2019 - Vienna, Austria

A New Method for Predicting the Impact of Precipitation and Land Use Change on Non-point Source Pollution from Mechanism Model to Dynamic Export Coefficient Model

Reporter: Wenzhuo Wang
Superviser: Lei Chen , Zhenyao Shen
Institution: Beijing Normal University, China

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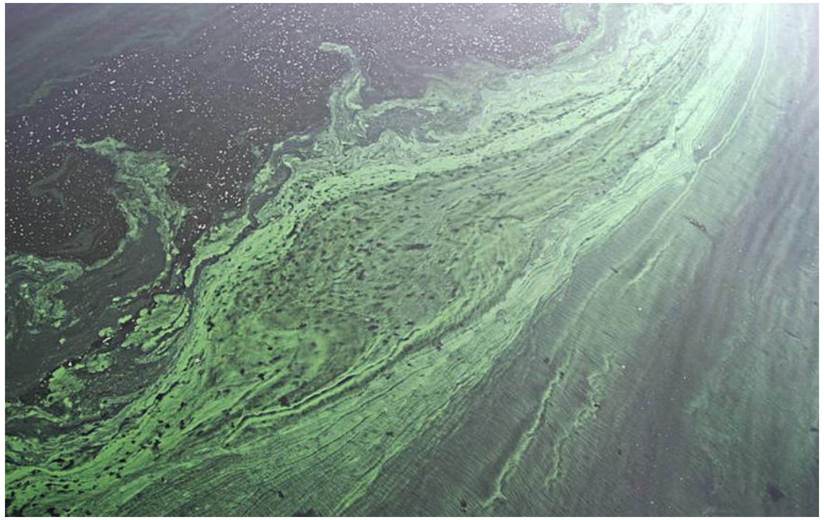
Background

Background

Non-point source (NPS) pollution has been a key threat to water quality



Dispersiveness and Stealthiness

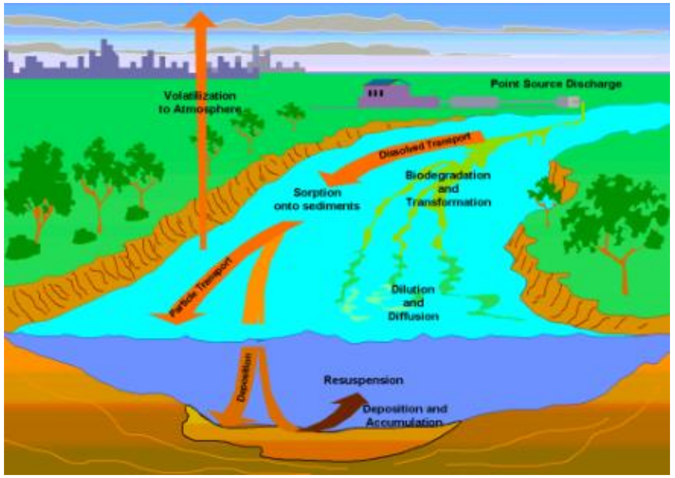
Randomness and Uncertainty

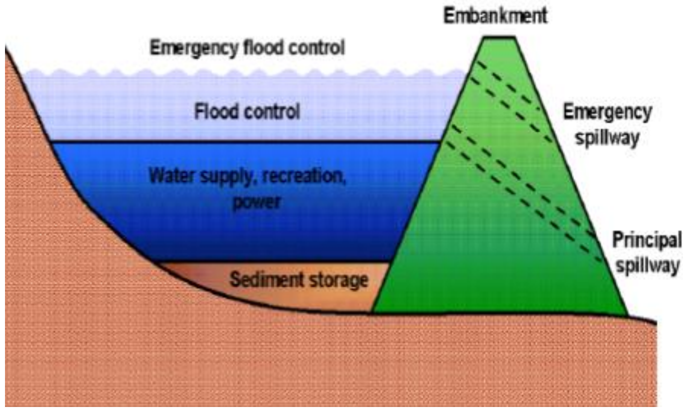
Universality and Undetectability

Soil and Water Assessment Tool (SWAT) models are the main tool used to quantify NPS pollution

Background

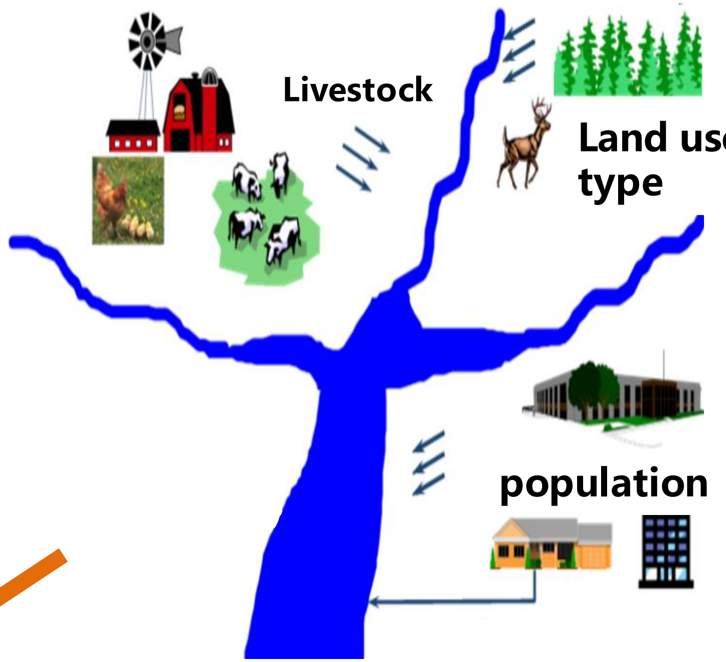
For Large and Mesoscale Watershed

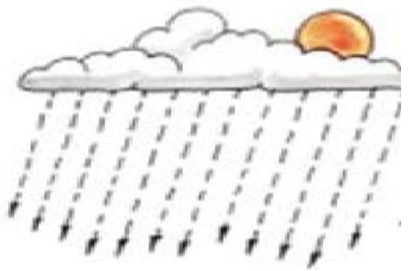


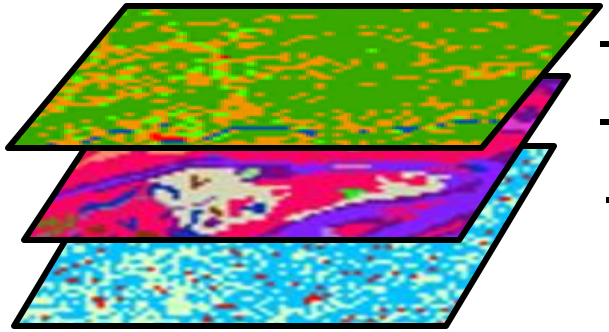


SWAT

Previous







Precipitation

Land use type

Soil type

Spatial location (Slope)

New

The NPS pollution in large-scale research area can be evaluated and predicted accurately.

