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Spatial Optimization of Ponds for Diffuse Pollution Mitigation in Paddy Field Watersheds: An Integrated SWAT-NSGA-II Decision Support Framework

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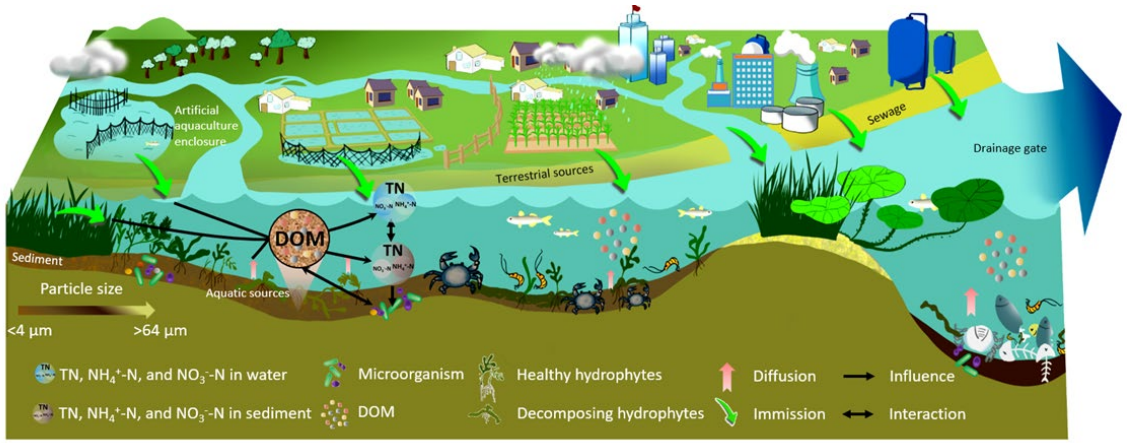
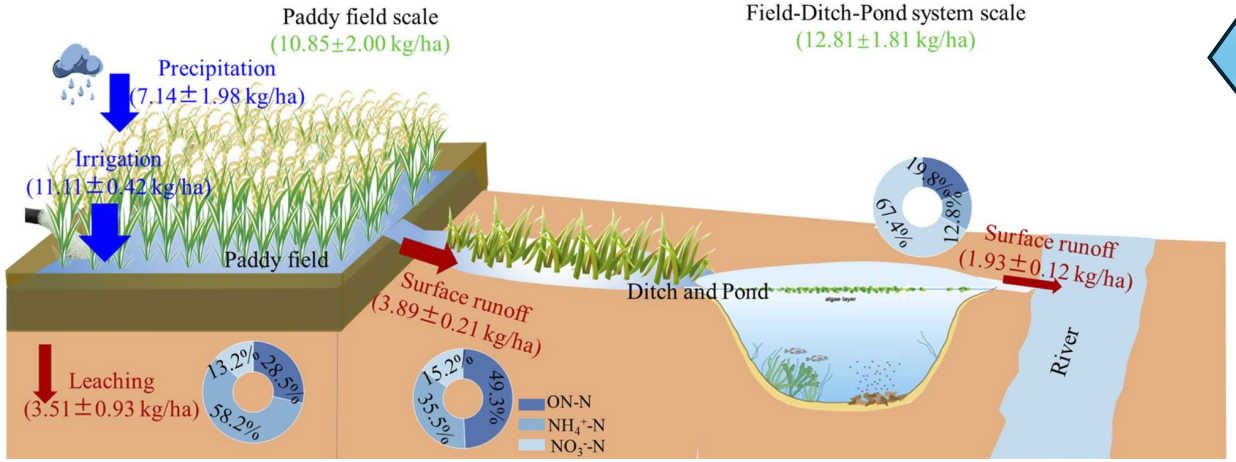
Introduction

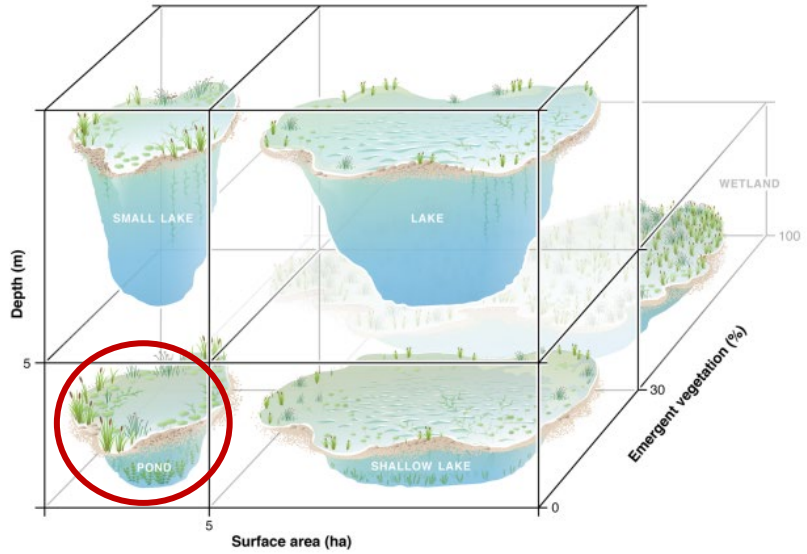
- The refined management of diffuse pollution in small watersheds



- Ponds control runoff and nutrient loss



- Small water bodies: Ditch and Pond



Research limitations:

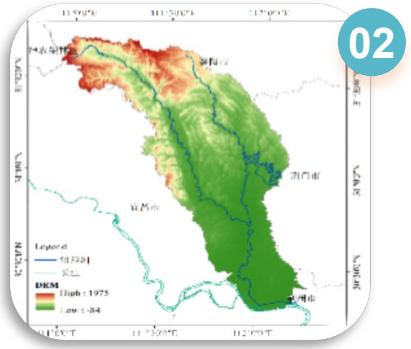
- Fragmented distribution of ponds
- Decentralized management of ponds
- Consumption of manpower and material resources

Liu L, Ouyang W. Process Safety and Environmental Protection, 2025.

