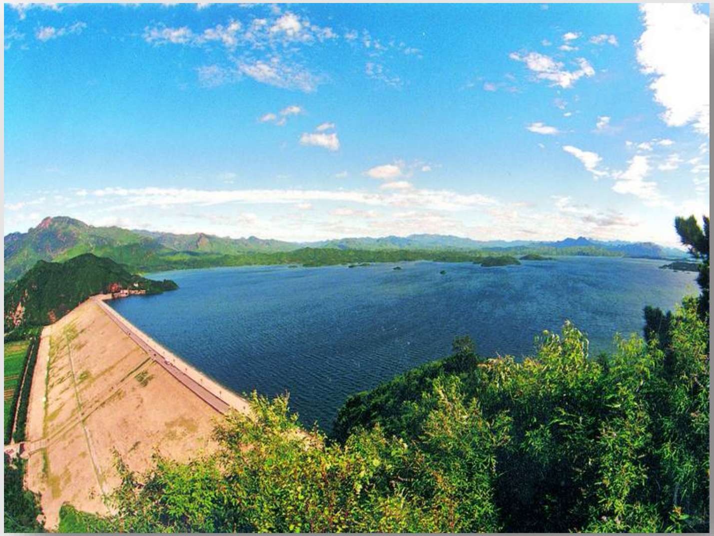
PART ONE

Background

1. Non-point source pollution

Non-point source pollution from agricultural area have a significant impact on water quality.

Main source:



2. The development of BMPs




Best management practices (BMPs) are defined as the state-of-the-art management practices that help prevent or reduce NPS pollution to a level compatible with water quality goals.

✓Structural BMPs
✓Non-structural BMPs

3. Models for assessing BMPs

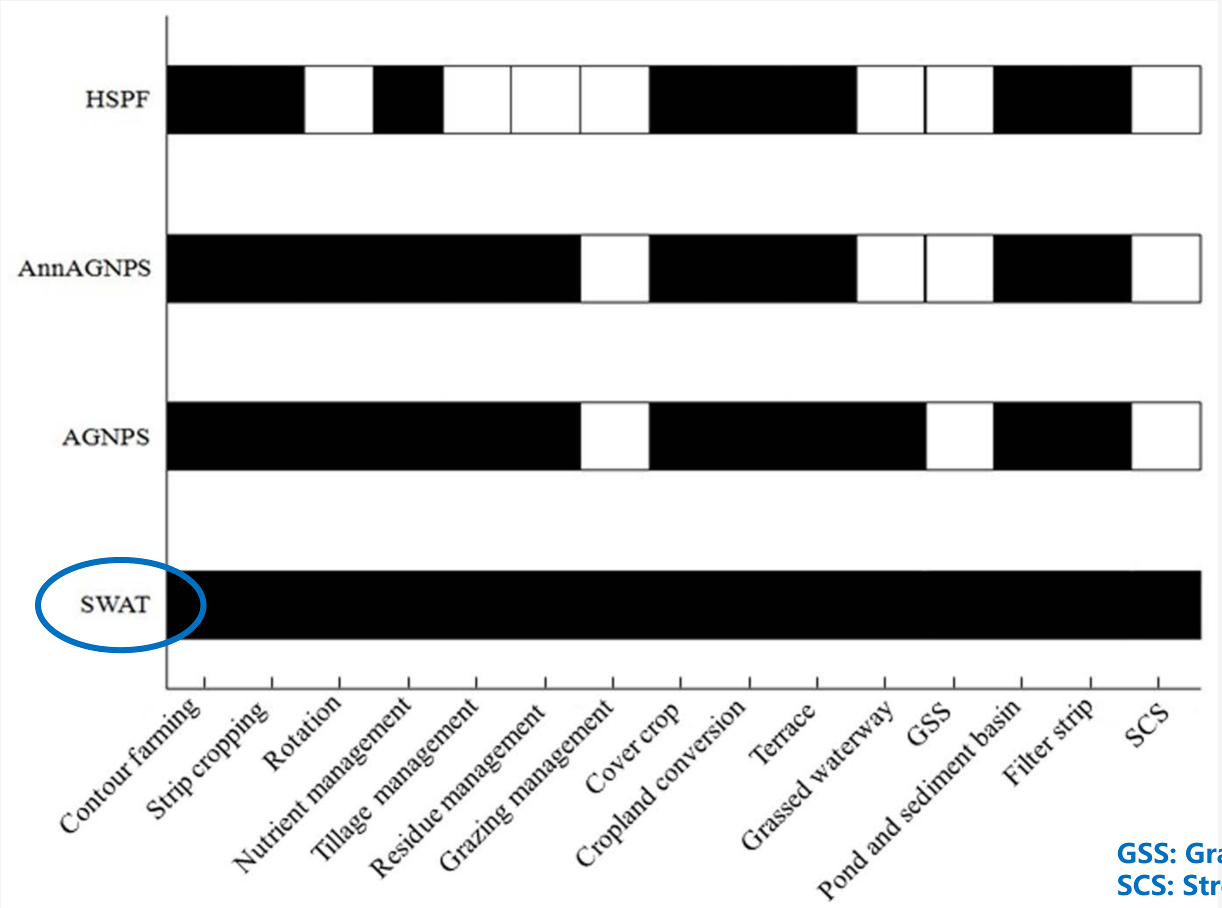
Models	Temporal Resolution	Spatial Representation	Overland Flow Routing	Overland Sediment Routing	Channel Processes	Developer
SWAT	Continuous; Daily or sub-daily time steps.	Sub-basins or further hydrologic response units defined by soil and land use/land cover.	SCS-CN method for infiltration and peak flow rate by modified Rational formula.	MUSLE represented by runoff volume, peak flow rate, and USLE factors.	Channel degradation and sediment deposition process including channel-specific factors.	USDA
AGNPS	Storm-event; One storm duration as a time step.	Cells of equal size with channels included.	SCS-CN method for infiltration, and flow peak using a similar method with SWAT.	USLE for soil erosion and sediment routing through cells with n, USLE factors to be concerned with.	Included in overland cells.	USDA
AnnAGNPS	Continuous; daily or sub-daily time steps.	Cells with homogeneous soil and land use.	SCS-CN method for infiltration and TR-55 method for peak flow.	RUSLE to generate soil erosion daily or user-defined runoff event.	Channel degradation and sediment deposition with Modified Einstein equation and Bagnold equation.	USDA
HSPF	Continuous; variable constant steps (from 1 min up to 1 day).	Pervious and impervious land areas, stream; hydrologic response units.	Philip's equation for infiltration.	Rainfall splash and wash off of detached sediment calculated by an experimental non-liner equation.	Non-cohesive and cohesive sediment transport.	USGS and USEPA

Hui Xie, Lei Chen * and Zhenyao Shen. Assessment of Agricultural Best Management Practices Using Models: Current Issues and Future Perspectives, Water 2015, 7, 1088-1108.