(Johnes 1996)

Background

Non-point source pollution

Time distribution | Space distribution | Characteristic law

↓

Changing environment

↙ ↘

Precipitation | Land use change

coupling influence

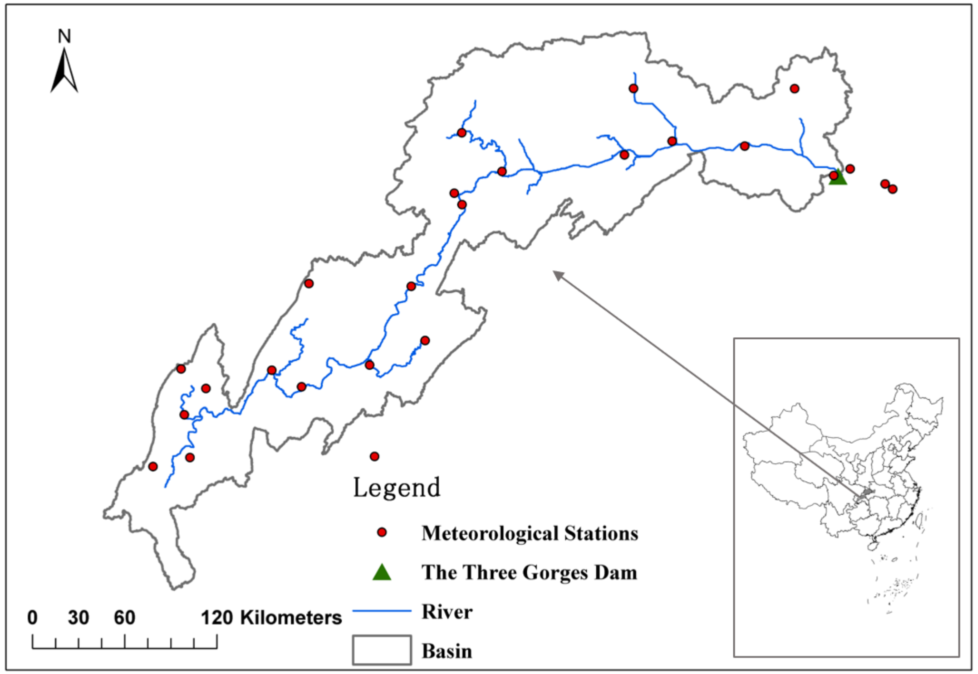
Hot spots

↓

Management measures

Background

Located in the hinterland of China, the Three Gorges Reservoir (TGR) is a river-type reservoir in the Yangtze River, which flows through 20 counties with a watershed area of 46,000km^2.



It suffers from severe NPS pollution, and nitrogen is the limiting nutrient causing eutrophication in the TGR Region.

Method

Method and Formula

For Large and Mesoscale Watershed：

Export Coefficient Model:

$$L=\sum_{i=1}^{n}E_i[A_i(I_i)]+p$$

where L=loss of nutrients;

E=export coefficient for nutrient source i;

A=area of watershed occupied by a specific land use or number of livestock, or people;

p=input of nutrients from precipitation.

(Johnes 1996).

Hydrological response units (HRUs)：
land use type/Soil type/Slope

➕

Fertilization management and tillage data

⬇

NPRUs

Dynamic Export Coefficient Model:

$$L=\sum_{i=1}^{n}E_i[B_i(I_i)]+p$$

where L=loss of nutrients;

E=export coefficient for nutrient source i;

B=area of watershed occupied by a specific NPRUs;

p=input of nutrients from precipitation.

Method flow

Database establishment

- Digital elevation model(DEM)
- Land use data
- Soil type data
- Meteorological data
- Fertilization and tillage management data

Calibration and verification by swat-cup

- Flow
- Total nitrogen (TN)
- Correlation coefficient R^2
- Nash-Sutcliffe coefficient (Ens)

Dynamic Export Coefficient Model

- NPURs
- flow=f(pcp)
- TN=f(pcp)

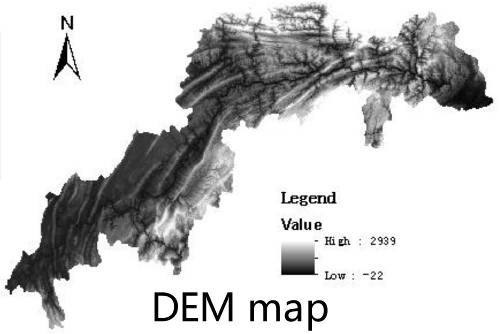
Applied to Three Gorges Reservoir Area

- Match with NPURs

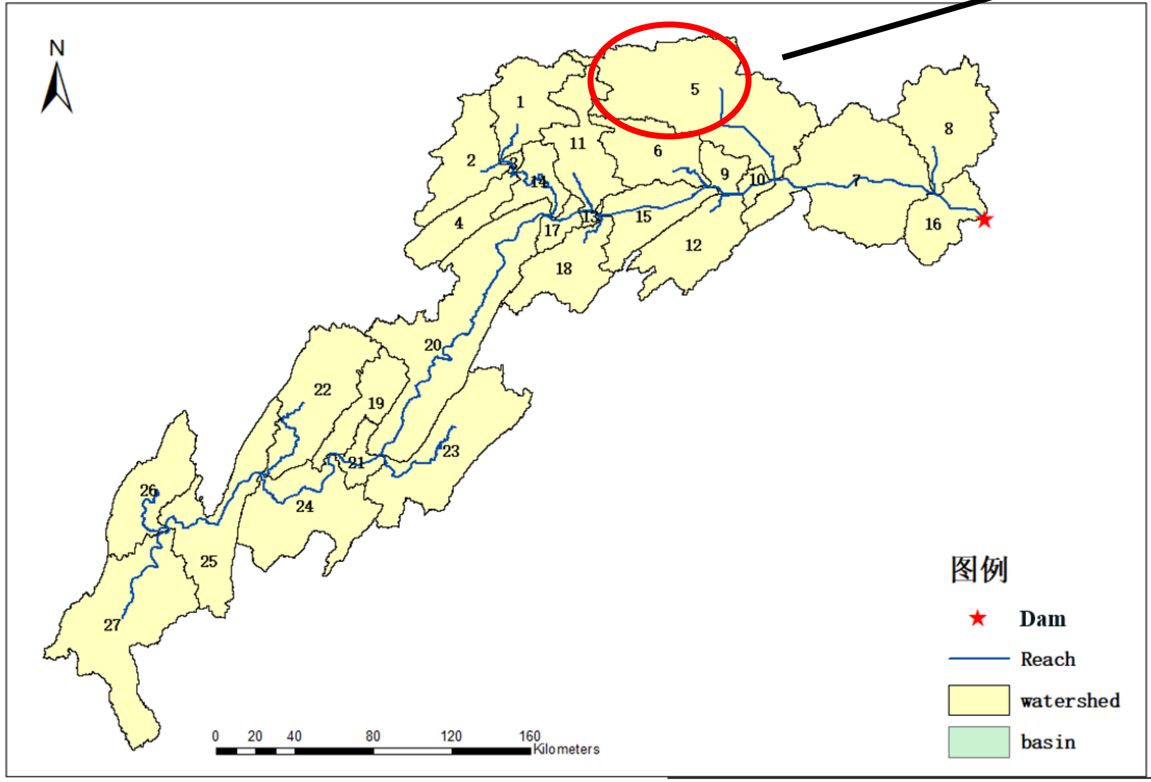
Analysis of influencing factors

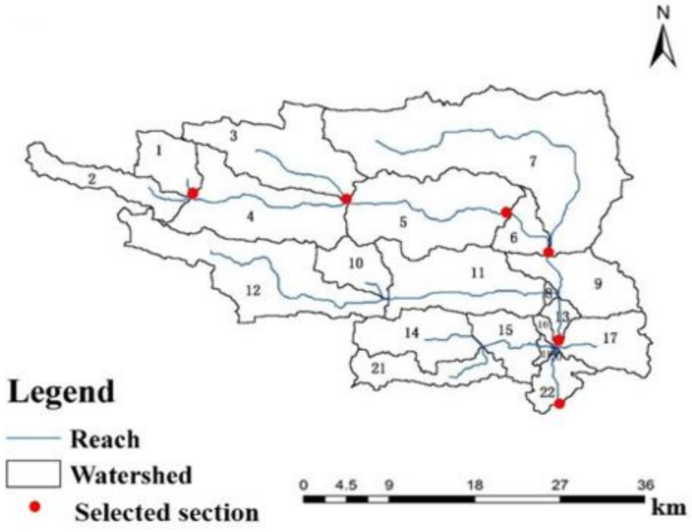
- Precipitation
- Land use change
- identification of hot area

STEP 1 Database establishment



DEM map





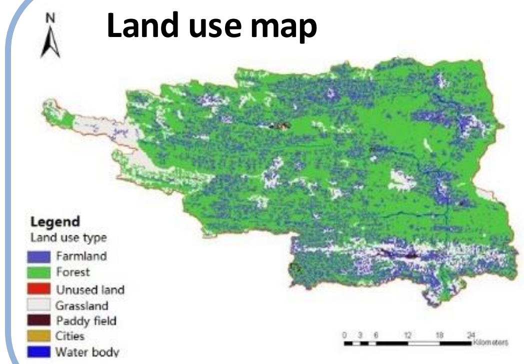
The Daning River watershed in the middle reaches of the TGR region is selected as a typical small watershed.