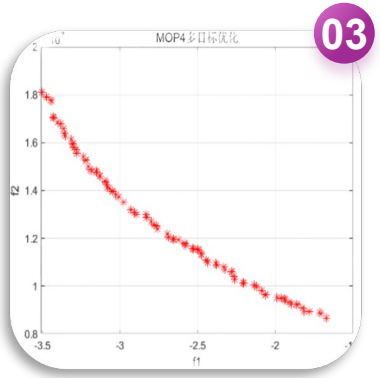
Framework

Field scale

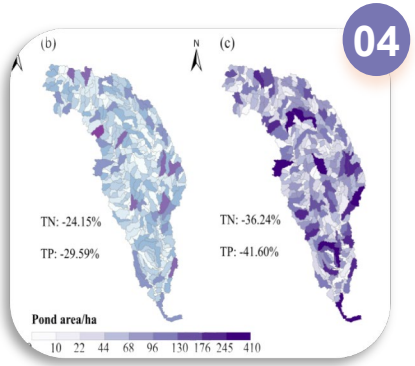
Watershed scale



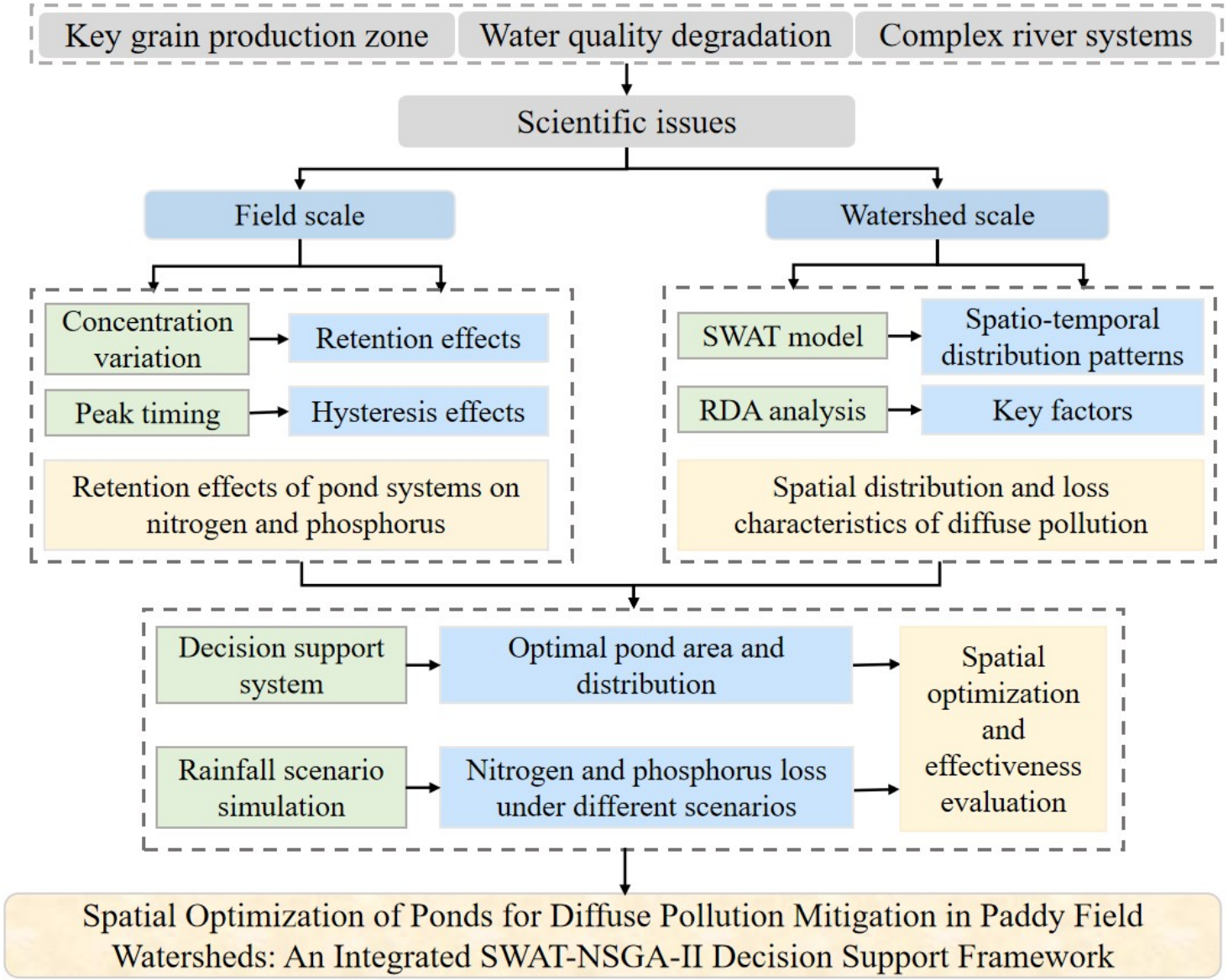
Different area



Space configuration



Spatial Optimization of Ponds for Diffuse Pollution Mitigation



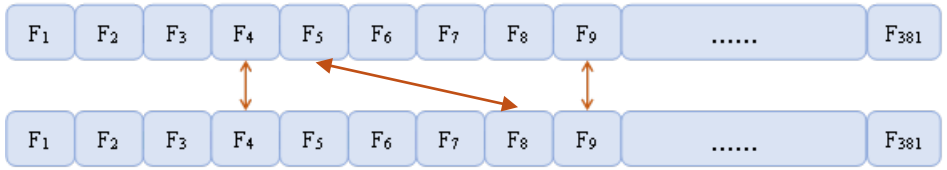
Methodology

An Integrated SWAT-NSGA-II Decision Support Framework

- **Population initialization**

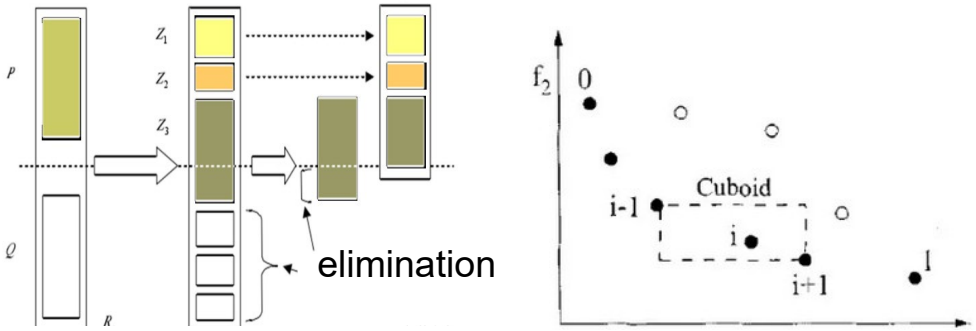
```
for i = 1 : nPop
    pop(i).Arg = varmin + (varmax - varmin).*rand(1, nVar);
    pop(i).Obj = pond(pop(i).Arg);
end
```