3. Models for assessing BMPs

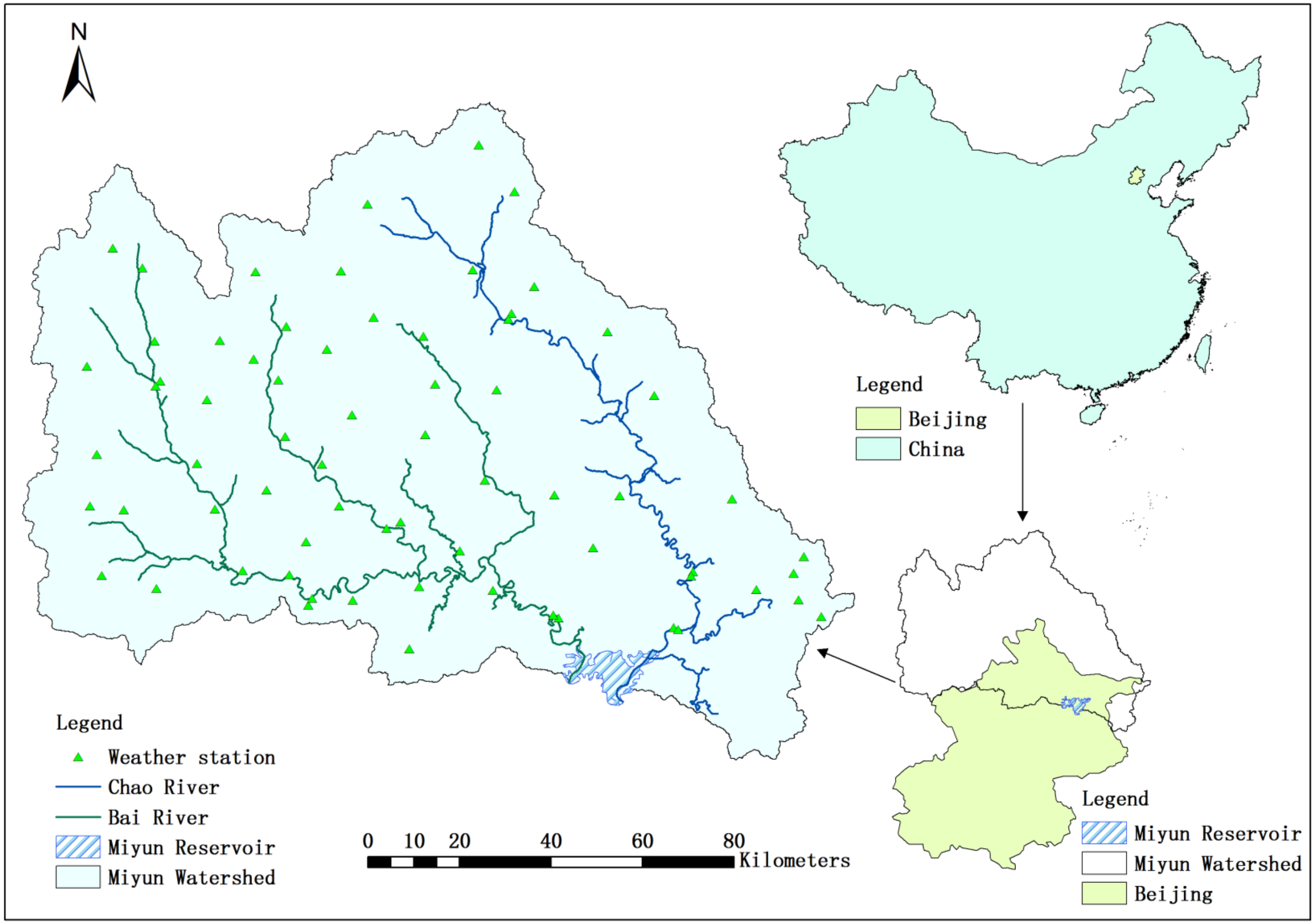
Representation of BMPs

The types of agricultural BMPs that can be assessed by different watershed models:



GSS: Grade stabilization structure;
SCS: Stream channel stabilization

4. Watershed description



Miyun Watershed is the water source protection area of Miyun Reservoir, which is one of the biggest reservoirs in North China, supplying Beijing residents with potable water.

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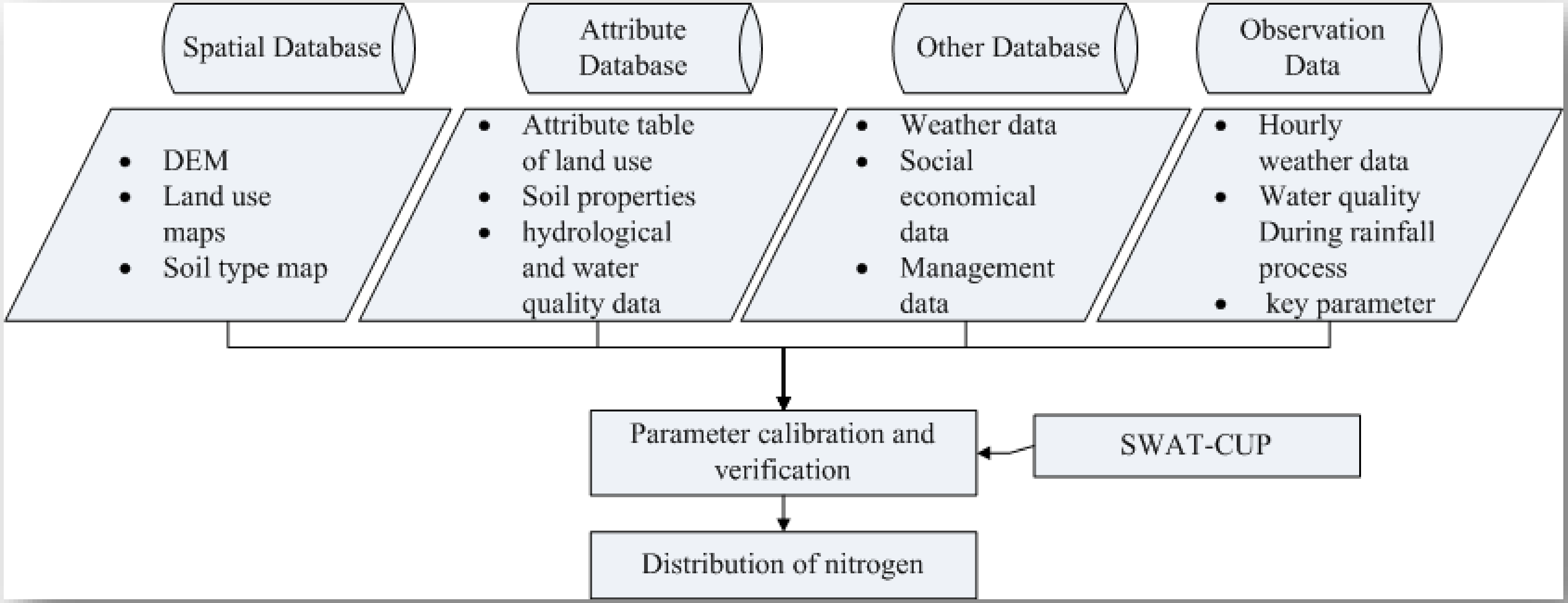
PART TWO

SWAT model description

1. SWAT description

➢The Soil and Water Assessment Tool (SWAT) was used to simulate the flow and nutrient loads in the watershed scale.
➢The SWAT-CUP program was used to calibrate and verify the model parameters.



1. SWAT description: hydrology

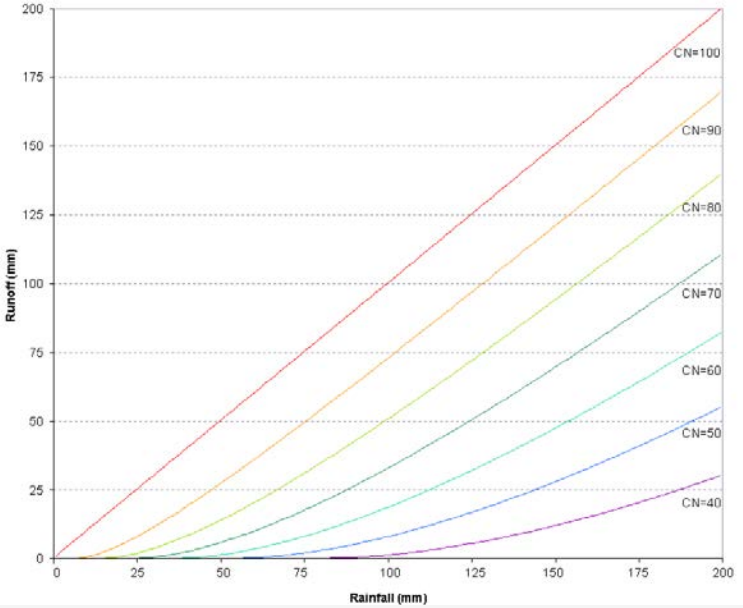
The land phase of the hydrologic cycle is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

Runoff volume	Peak runoff rate	Base flow

SCS curve number procedure :

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad S = \frac{25400}{CN} - 254$$



Modified rational method :

$$q_{peak} = \frac{C \cdot i \cdot Area}{3.6} \qquad C = Q_{surf} / R_{day}$$

Steady-state response of base flow to rescharge :

Base dlow is allowed to enter the reach only if the amount of water stores in the shallow aquifer exceeds a threshold value specified by the user, $aq_{shthr,q}$

$$Q_{gw} = \frac{8000 \cdot K_{sat}}{L_{gw}^2} \cdot h_{wtbl}$$

1. SWAT description: nutrients

Nitrate: The concentration of nitrate in the mobile water fraction is calculated:

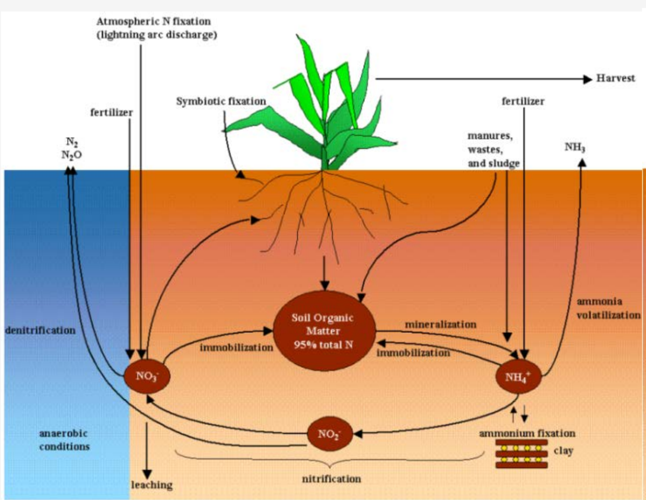
$$conc_{NO3,mobile} = \frac{NO_{3,ly} \cdot \left\{ 1 - \exp\left[\frac{-w_{mobile}}{(1-\theta_e) \cdot SAT_{ly}} \right] \right\}}{w_{mobile}} \qquad w_{mobile} = Q_{surf} + Q_{lat,ly} + w_{perc,ly}$$