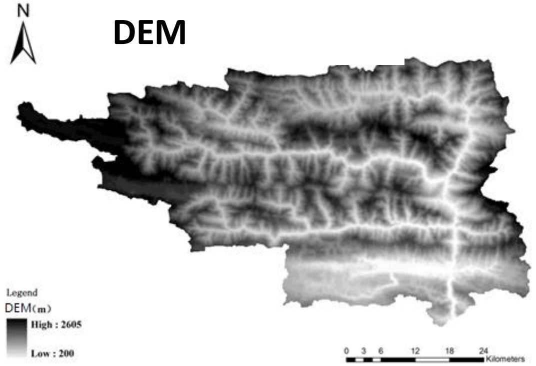
The Daning River watershed is a significant tributary of the TGR region area and is located in Wushan and Wuxi Counties in the municipality of Chongqing, China.

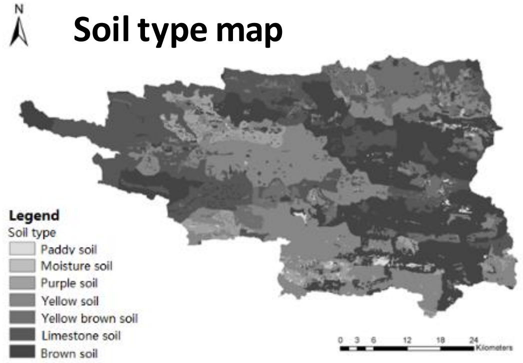
The basic data of the Daning River Basin are as follows:

Data types	Resolution	Acquisition path
Digital Elevation Model (DEM)	1:250000	National Fundamental Geographic Information Center of China.
land use map	1:100000	Resources and Environment science data Center of the Chinese Sciences Academy
Soil type map	1:1000000	Agricultural Science Committee of Wuxi city
Hydrologic data	Daily and monthly	Meteorological Bureau of Wuxi County and China National Meteorological Administration
Meteorological data	Daily and monthly	Meteorological Bureau of Wuxi County

STEP 2 SWAT: Model use, calibration, and validation







\+ Meteorological data for each site

Fertilization management and tillage data

Calibration verification by SWAT-cup

HRUs types in the Daning River watershed

HRUs : land use type/Soil type/Slope

\+

Fertilization and tillage management data

→ *NPRUs*

Evaluation indicators

① The correlation coefficient R^2 :

$$R^2 = \left[\left(\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})\right)\Big/\left(\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})}\sqrt{\sum_{i=1}^{n}(P_i-\bar{P})^2}\right)\right]^2$$

② The Nash-Sutcliffe coefficient (Ens) :

$$Ens = 1-\sum_{i=1}^{n}(O_i-P_i)^2/\sum_{i=1}^{n}(O_i-\bar{O})^2$$

Simulation period	Data type	R^2	E_{NS}
2000.1-2015.12	Flow	0.83	0.79
	TN	0.71	0.64

STEP 3 Dynamic Export Coefficient Model

For each NPRUs:

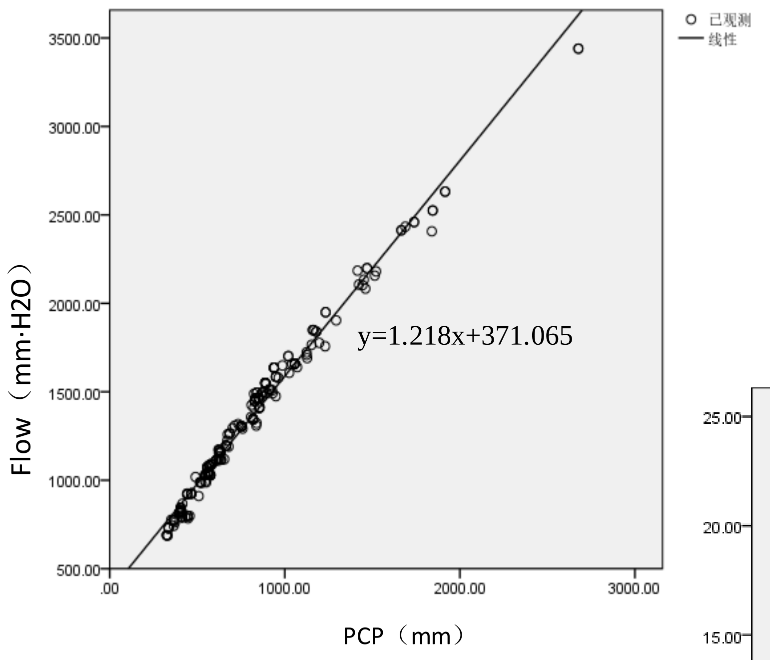
Flow=f(pcp)

Construction of Linear Equation between Rainfall-flow

TN=f(pcp)

Construction of Cubic equation between Rainfall-TN

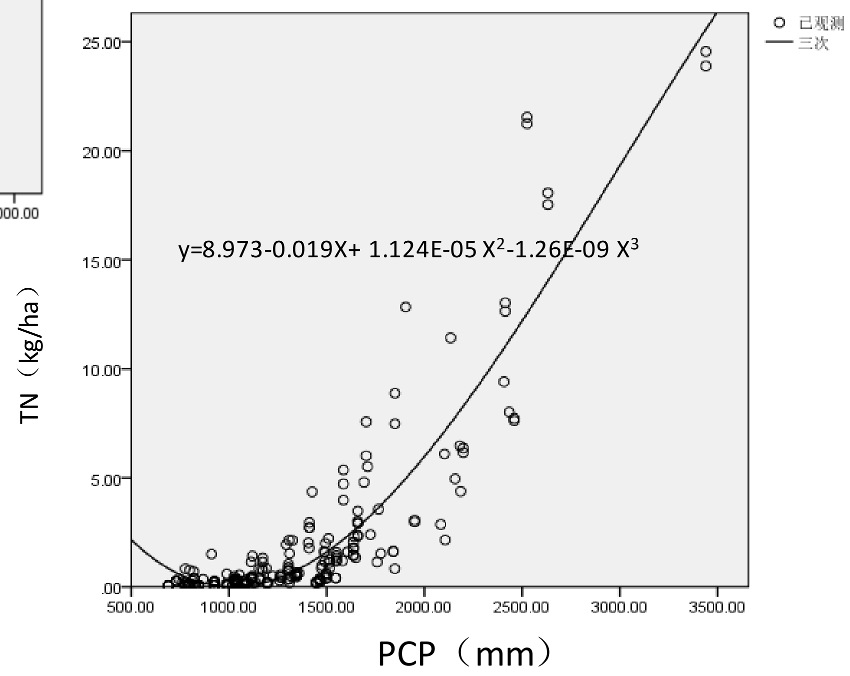
Flow



E.g. FRST/HUZR/0-27

(its land use type is forest land; soil type is yellow earth; slope is less than 15 degrees .)