- **Crossover Variation**

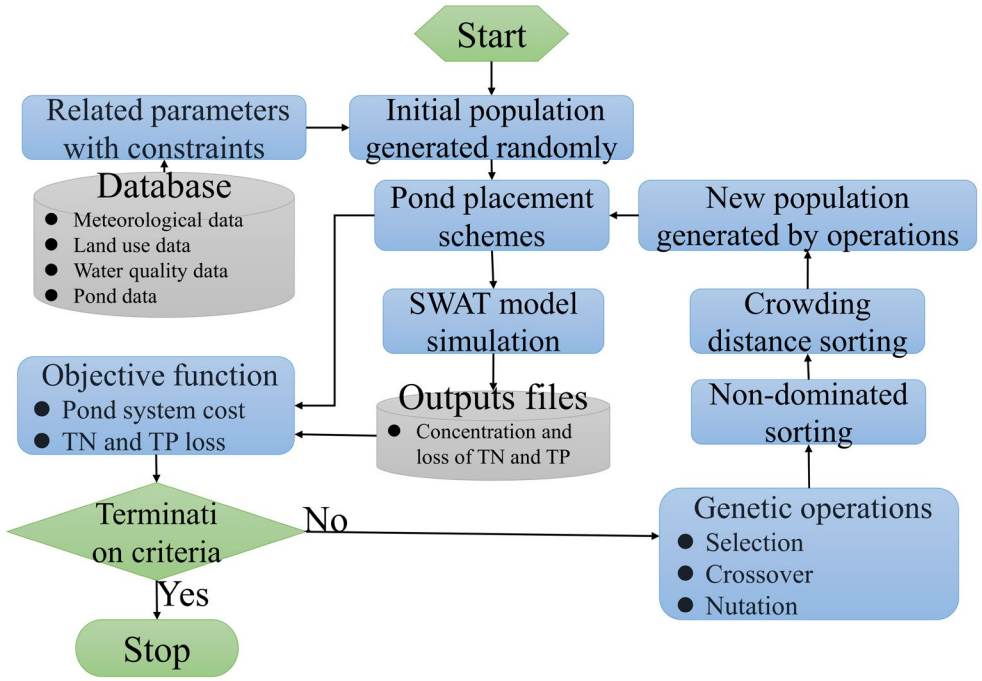


- **Non-dominated sorting**

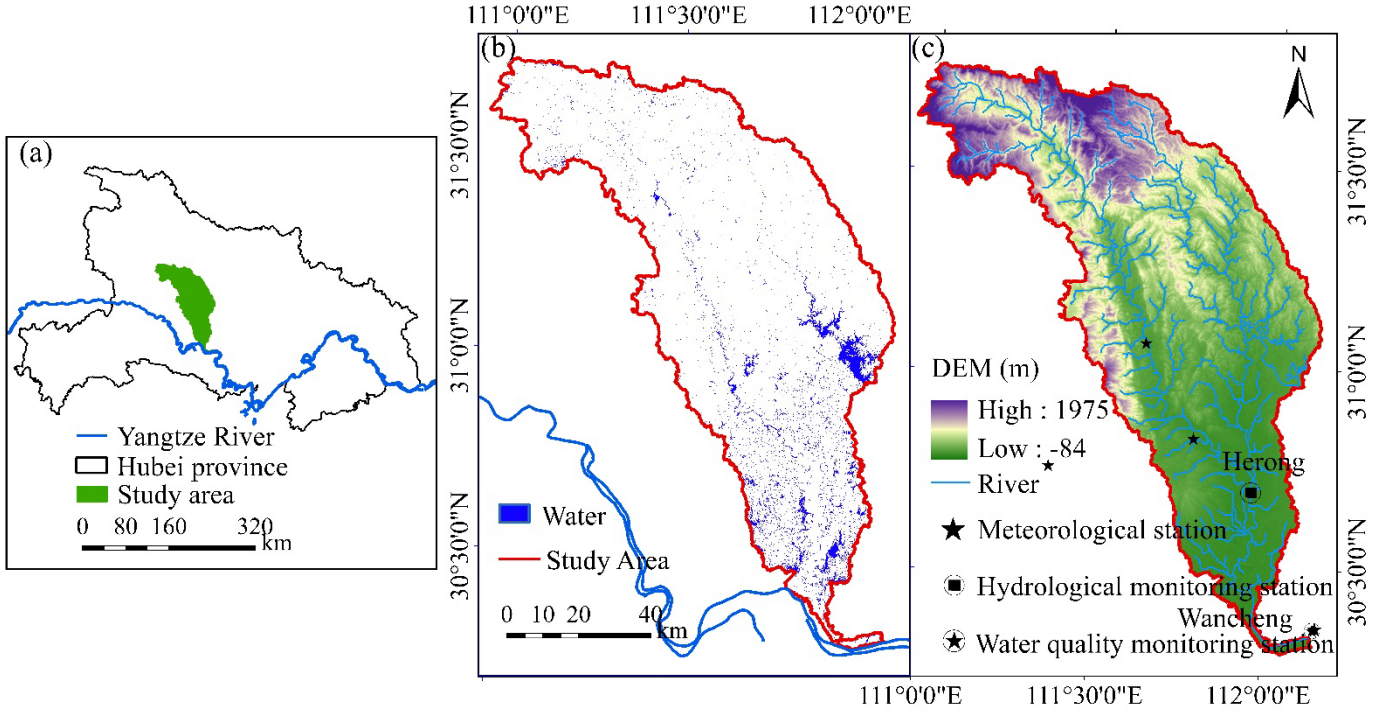
- **Crowding degree calculation**



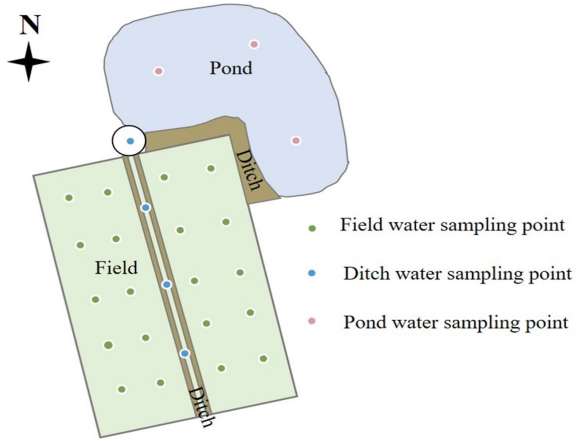
- **Based on the water quality objectives and available area constraints**



Study area

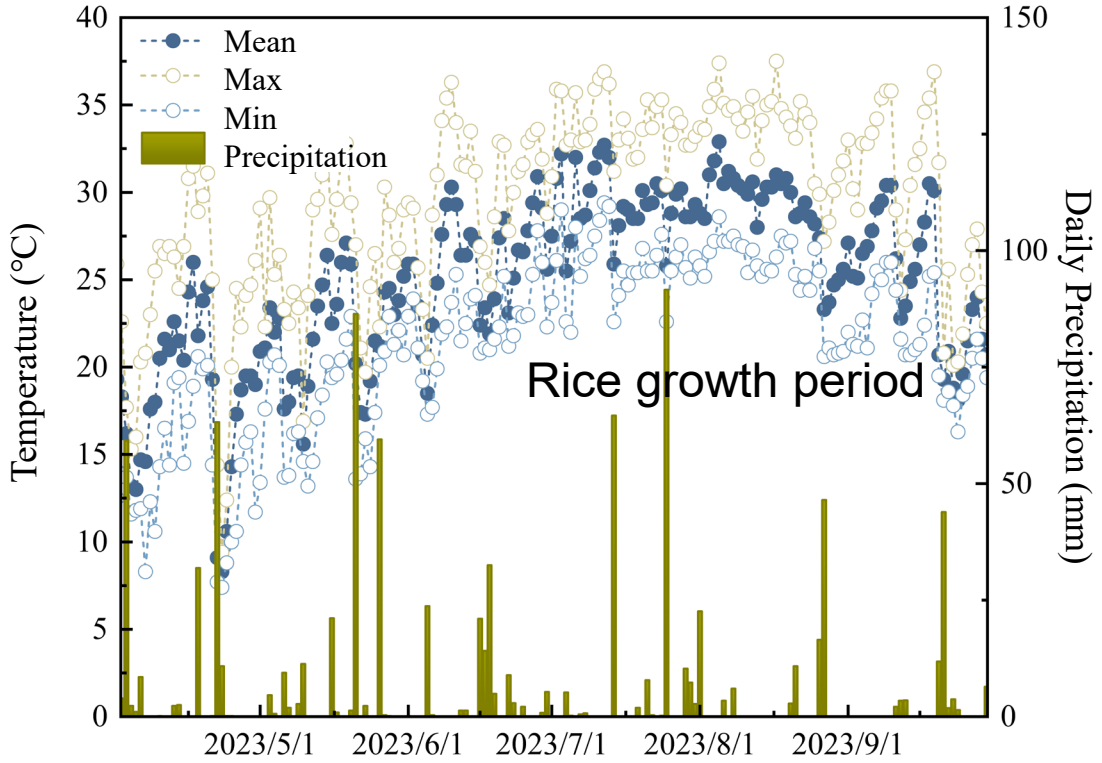


- The Juzhang River watershed is in the middle reaches of the Yangtze River (7441 km^2), located in the sub-tropical monsoon climate zone.
- There are crisscrossing natural channels and ponds.