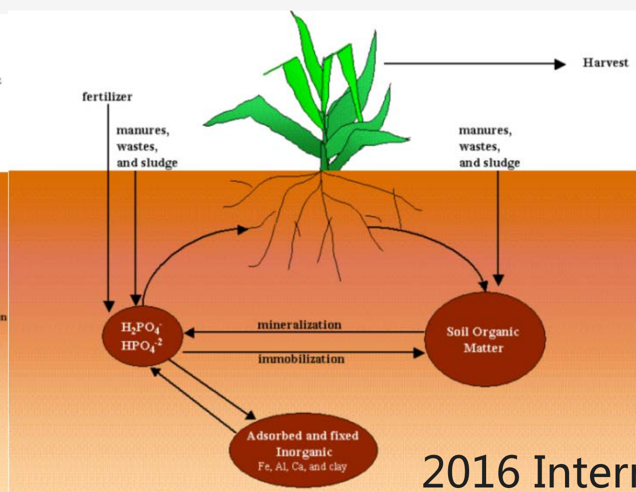
Organic N: The amount of organic N transported with sediment to the stream is calculated with a loading function:

$$orgN_{surf} = 0.001 \cdot conc_{orgN} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{N:sed}$$

Solution phosphorus: the amount transported in surface runoff is:

$$P_{surf} = \frac{P_{solution,surf} \cdot Q_{surf}}{\rho_b \cdot depth_{surf} \cdot k_{d,surf}}$$





Organic & mineral P transported with sediment to the stream is calculated:

$$sedP_{surf} = 0.001 \cdot conc_{sedP} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{P:sed}$$

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PART THREE

BMP tool description

1. Representation of BMPs

Subbasins, HRUs, and reaches → **Long-term impacts of BMPs** → **Key parameters** → **Specific module**

The common principle of BMPs representation is to depict the change in watershed processes and the response of water quality under or without BMPs.

By changing model inputs or parameter values according to *conservation practices modelling guide* .

Outputs from a particular BMP scenario were annual load change of sediment, total phosphorus (TP) and total nitrogen (TN).

2. BMP modelling

BMP	Parameters	Specific Module
Contouring	CN2, USLE_P	.OPS
Strip cropping	CN2, *n*, USLE_P, USLE_C	.OPS
Residue management	CN2, *n*, USLE_C	.OPS
Tillage management	CN2, EFFMIX, DEPTIL	.MGT
Filter strip	VFS routine (FILTER_RATIO, TILTER_CON, FILTER_CH) or FILTERW	.OPS
Grassed waterway	CH_depth, CH_width, CH_COV, CH_*n*	.OPS
Sediment basins and detention pond	CH_EROD, CH_N2 PND_FR, PND_PSA and PND_K	.PND

Notes: EFFMIX: The mixing efficiency of a tillage options; EFFTIL: Depth of mixing caused by tillage options.

Land management

SWAT model introduce a land use change (LUC) module, which allows manually adjusting fractional coverage of land use types in each HRUs.

Converting cropland to for forest over 15° slope and 25° slope

Nutrient management tillage practice

SWAT model allows information about these measures to be modified by scheduling the amount, timing and period of agricultural activities.

*.mgt

20% and 30% fertilizer reduction

Structural BMPs

*Management Operations (.ops) file for each HRU

Grassed way, filter strip, sediment basin, etc.

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PART FOUR

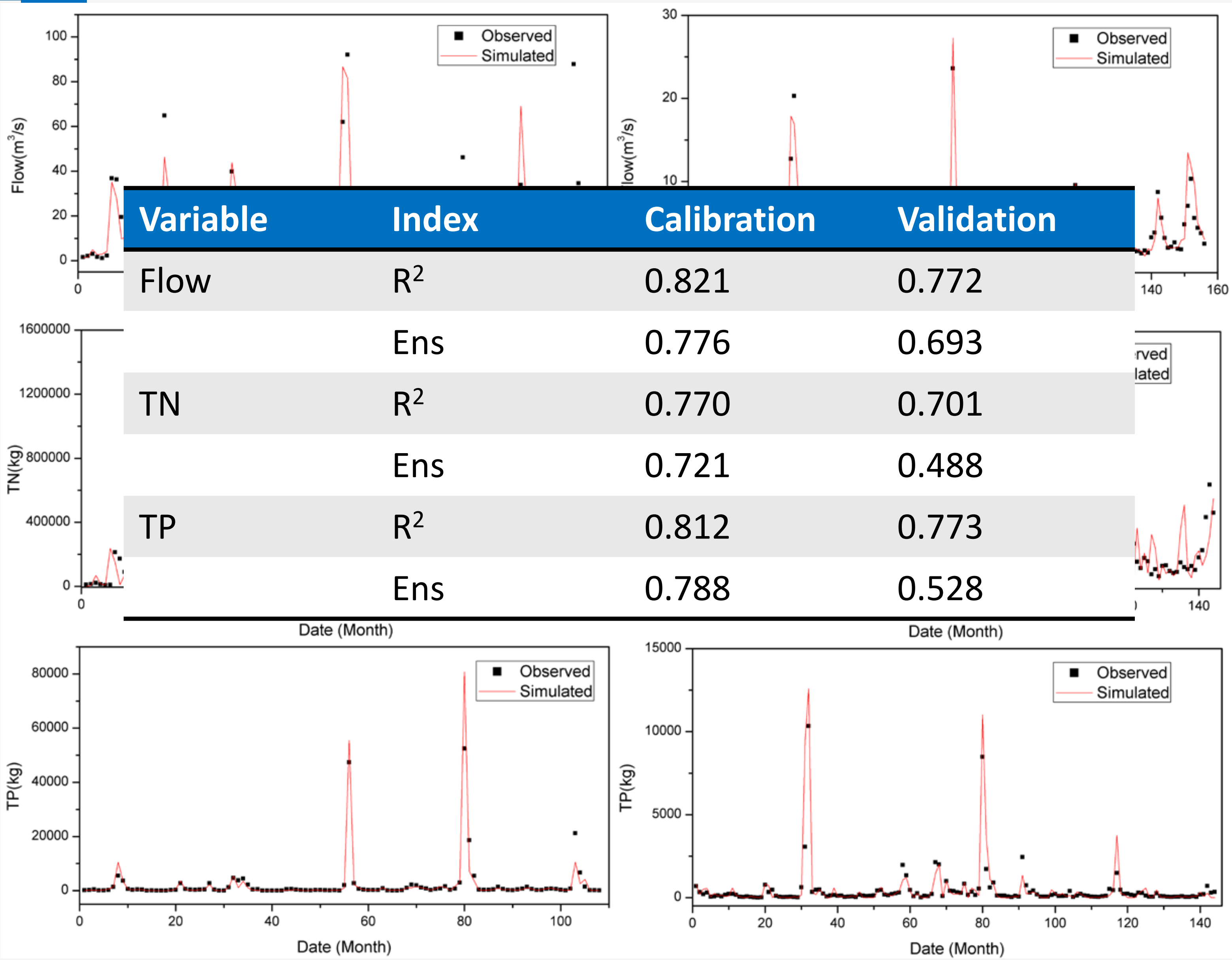
Results and discussion

1. Parameter sensitivity

Variable	Parameter	Description	Lower limit	Upper limit	Conversion	Rank
FLOW	*GWQMN*	Threshold water level in the shallow aquifer for the base flow	0	5000	v	1
	SOL_BD	Moist bulk density	0.9	2.5	v	2
	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0	500	v	3
	ESCO	Soil evaporation compensation coefficient	0	1	v	4
	ALPHA_BNK	Baseflow alpha factor for bank storage	0	1	r	5
	CN2	SCS moisture condition II curve number for pervious areas	-0.2	0.5	r	6
	SOL_Z	Depth from soil surface to the bottom of the layer	-1	1	r	7
	CANMX	Maximum canopy storage	0	100	v	8
	SOL_AWC	Available water capacity of the soil layer	0	1	v	9
	SOL_K	Saturated hydraulic conductivity of the first layer	-0.8	0.8	r	10
	CH_K2	Effective hydraulic conductivity in main channel alluvium	-0.01	500	v	11
	EPCO	Plant uptake compensation factor	0	1	v	12
TP	*SOL_SOLP*	Initial labile (soluble) P concentration in surface soil layer	0	100	v	1
	BC4	Rate constant for decay of organic phosphorus to dissolved phosphorus (1/day)	0.01	0.7	v	2
	PSP	Phosphorus sorption coefficient	0.01	0.7	v	3
	K_P	Michaelis-Menton half-saturation constant for phosphorus	0.001	0.05	v	4
	PPERCO	Phosphorus percolation coefficient	10	17.5	v	5
TN	*SOL_NO3*	Initial NO3 concentration in the soil layer	0	100	v	1
	BC2	Rate constant for biological oxidation NO2 to NO3 (1/day)	0.2	2	v	2
	BC3	Rate constant for hydrolysis of organic nitrogen to ammonia (1/day)	0.02	0.4	v	3
	ERORGN	Organic N enrichment ratio	0	5	v	4
	SOL_ORGN	Initial humic organic nitrogen in the soil layer	0	100	v	3