TN

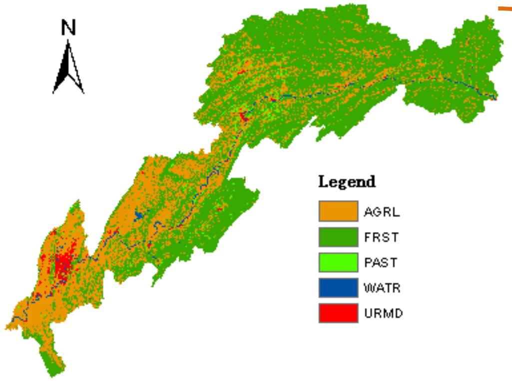


$$Flow=1.218(pcp)+371.065$$

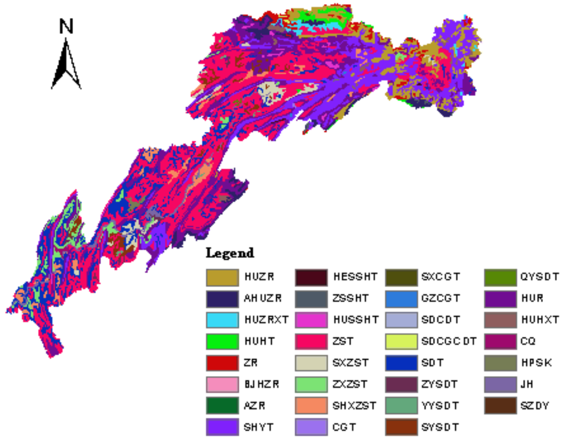
$$TN= 8.973-0.019\ (pcp)+1.124E\text{-}05\ (pcp)^2-1.26E\text{-}09\ (pcp)^3$$

STEP 4 Applied to Three Gorges Reservoir Area

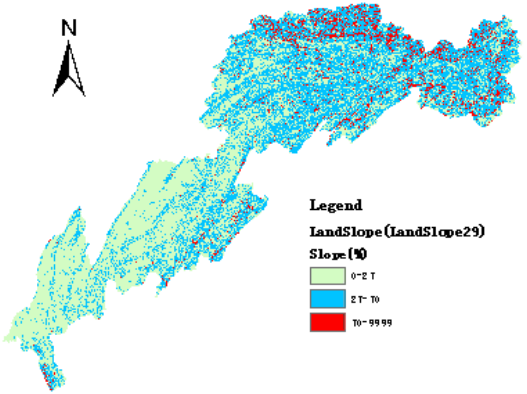
Land use map



Soil type map



Slope map



HRUs type in the Three Gorges Reservoir Region + Fertilization and tillage management data

NPRUs type in the Three Gorges Reservoir Region

How to match ?

NPRUs type in the Daning River watershed

STEP 4 Applied to Three Gorges Reservoir Area

Match the NPRUs between the Three Gorges Reservoir Area and the Daning River Watershed

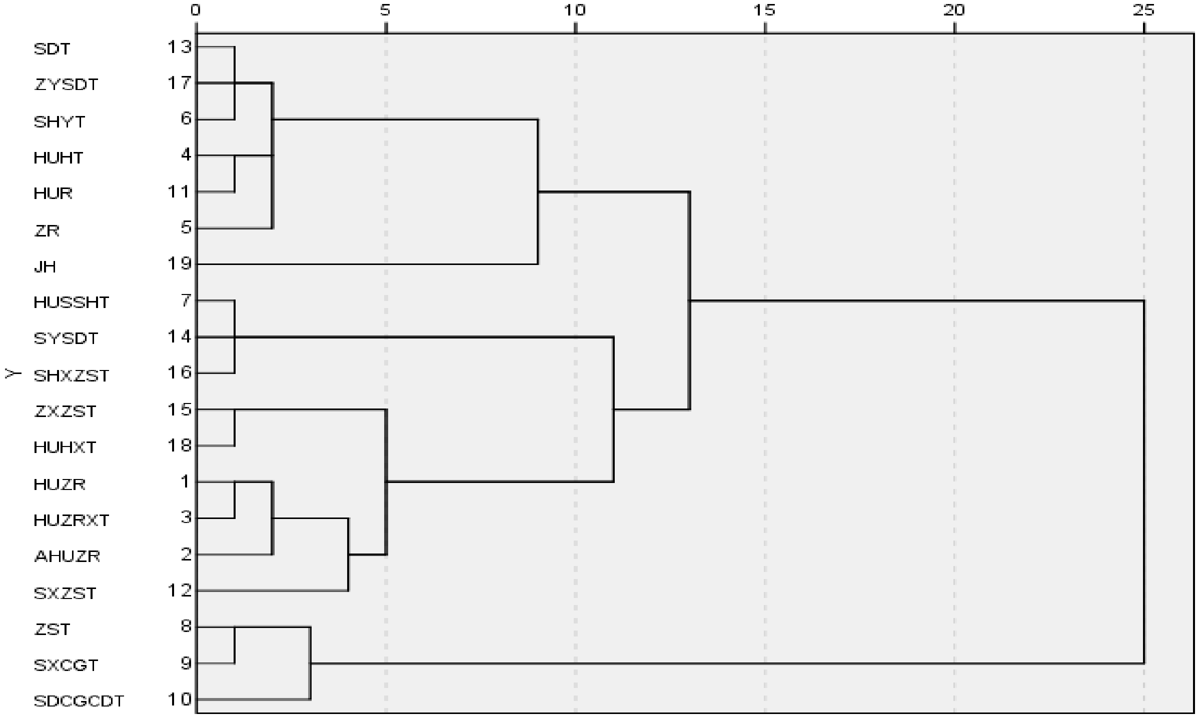
In two watersheds, both land use types and slope types match. The key is to match the soil data.

Cluster analysis was conducted for all soil types, taking into account the physical and chemical properties of the soil, such as soil hydrological unit (HYDGRP), clay content (CLAY), and silt content (SILT).

Land use type

Slope type

Cluster Analysis of Soil Types



STEP 5 Experimental settings

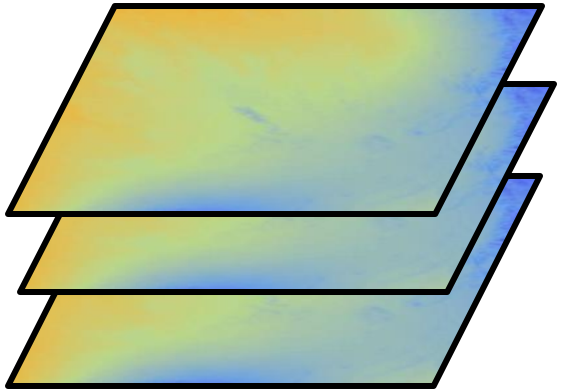
To distinguish the Impact of Precipitation and Land Use Change on Non-point Source Pollution in the TGR Region. Two experiments were carried out.

①

Normal years

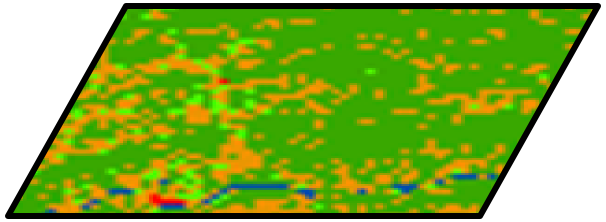
Wet years

Dry years



Precipitation

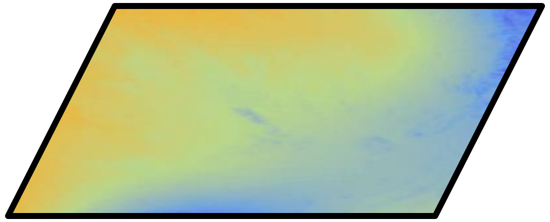
(1995-2015)