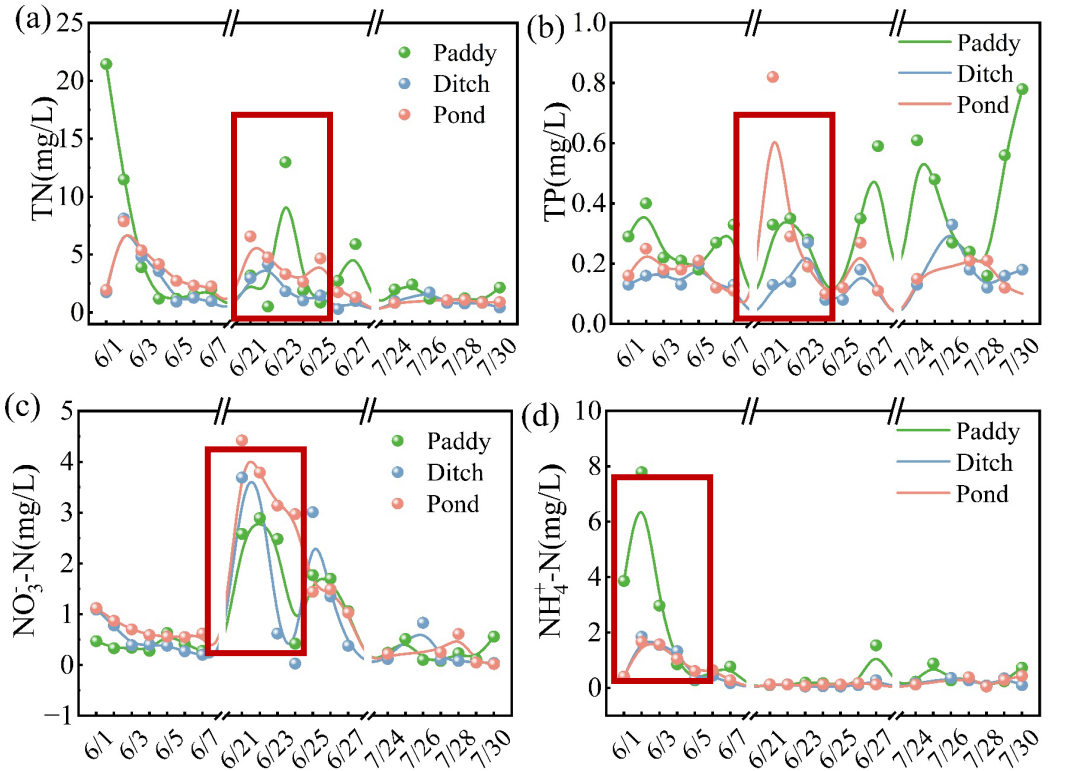


Results

The retention effect of the Paddy-Ditch-Pond system on nitrogen and phosphorus loss



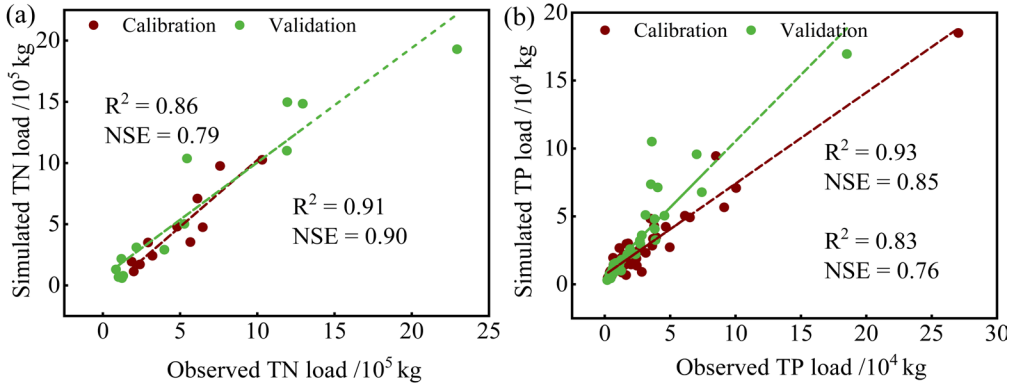
Single peak occurrence time: Paddy<Ditch<Pond



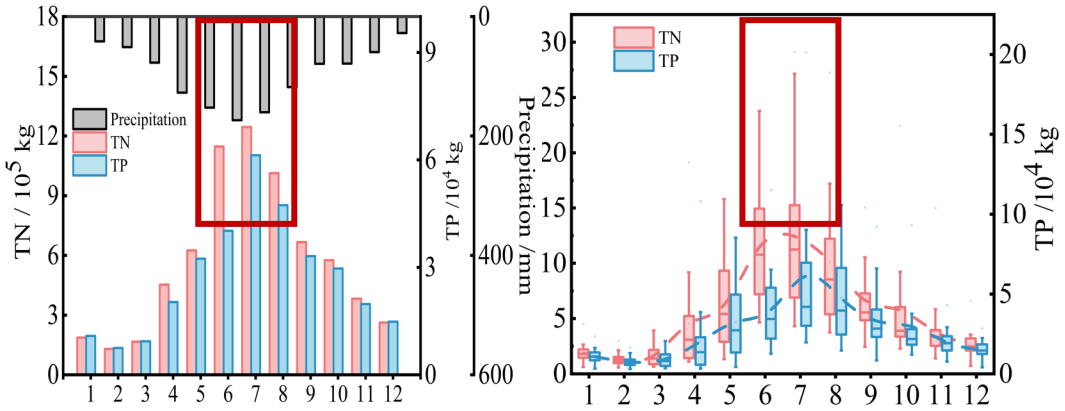
- Abundant precipitation may accelerate nitrogen and phosphorus loss.
- Average removal rates of TN and TP: 69.67% and 61.12%.

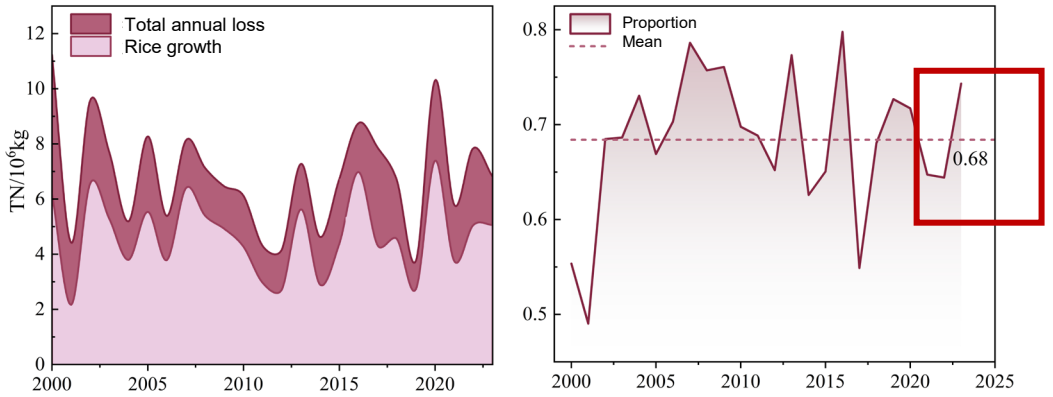
Results

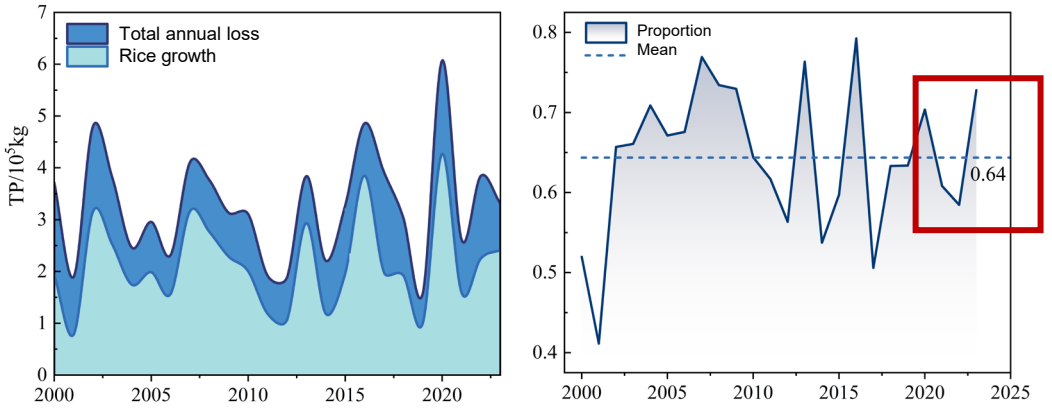
The rice growth period is critical for controlling nitrogen and phosphorus loss



The simulation results are reliable.