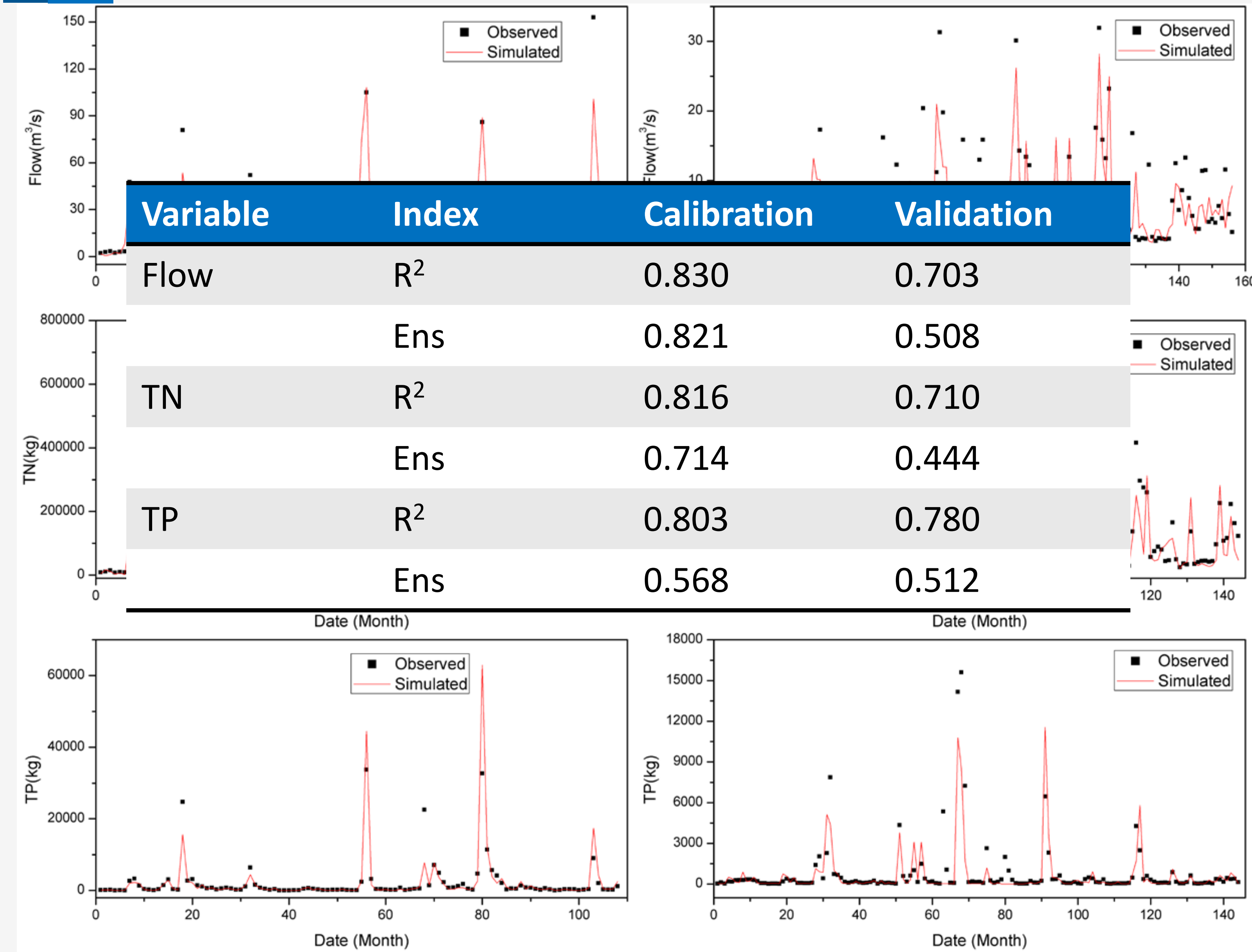
Variable	Parameter	Description	Lower limit	Upper limit	Conversion	Rank
FLOW	*SOL_Z*	Depth from soil surface to the bottom of the layer	-1	1	r	1
	CH_K2	Effective hydraulic conductivity in main channel "alluvium"	-0.01	500	v	2
	SLSUBBSN	Average slope length	10	150	v	3
	CN2	SCS moisture condition II curve number for pervious areas	-0.2	0.5	r	4
	SOL_K	Saturated hydraulic conductivity of the first layer	-0.8	0.8	r	5
	GWQMN	Threshold water level in the shallow aquifer for the base flow	0	5000	v	6
	TRNSRCH	Fraction of transmission losses from main channel that enter deep aquifer	0	1	v	7
	EPCO	Plant uptake compensation factor	0	1	v	8
	CANMX	Maximum canopy storage	0	100	v	9
	SOL_AWC	Available water capacity of the soil layer	0	1	v	10
	GW_DELAY	Groundwater delay (days)	0	500	v	11
	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0	500	v	12
	RCHRG_DP	Deep aquifer percolation fraction	0	1	v	13
TP	*SOL_SOLP*	Initial labile (soluble) P concentration in surface soil layer	0	100	v	1
	ERORGP	Organic P enrichment ratio	0	5	v	2
	BC4	Rate constant for decay of organic phosphorus to dissolved phosphorus (1/day)	0.01	0.7	v	3
	AI2	Fraction of algal biomass that is phosphorus	0.01	0.02	v	4
	SOL_ORGP	Initial humic organic phosphorus in the soil layer	0	100	v	5
TN	*SOL_NO3*	Initial NO3 concentration in the soil layer	0	100	v	1
	RS4	Rate coefficient for organic N settling in the reach at 20℃ [1/day]	0.001	0.1	v	2
	AI6	Rate of oxygen uptake per unit NO2-N oxidation	1	1.14	V	3
	CH_N2	Michaelis-Menton half-saturation constant for nitrogen	0.01	0.3	V	4
	NPERCO	Nitrogen percolation coefficient	0	1	v	3

2. Parameter calibration and validation



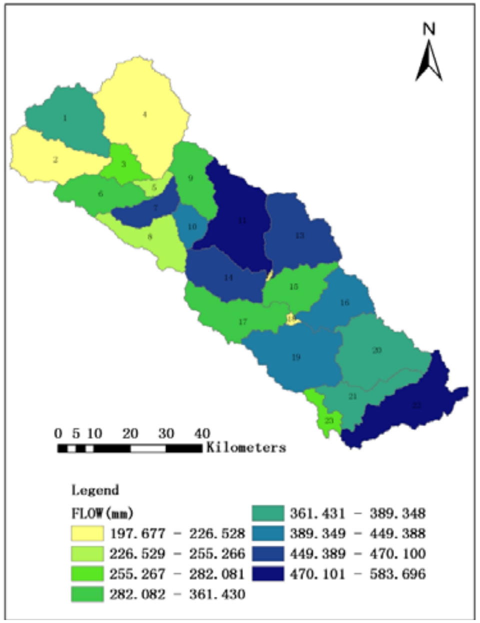
Variable	Index	Calibration	Validation
Flow	R^2	0.821	0.772
	Ens	0.776	0.693
TN	R^2	0.770	0.701
	Ens	0.721	0.488
TP	R^2	0.812	0.773
	Ens	0.788	0.528