Average change of land use from 1995 to 2015

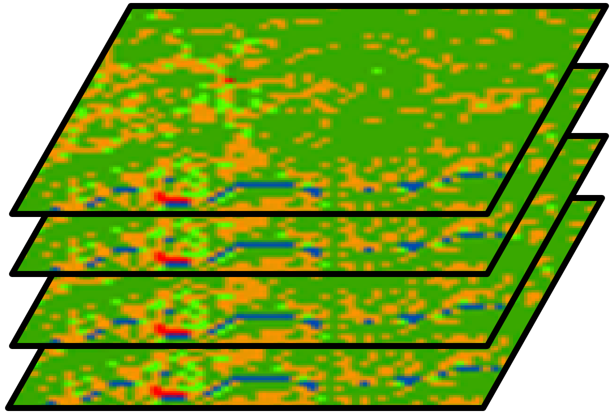
②

Normal years



Precipitation

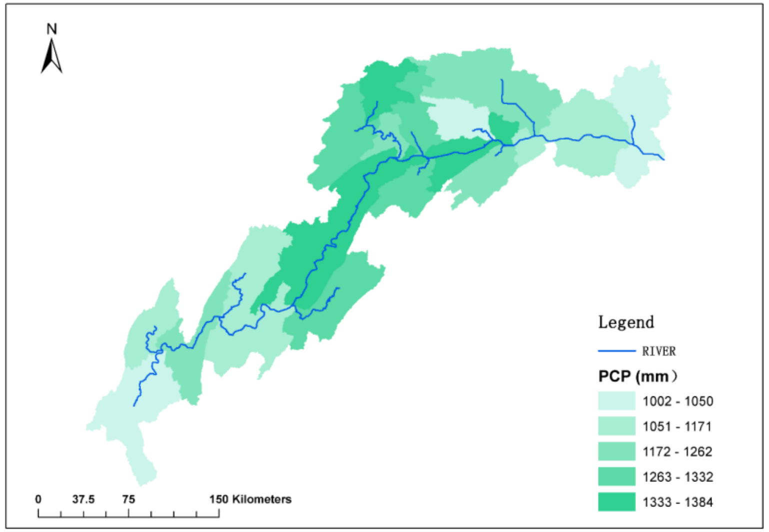
(1995-2015)



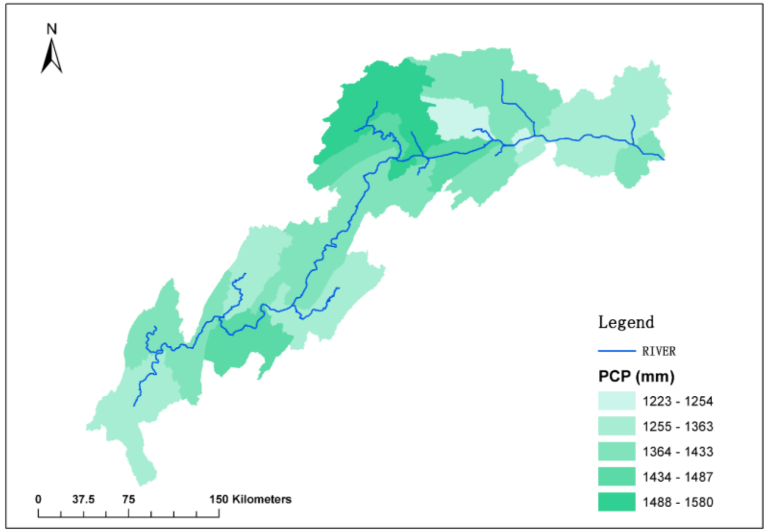
Land use maps from 1995 to 2015

STEP 5 Analysis of influencing factors: precipitation

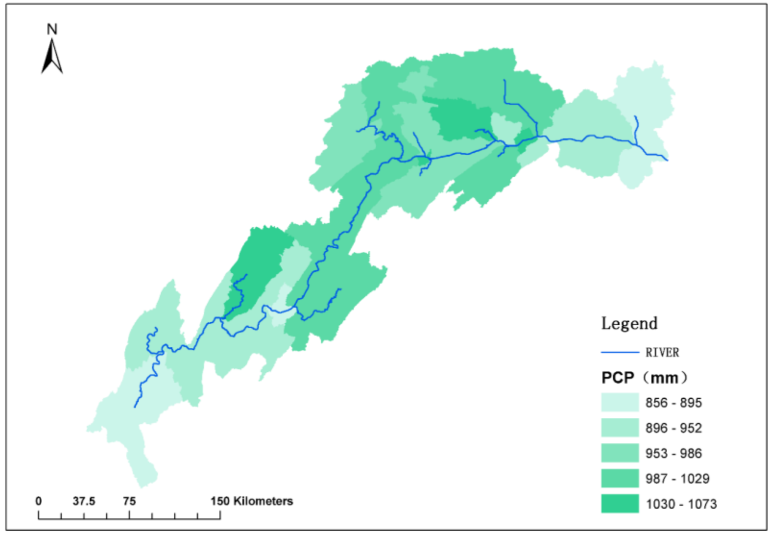
S1 PCP in normal year



S2 PCP in wet years



S3 PCP in dry years



The Three Gorges of the Yangtze River belongs to the subtropical monsoon climate zone. Average annual precipitation is from 1000mm to 1400mm.

Through the transformation of different precipitation conditions, the change of NPS pollution in the TGR region under the same land use change was studied.

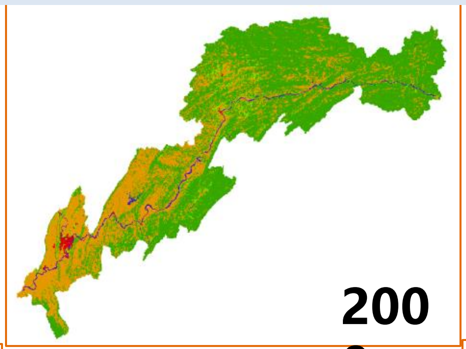
Three scenarios of rainfall conditions were constructed, S1, S2, S3.

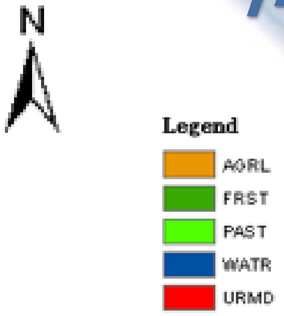
S1 PCP in normal year（the precipitation data in 1995）

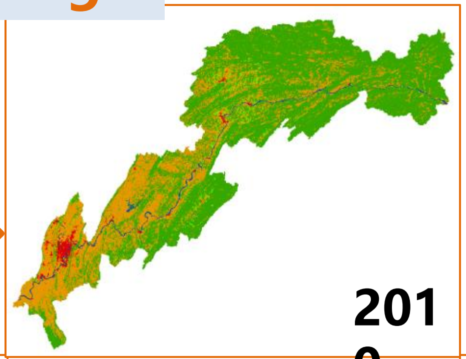
S2 PCP in wet year（the precipitation data in 2014）

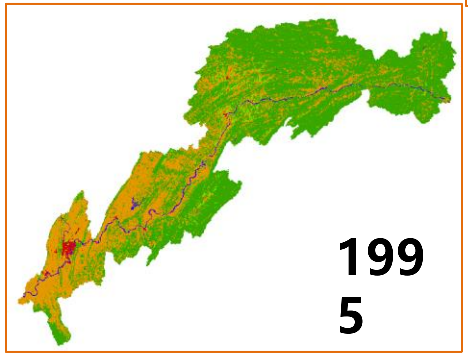
S3 PCP in dry year（the precipitation data in 2001）