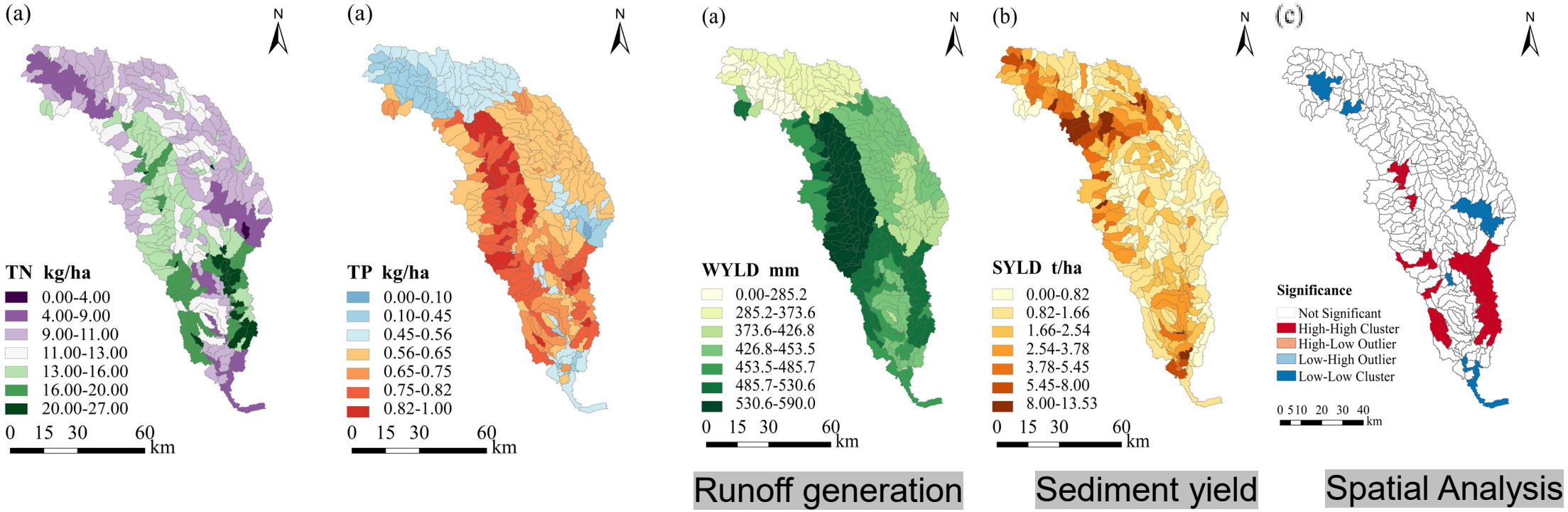


◆ May to September are the critical for Nutrient loss.

◆ Nutrient loss during rice growth period accounts for about 65% .

Results

Nitrogen and phosphorus loss shows strong spatial agglo-meration characteristics.

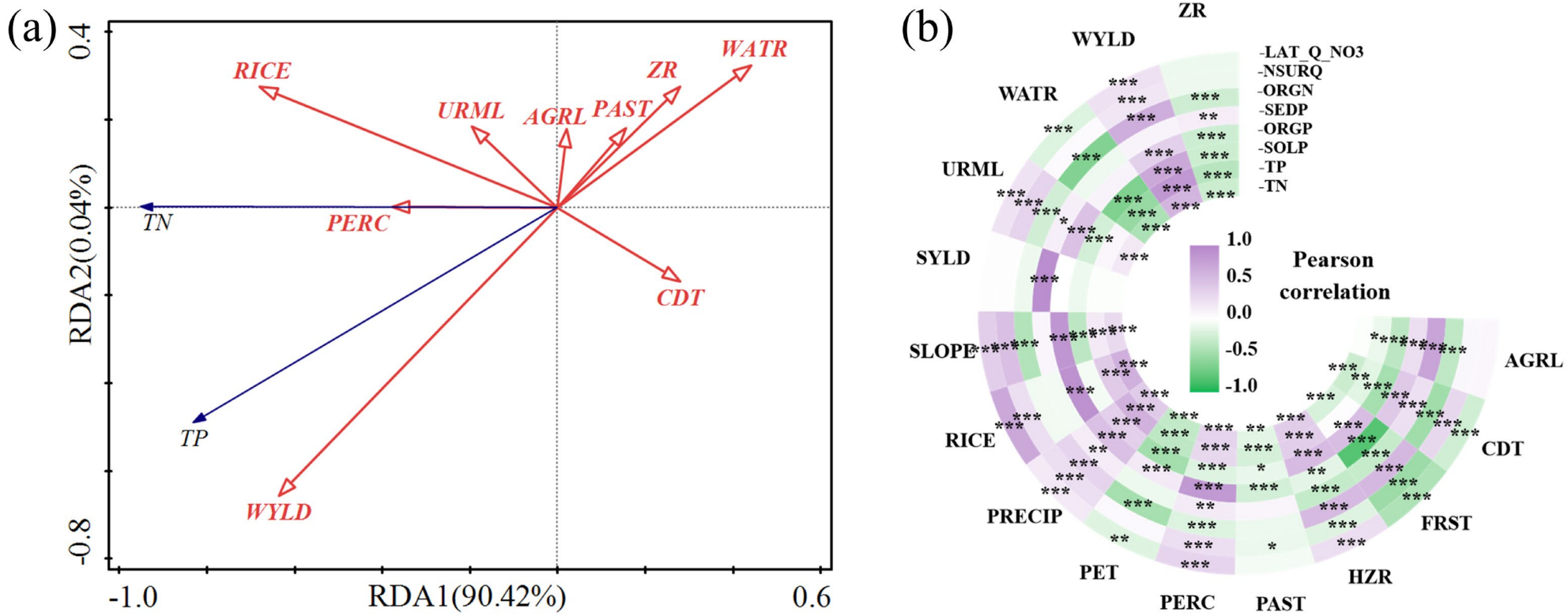


Runoff generation | Sediment yield | Spatial Analysis

- High-intensity loss area: two rivers' Confluence and dense Paddy field.
- Overlap: High water-yielding area and Nutrient loss area, Upstream areas with larger slopes and Sediment loss area.

Results

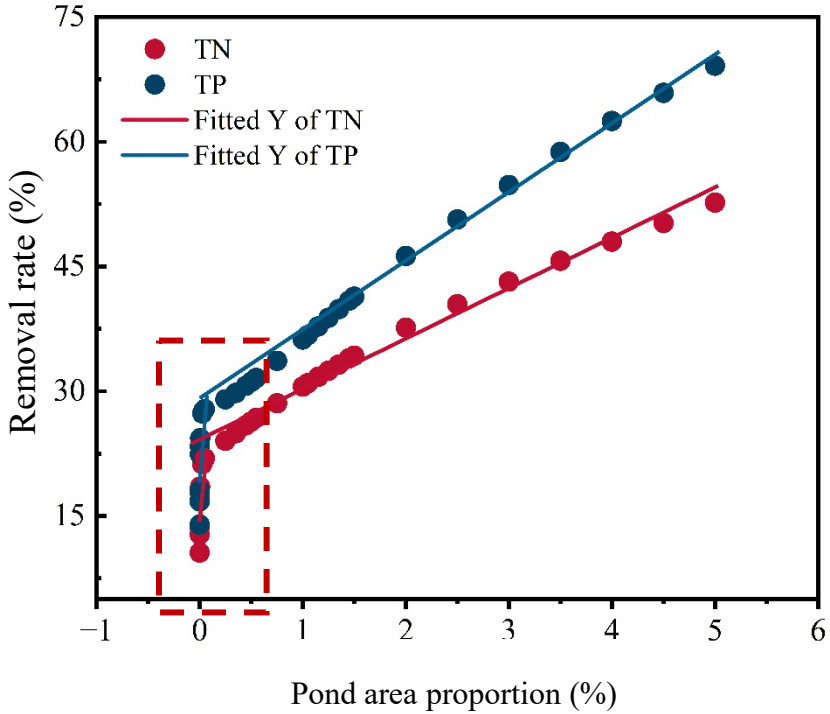
Precipitation and land use types are the main driving factors