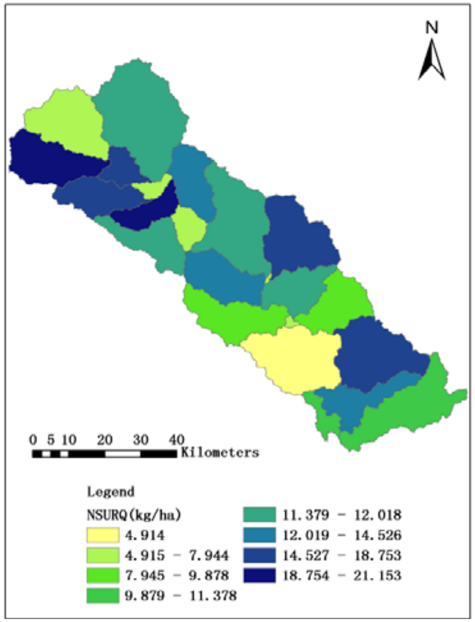
2. Parameter calibration and validation

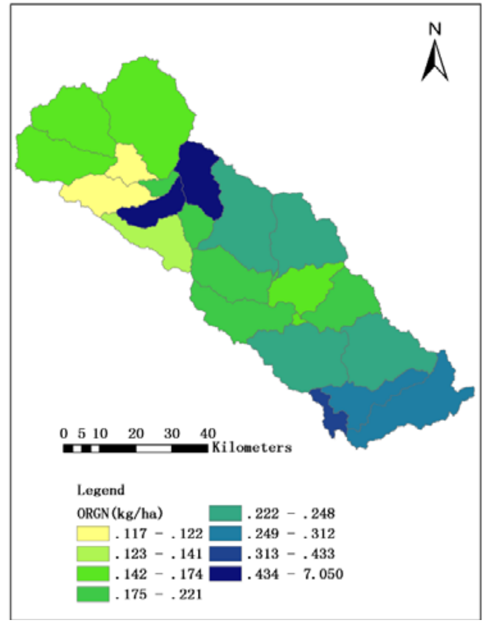


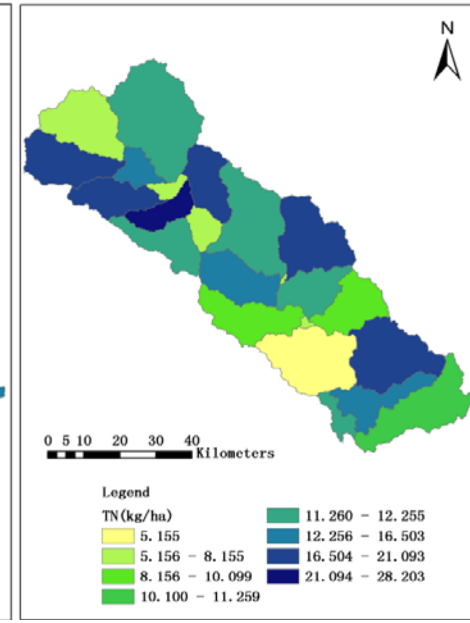
Variable	Index	Calibration	Validation
Flow	R^2	0.830	0.703
	Ens	0.821	0.508
TN	R^2	0.816	0.710
	Ens	0.714	0.444
TP	R^2	0.803	0.780
	Ens	0.568	0.512