STEP 5 Analysis of influencing factors： land use change

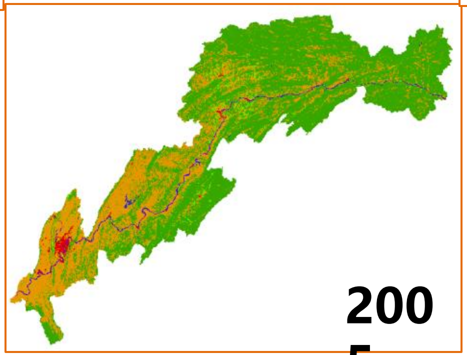


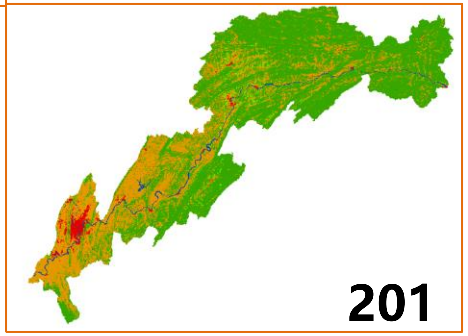






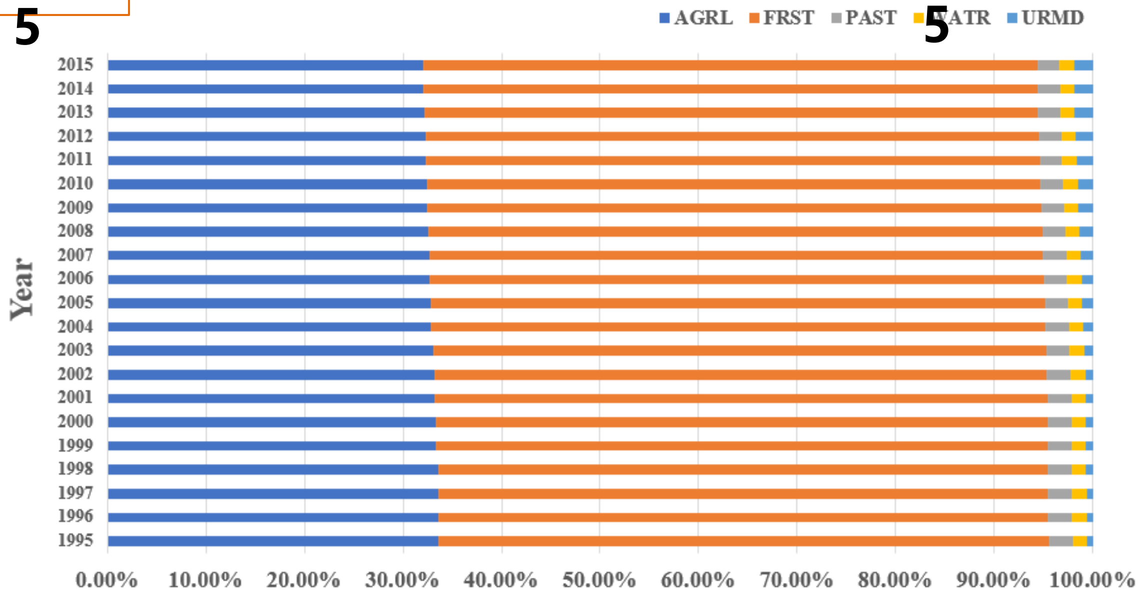
Land use maps from 1995 to 2015





Under the normal year , through the change of NPS pollution under land use change in the 20 years, the influence of land use change on NPS pollution was studied.

From 1995 to 2015， the proportion of cultivated land area declines year by year from 33.56% to 32.03%. At the same time, the proportion of construction land area increased year by year from 0.62% to 1.87%.



Percentage of annual change in land use

Results

Results

Dynamic Export Coefficient Model

The correlation coefficient (R^2):

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y}_i)^2}$$

Almost the R^2 of flow-pcp regression equation greater than 0.99 , and the R^2 of TN-pcp regression equation greater than 0.6.

The fitting effect of regression equation is well.

Some NPRUs dynamic coefficient equations are shown in the table below:

NPRUs	Flow=f(pcp)	R^2	TN=f(pcp)	R^2
AGRL/HUHT/0-27	y=0.85x+320.72	0.988	$y=-47.051+0.174X-0.00004235X^2+0.000000003525X^3$	0.445
AGRL/HUHT/27-70	y=0.86x+309.61	0.991	$y=-0.693+0.161X-0.00007995X^2+0.0000001254X^3$	0.684
AGRL/HUHT/70-9999	y=0.86x+318.07	0.856	$y=18.437+0.092X-0.00004424X^2+0.000000007682X^3$	0.541
AGRL/HUR/0-27	y=0.83x+301.79	0.987	$y=201.69-0.334X+00000011X^2-0.00000006813X^3$	0.683
AGRL/HUR/27-70	y=1.28x+880.2	0.986	$y=-133.867+0.518X+0.111114X2+0.00000007838X^3$	0.712
AGRL/HUSSHT/0-27	y=0.78x+208.34	0.995	$y=667.674-1.525X+0.001X^2+-0.0000002813X^3$	0.842
AGRL/HUSSHT/27-70	y=0.8x+204.52	0.997	$y=344.036-0.723X+0.001X^2+-0.0000001398X^3$	0.787
FRST/SHYT/0-27	y=0.8x+296.9	0.992	$y=4.099+0.001X-0.00001114X^2+0.000000009031X^3$	0.795
FRST/ZST/0-27	y=0.81x+349.87	0.962	$y=-0.208+0.001X-0.0000007944X^2+0.0000000007787X^3$	0.765
FRST/ZST/27-70	y=0.81x+349.87	0.897	$y=-37.062+0.089X-0.00006681X^2+0.0000000166X^3$	0.893
FRST/ZST/70-9999	y=0.82x+358.52	0.956	$y=-61.917+0.147X+0.00000023X^2+0.00000002692X^3$	0.667
URMD/SDCGCDT/0-27	y=0.8x+210.94	0.985	$y=31.151-0.07X+0.00005507X^2-0.0000001279X^3$	0.721
URMD/SHYT/0-27	y=0.8x+255.42	0.948	$y=32.825-0.009X+0.00001026X^2-0.000000001353X^3$	0.664