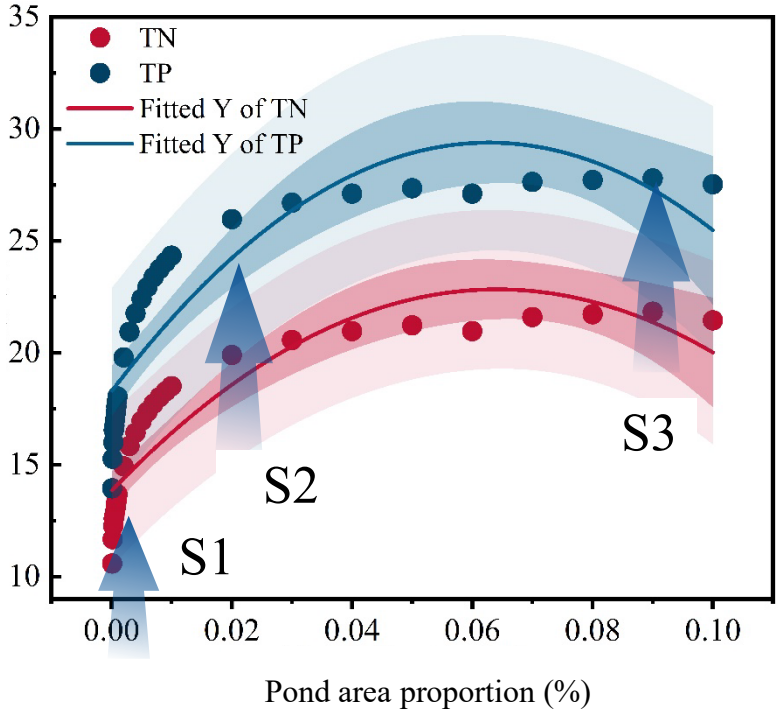


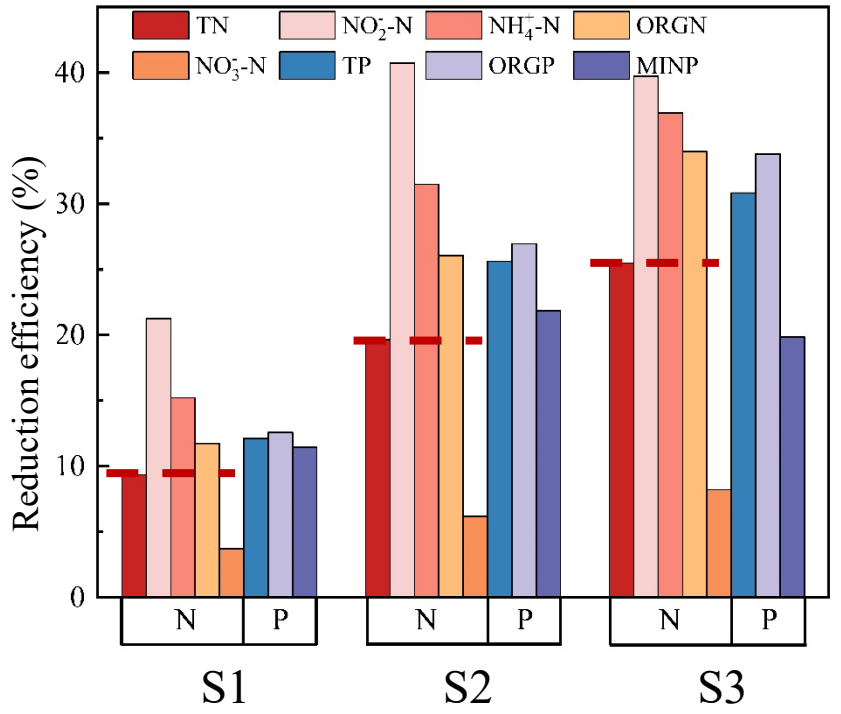
- The interpretation degrees of RICE, PRECIP, and WYLD for nitrogen and phosphorus load output are 41.9%, 20.1%, and 11.7% respectively.

Results

Pond area is positively correlated with N and P removal rates







- Larger ponds boost N/P reductions rapidly.
- Growth slows past 0.5% area ratio.
- N reduction stays lower than P throughout.

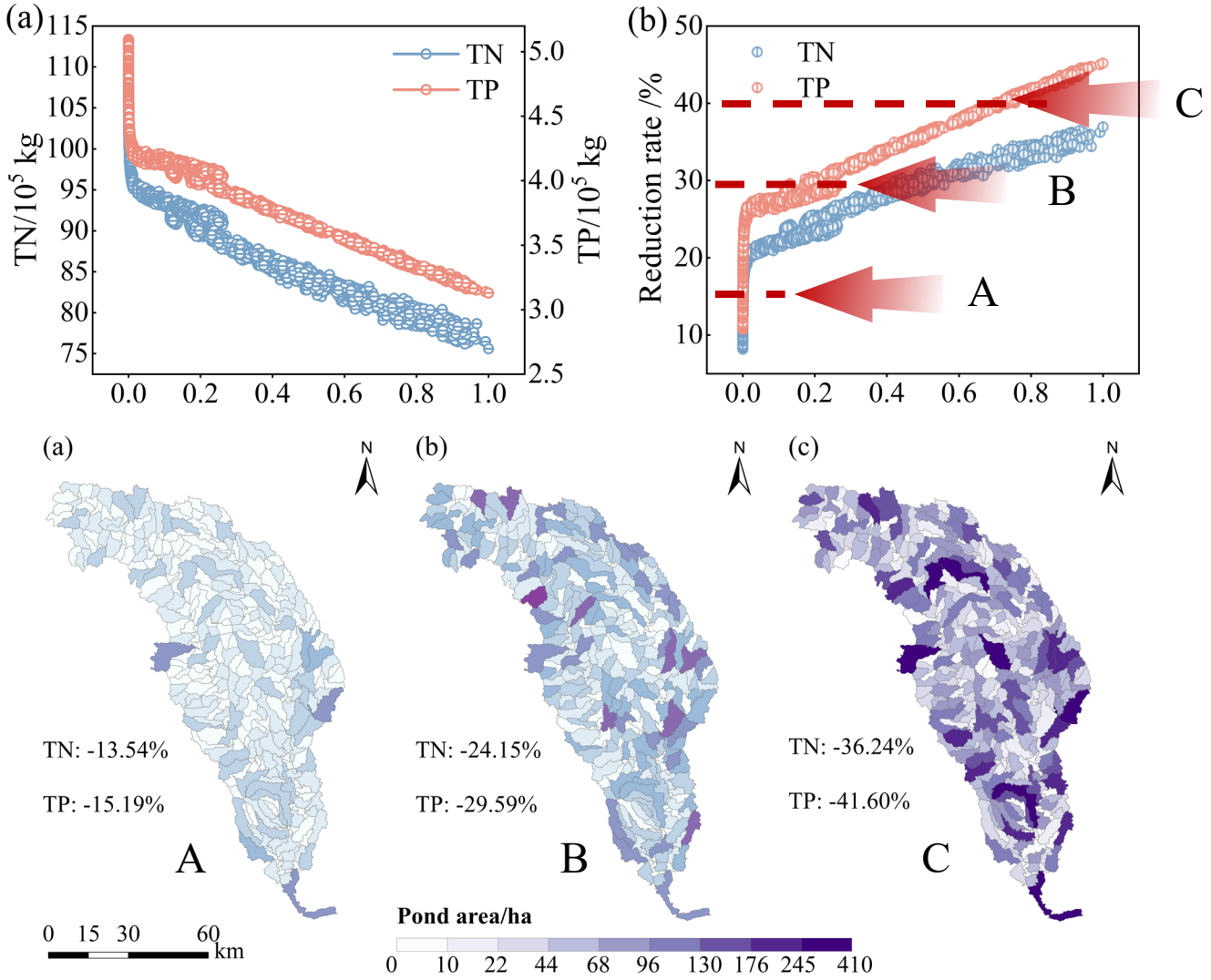
- Key intercepted forms:

  NH_4^+-N, org-N,

  NO_2^--N, org-P

Results

Higher removal rates demand more ponds per sub-watershed

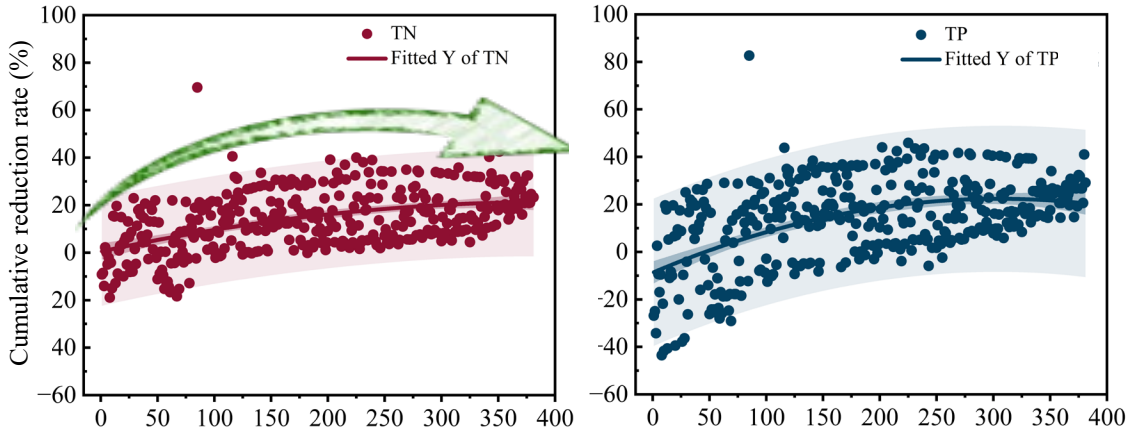


- Optimal spatial distributions of different pond area can achieve **8.4%-36.9% TN and 11.12%-45.7% TP** removal.
- The DSS optimal configuration delivers **24.15% TN and 29.59% TP** removal efficiencies.
- Higher removal rates demand more ponds per sub-watershed.

Results

Pond removal efficiency decreases with rainfall

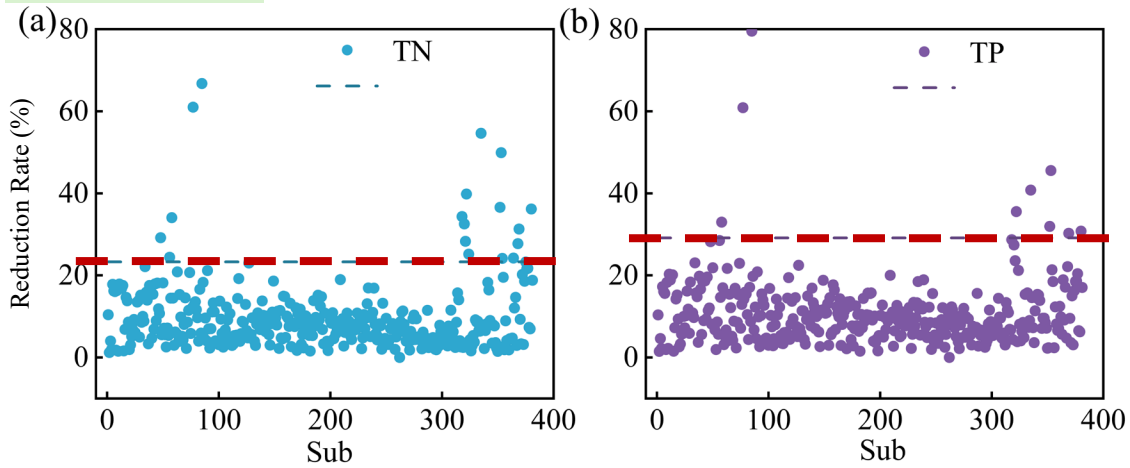
Longitudinal riverine profile

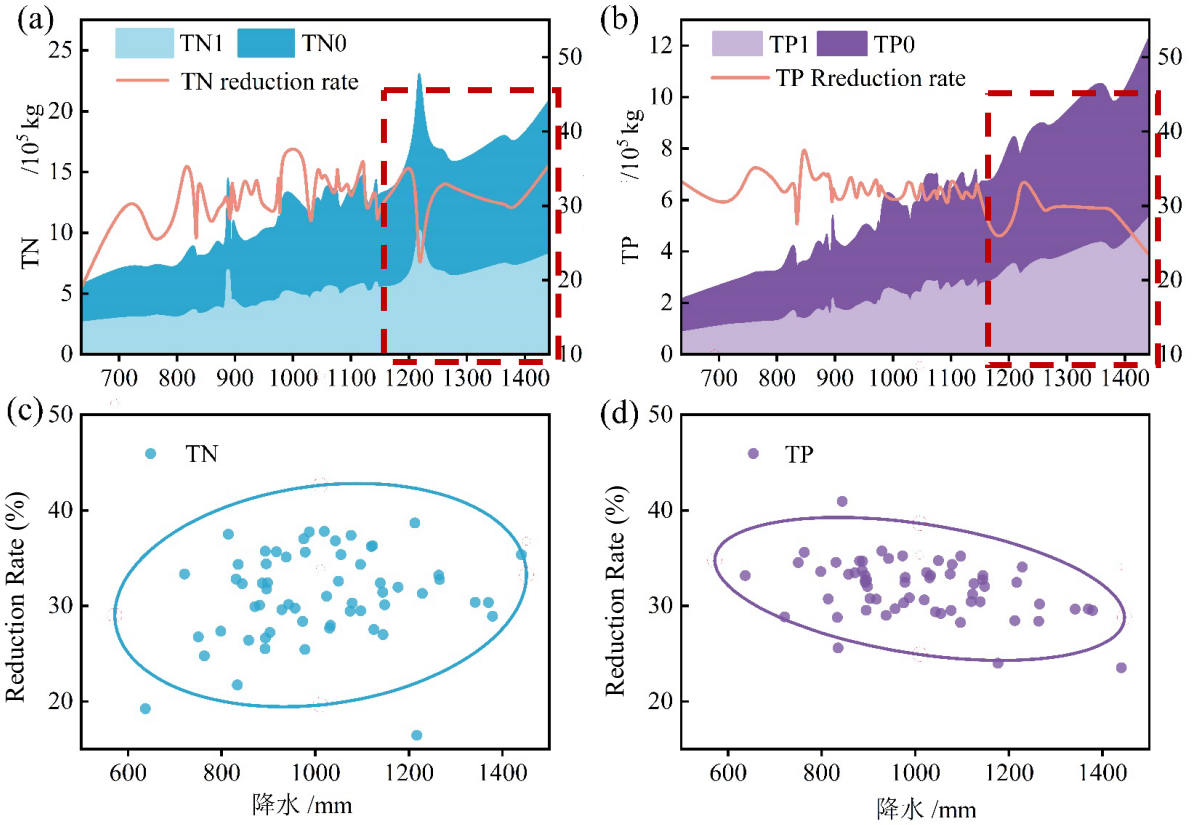


TN : 0-66.77% (mean 9.5%)

TP : 0-79.52% (mean 10.6%)