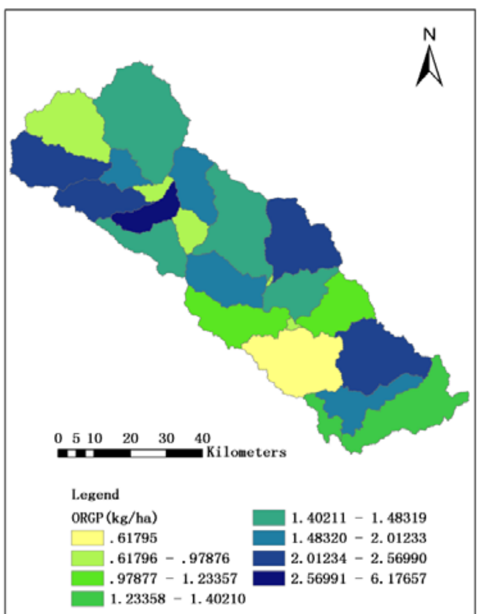
3. Spatial distribution of pollution

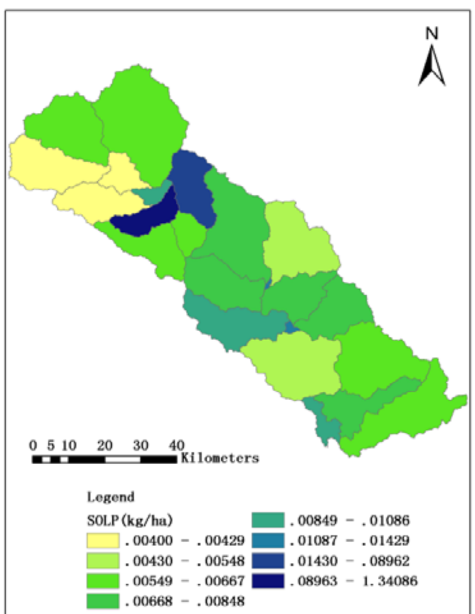


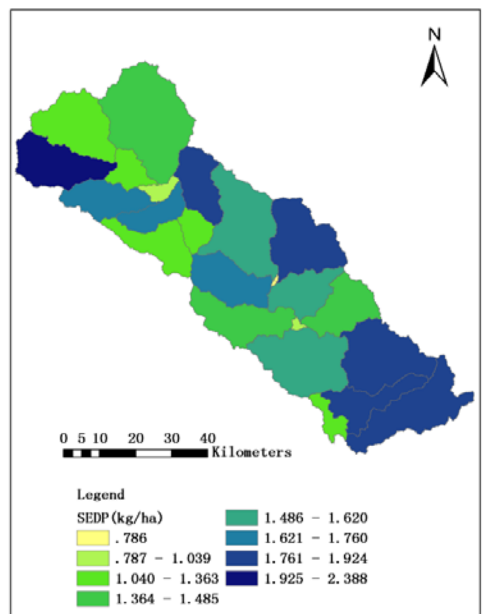


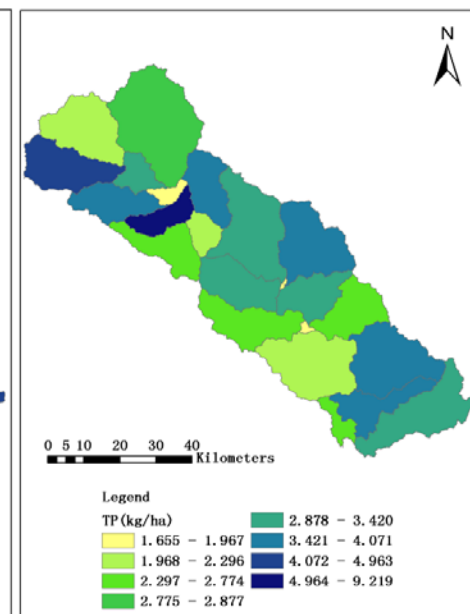




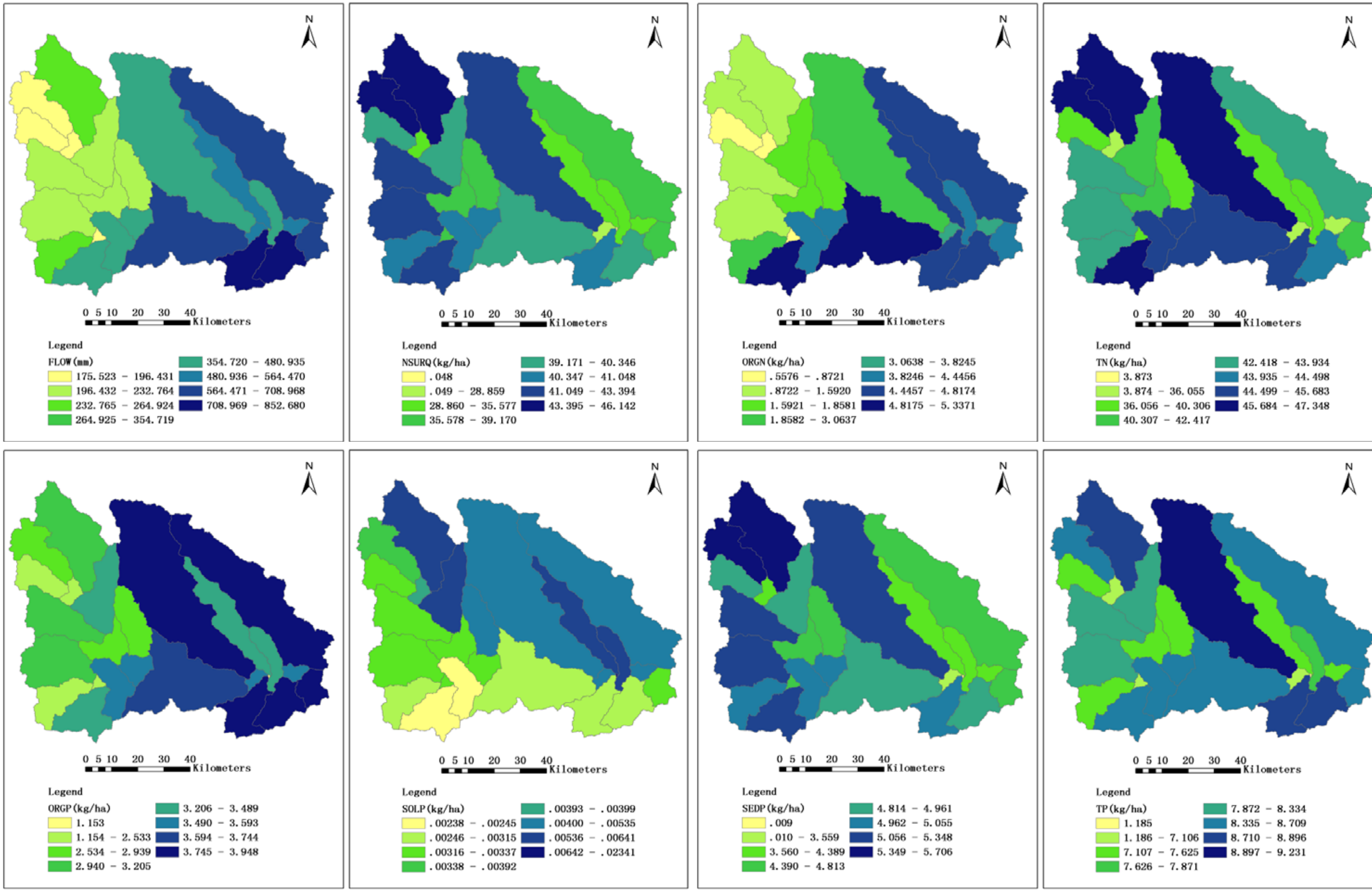




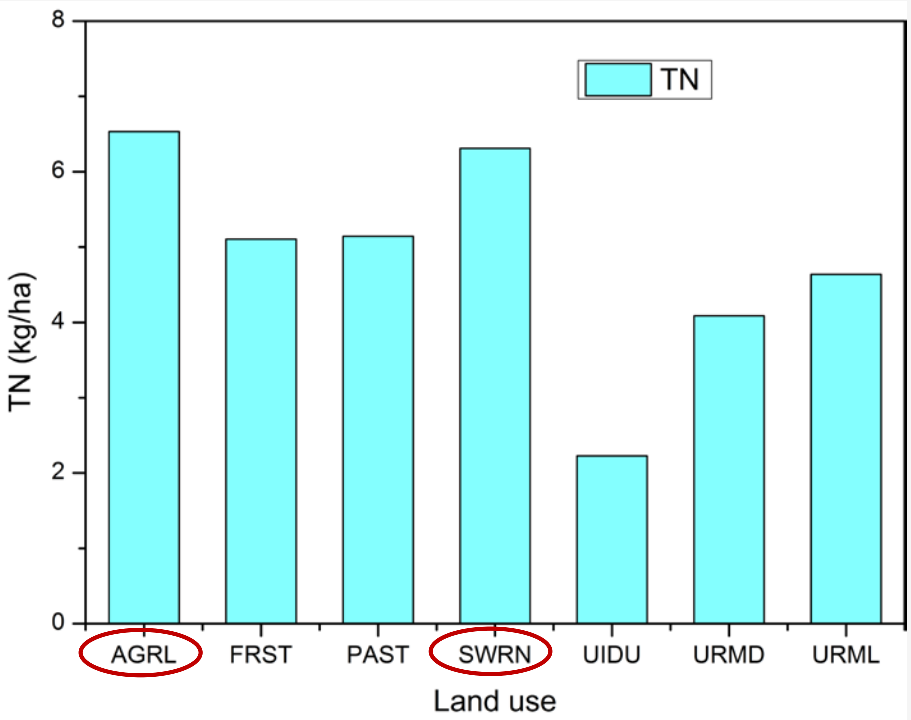


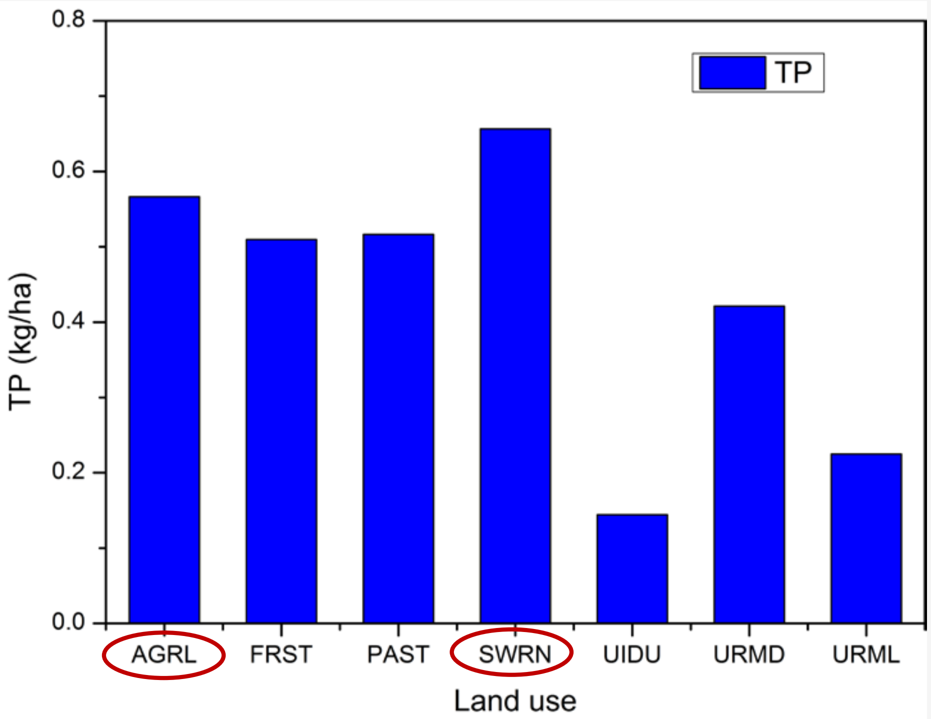


3. Spatial distribution of pollution



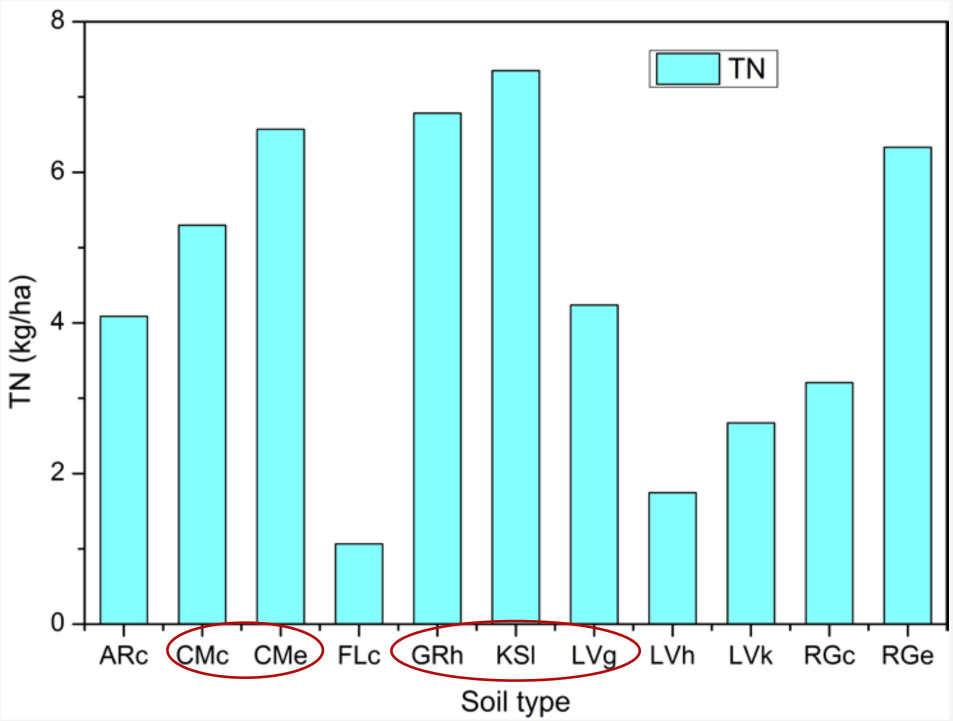
4. The loads from different land uses

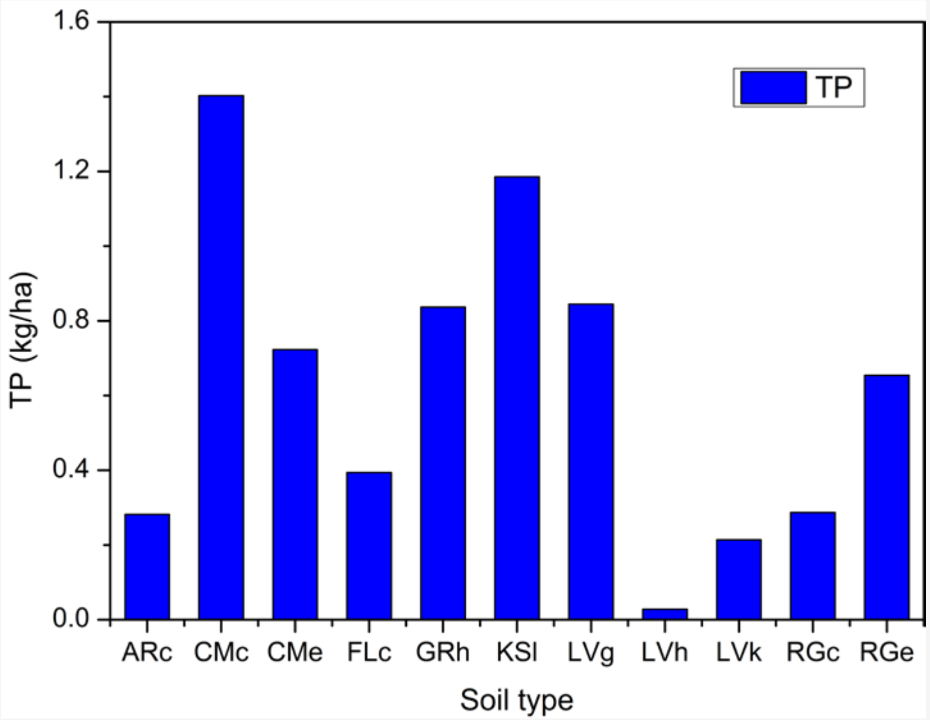




AGRL, Agricultural Land-Generic