Results

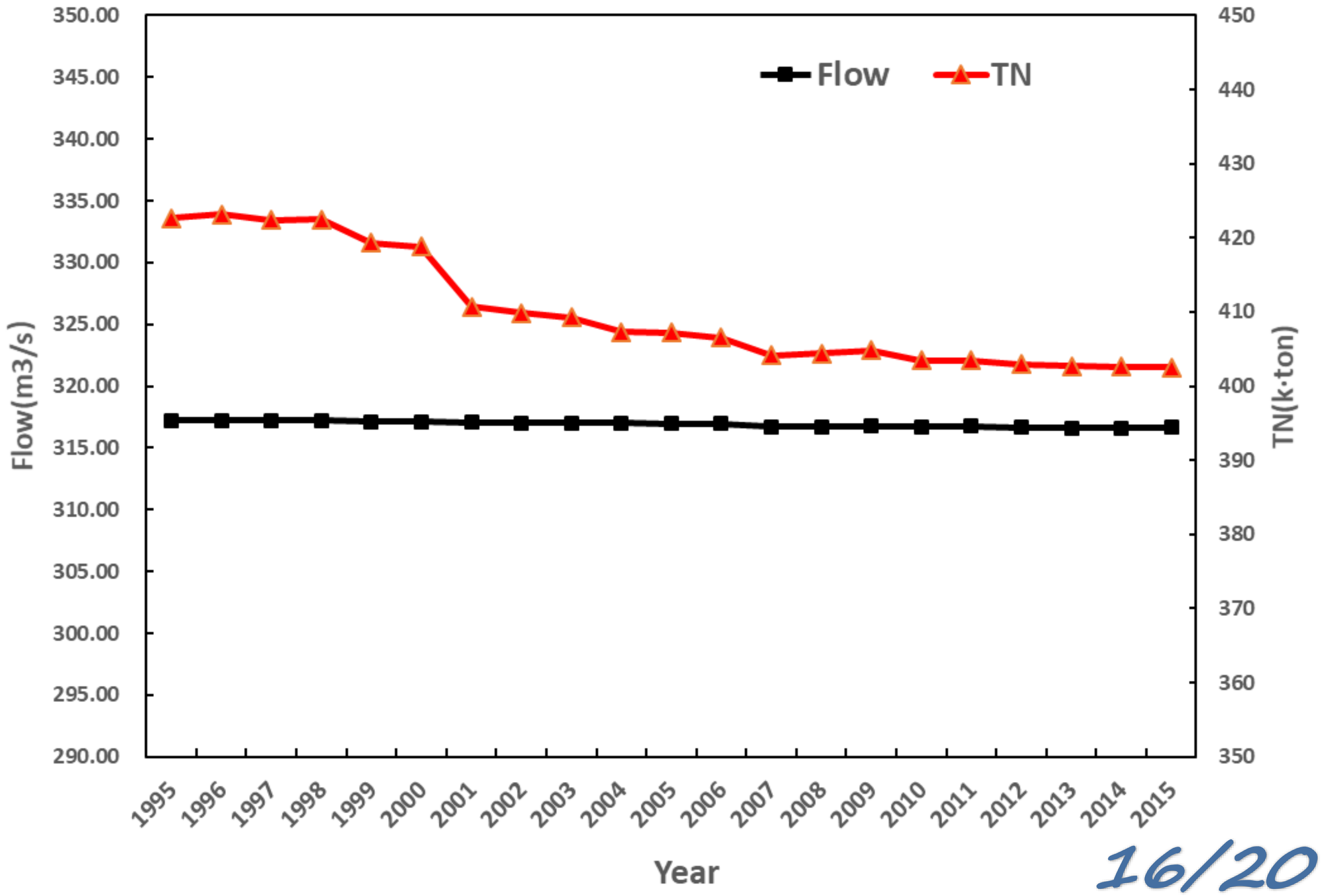
For the whole watershed

①

	change rate of pcp	change rate of flow	change rate of TN
S1-S2	15.73%	21.48%	29.69%
S1-S3	19.30%	28.99%	34.21%

For the whole watershed, the results of NO.1 experiments (the different precipitation) were shown in this table. And the NO.2 was shown in this figure.

②



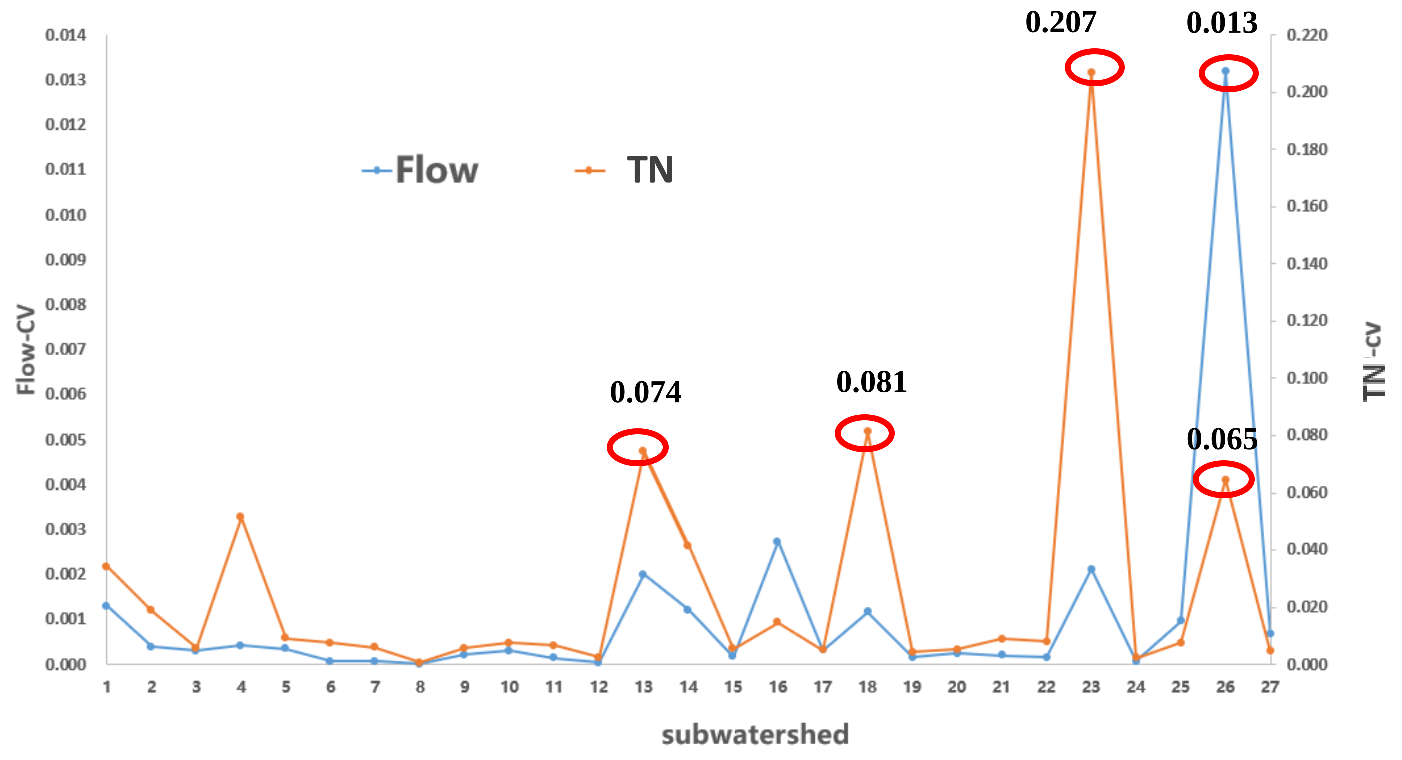
- When land use shows the same trend, the adjustment of different precipitation conditions has a greater impact on NPS pollution.
- Under the normal precipitation condition， the flow decreased 0.19% and the TN decreased 4.88%, which changed smoothly.

Results

For sub-watershed

C.V.=σ/μ

In normal year, the CV values of flow and TN caused by land use change in each sub-watershed are as follows:



Flow:

Jialing River Watershed (sub 26) CV=0.013

TP:

Longhe River Watershed(sub 23) CV=0.207

Modao River Watershed(sub 18) CV=0.081

The middle reach of trunk stream CV=0.074

Jialing River Watershed(sub 26) CV=0.065

Reason

From 2000 to 2001, the land use changes dramatically in Longhe River Watershed, and about 12.8% of cultivated land was converted into woodland.

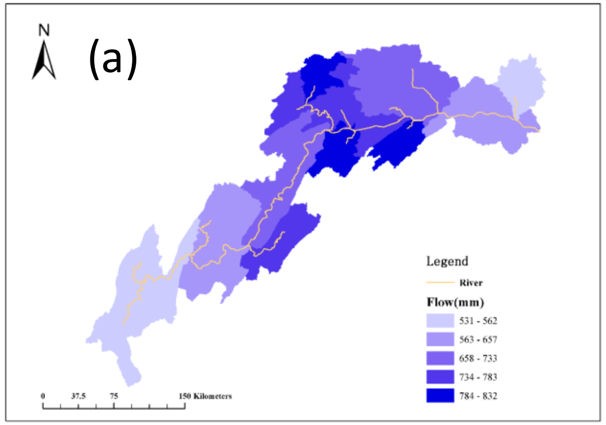
From 2006 to 2007, the proportion of construction land in Jialing River Watershed increased sharply, 10.9% of low-slope farmland and 11.1% of low-slope forest land were converted into construction land.

Results

The relative values of change between flow and TN among sub-watersheds were graded.

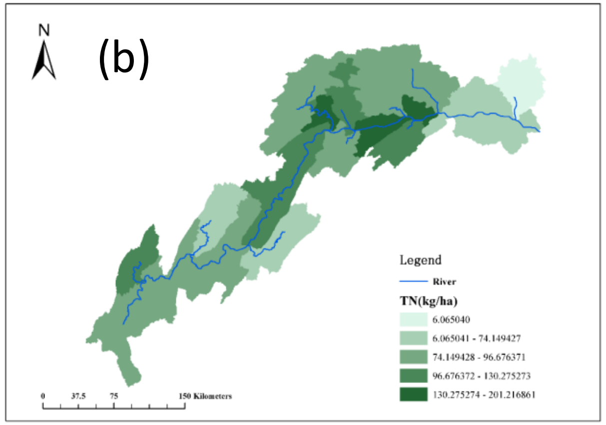
Relative value	Grade
0-10%	IV
10%-20%	III
20%-30%	II
30%-40%	I

S1



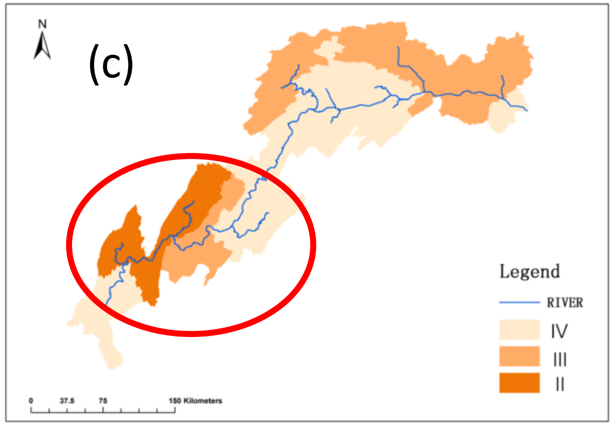
The water yield in normal year

S1



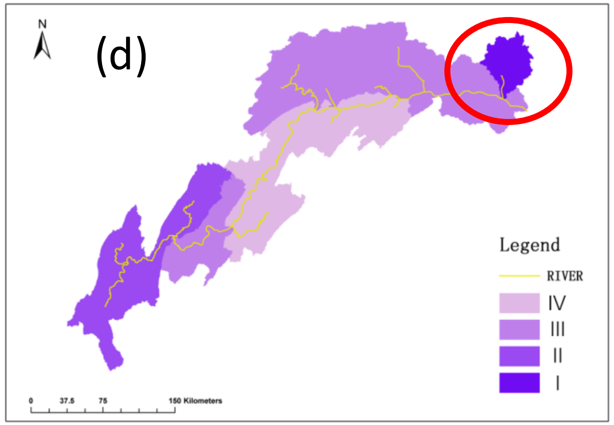
The total phosphorus load per hectare in normal year

S1-S2 flow



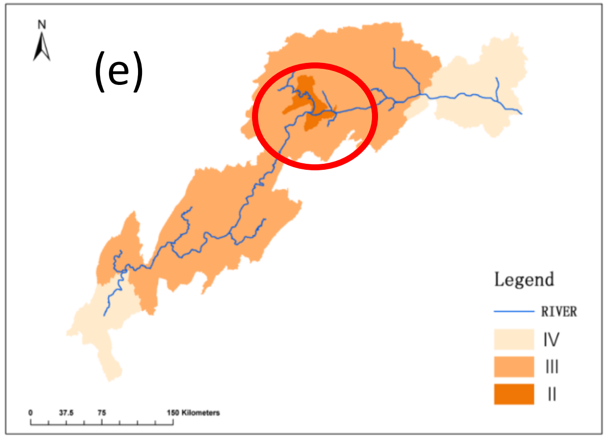
The change of flow from the normal year to the wet year

S1-S2 TN



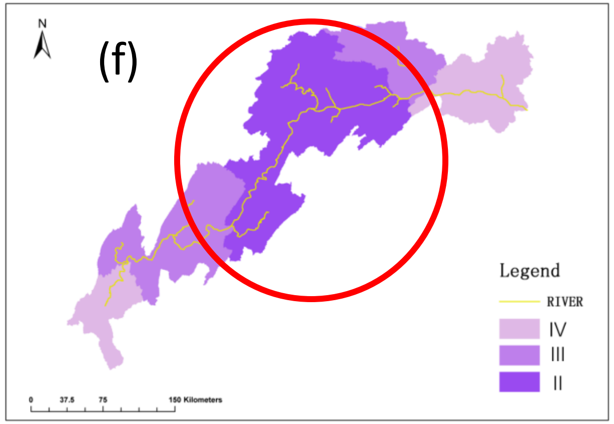
The change of TN from the normal year to the wet year

S1-S3 flow



The change of flow from the normal year to the dry year

S1-S3

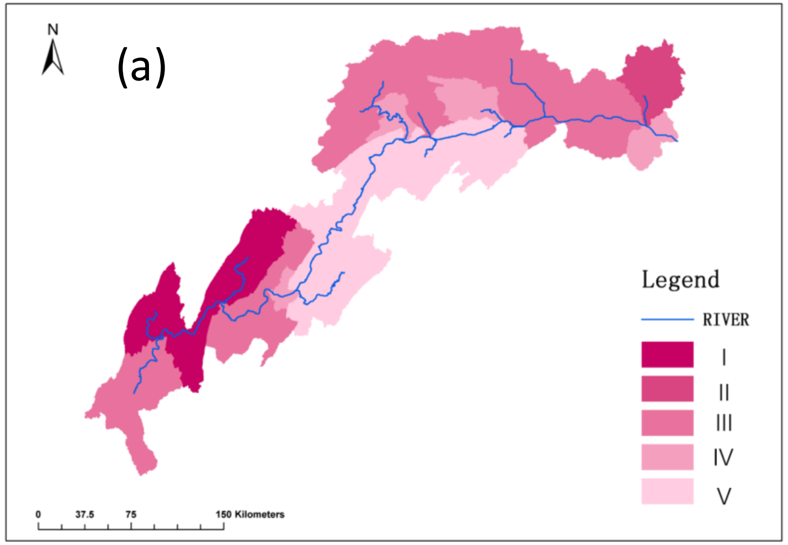


The change of TN from the normal year to the dry year

Results

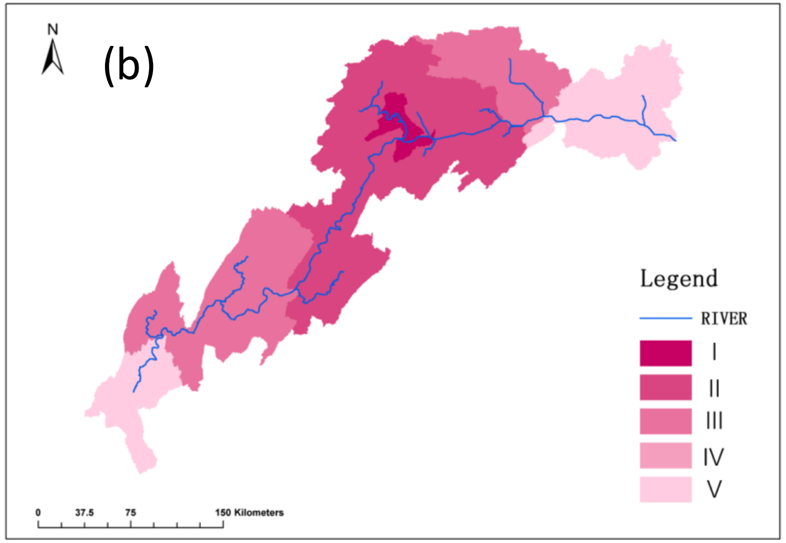
Identification of hot spots

S1-S2



Both the change of flow and TN from the normal year to the wet year

S1-S3



Both the change of flow and TN from the normal year to the wet year

Based on the above results, hot spots were identified.

- From the normal year to the wet year, the hot spots are Quxi River Watershed and the upper reach of trunk stream area.
- From the normal year to the dry year, the hot spots are the middle reach of trunk stream and the lower reach of Xiaojiang River Watershed.

Conclusions

Conclusions

- Combining SWAT and export coefficient model, considering the influence of precipitation and other factors, the dynamic export coefficient model is proposed. This method can evaluate the impact of precipitation change on NPS pollution in watershed.
- For the Three Gorges Reservoir Region, the contribution of precipitation change to flow is about 21% in dry year and 28% in wet year , to TN is about 29% in the dry year and 34% in wet year. And for land use, it is about 0.07% - 1.52% for flow, and about 1.65% - 1.86% for TN. The impact of precipitation change on NPS pollution is much higher than that of land use change. The output of NPS pollution will increase in the future.
- The response of NPS pollution (runoff and total phosphorus) to precipitation and land use change in Jialing River Watershed and Longhe River Watershed is more intense.

END

THANK YOU FOR YOUR ATTENTION!

Mail：201721180031@mail.bnu.edu.cn