FRST, Forest-Mixed
PAST, Pasture
SWRN, Southwestern US (Arid) Range or vacant land
UIDU, Industrial
URMD, Residential-Medium Density
URML, Residential-Med/Low Density

5. The loads from different soil types

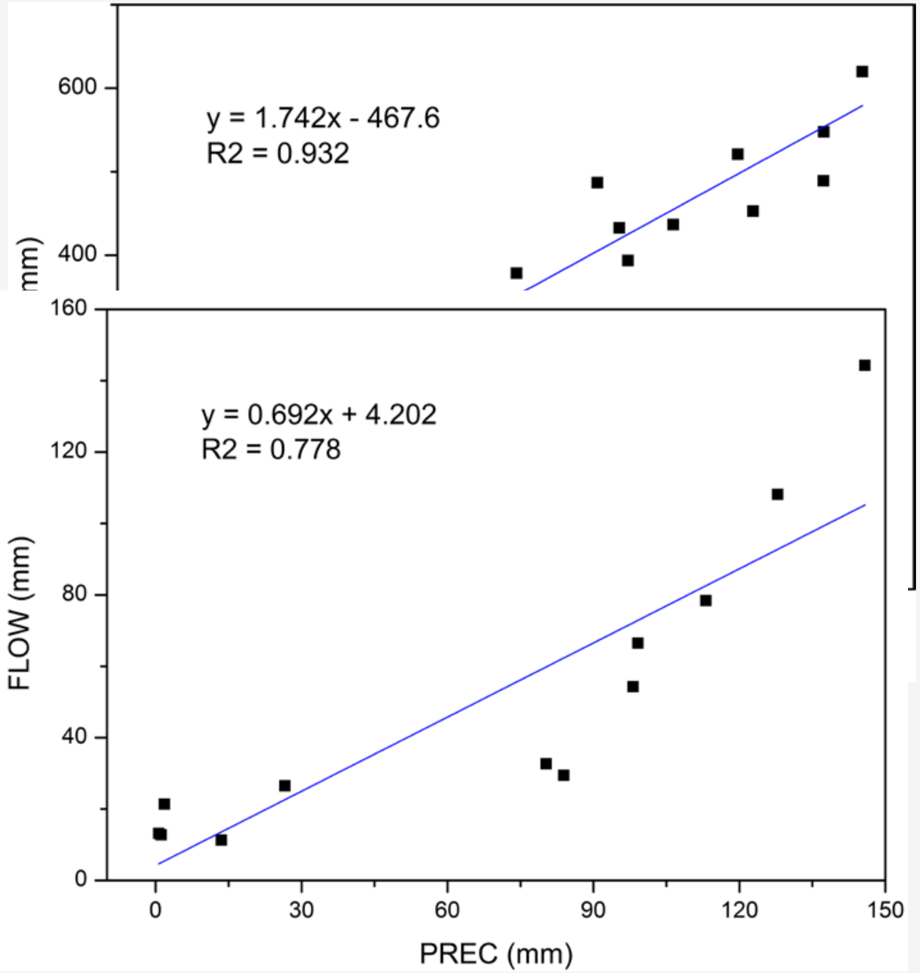


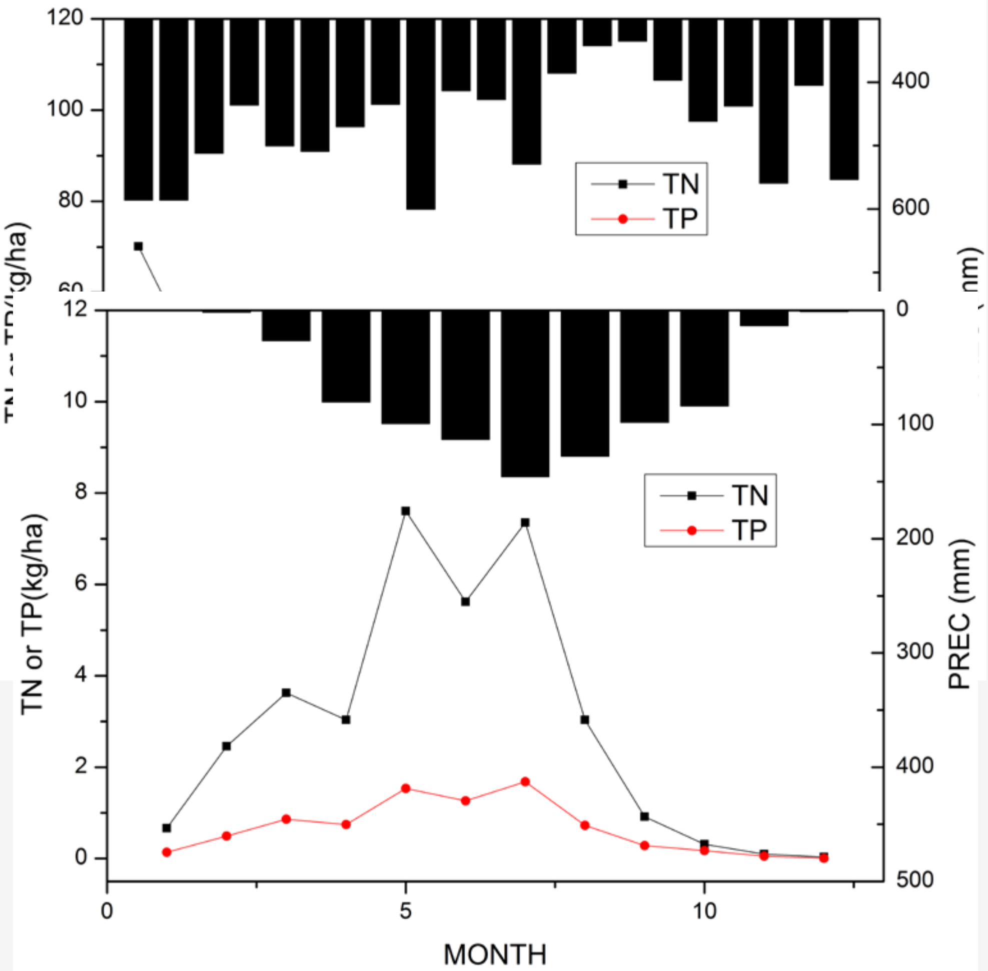


Arc, Calcaric Arenosols
CMc, Calcaric Cambisols
CMe, Eutric Cambisols
FLc, Calcaric Fluvisols
GRh, Haplic Greyzems
KSl, Luvic Kastanozems

LVg, Gleyic Luvisols
LVh, Haplic Luvisols
LVk, Calcic Luvisols
RGe, Eutric Regosols
RGc, Calcaric Regosols

4. Temporal distribution of pollution



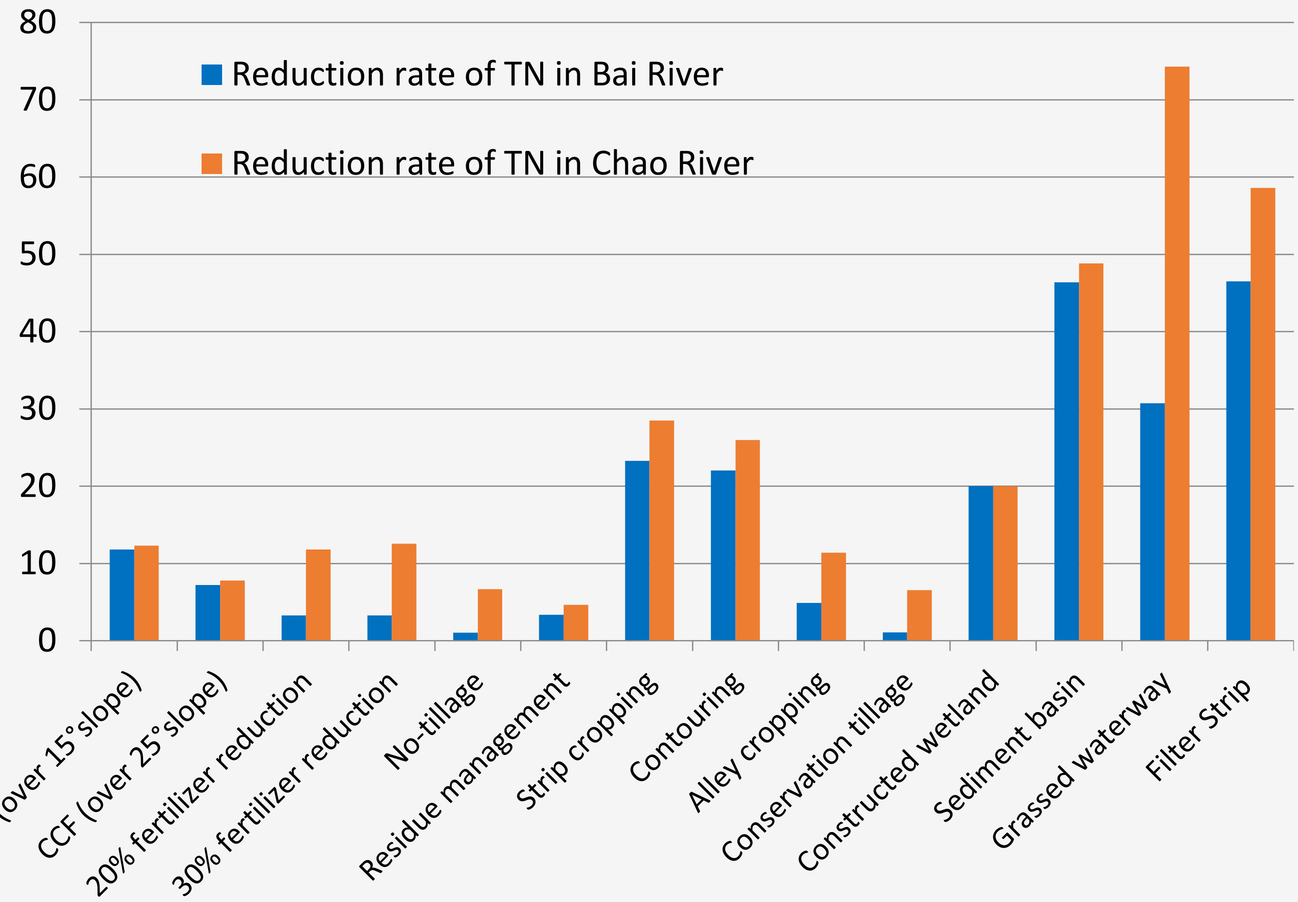


FLOW-PREC: $R^2 = 0.778$

TN-PREC: $R^2 = 0.396$

TP-PREC: $R^2 = 0.465$

5. BMP efficiencies



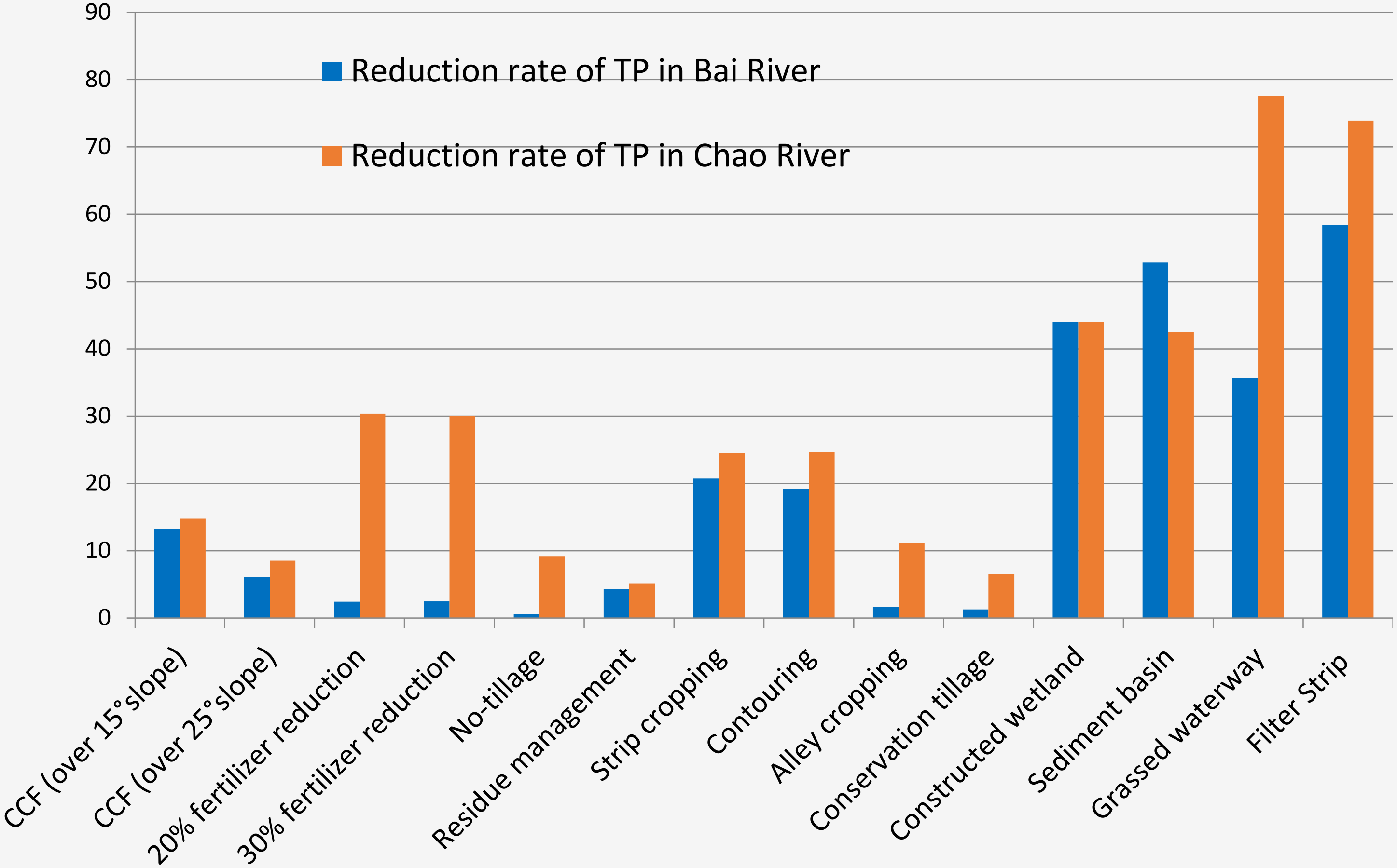
Efficiency of structural BMPs were better than non- structural BMPs.

Lower efficiencies in Bai River.

The efficiency of each BMP varied in the different sub-basins.

CCF: Converting cropland to forest

5. BMP efficiencies



The high content of nitrogen in the fertilizer resulted in the non-structural BMPs have better effects on nitrogen than on phosphorus.

Structural BMPs have similar effect on nitrogen and phosphorus, even have better efficiency for P.

CCF: Converting cropland to forest

Conclusions and Outlook

1

The SWAT model has good applicability for NPS pollution simulation in this area. The NPS pollution exhibited apparent tempo-spatial heterogeneity. The pollutant loads were positively correlated with the annual rainfall amounts and with agricultural activities.

2

The efficiency of each BMP varied in the different sub-basins. The structural BMPs such as filter strip, grassed waterways and constructed wetland was better than that of non-structural BMPs such as converting cropland to for forest, soil testing and fertilizer recommendation and conservation tillage.

3

Further research is required to analyze the influence factors on BMP efficiency and to select a preferred set of BMPs that would result in the greatest reduction in pollutant loads for the least cost to achieve the water environmental control targets.

Thanks for Attention

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