Sub-basin





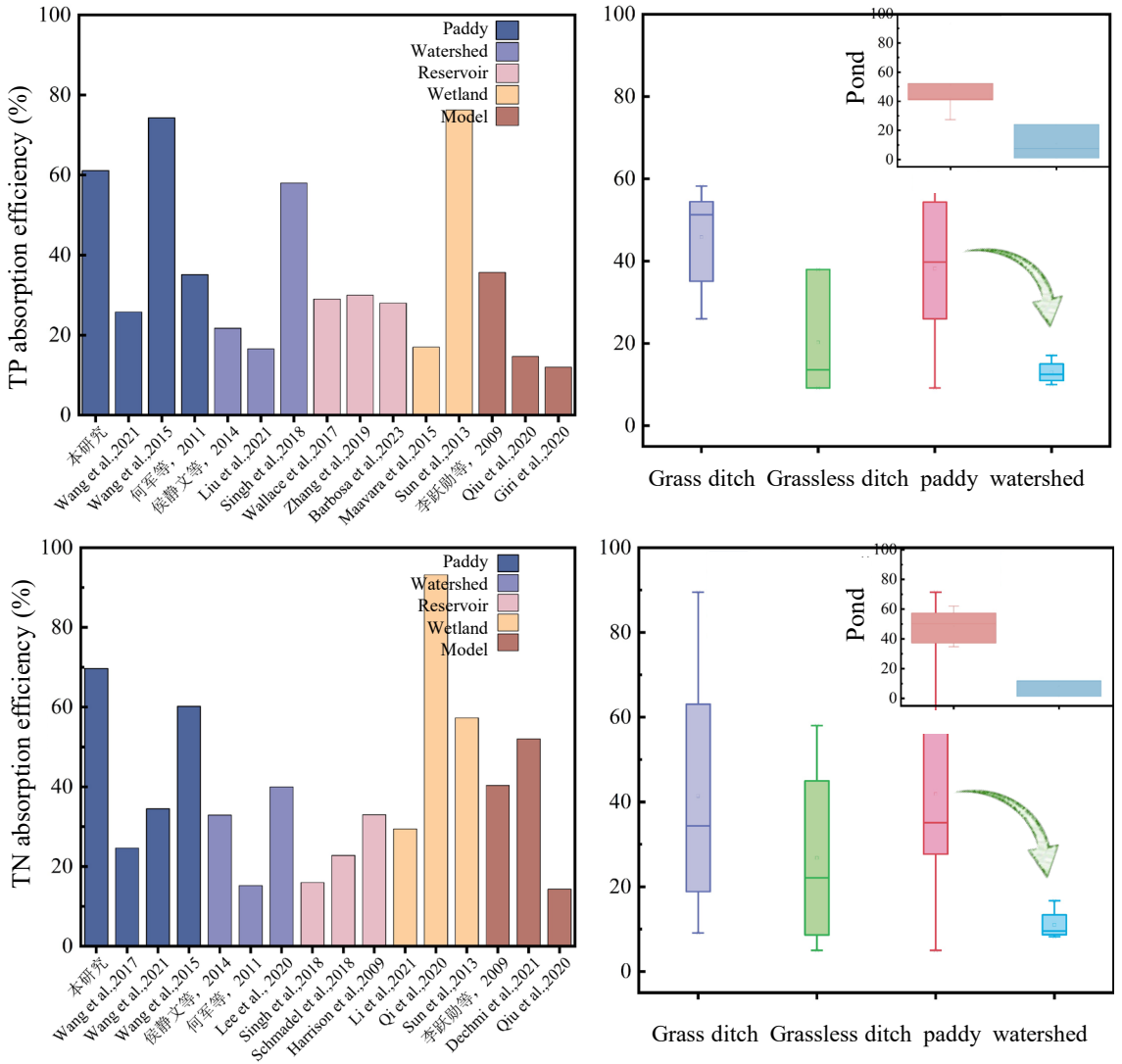
- At 600-1450 mm precipitation:

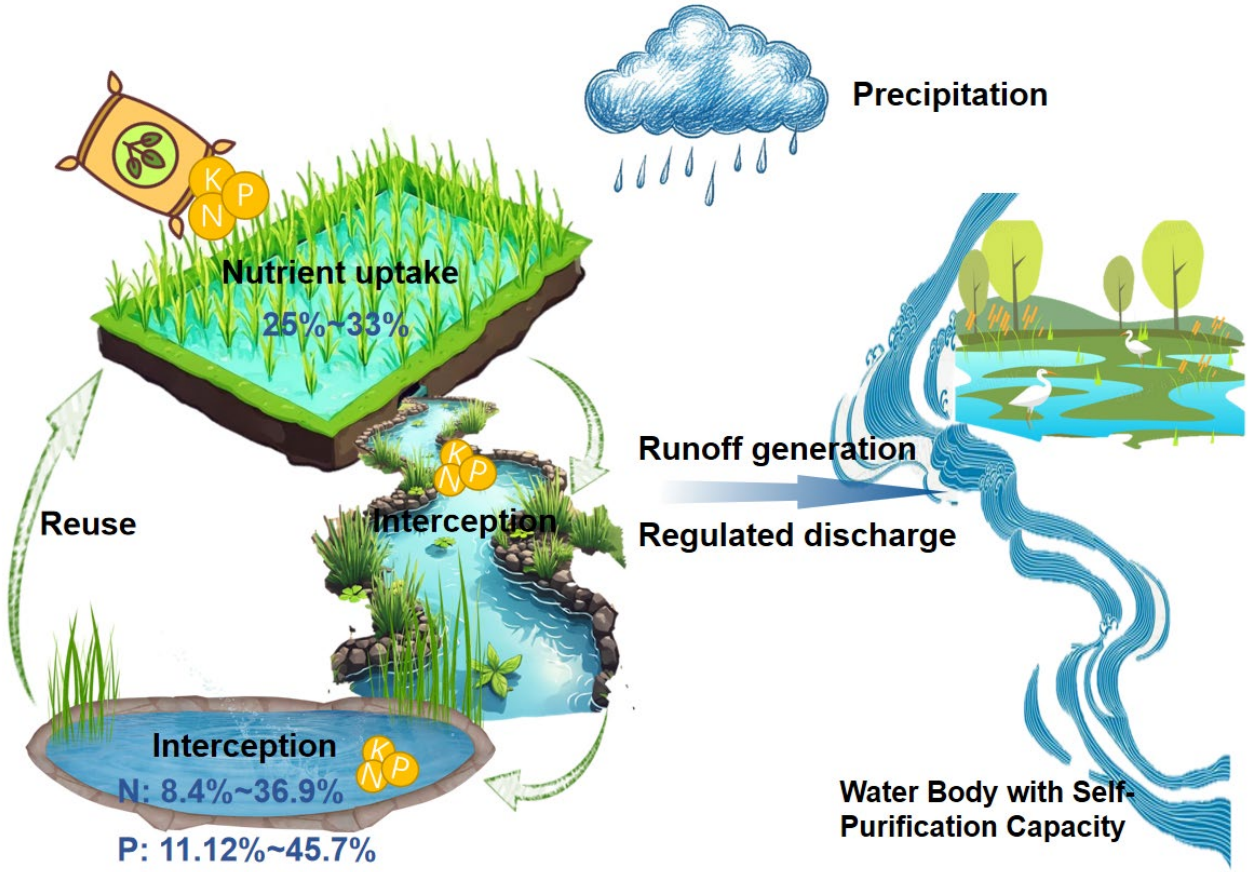
TN removal: 16.4-38.68%

TP removal: 23.52-40.94%.

Discussion

Field-scale removal efficiency exceed watershed-scale performance.





- The paddy-ditch-pond systems across southern China exhibit **distinctive hydrological regulation capacities**.

Conclusion

- The paddy - ditch - pond system exhibits a notable lagging effect and retention capacity for nitrogen and phosphorus in paddy fields.
- The critical period of diffuse pollution and loss is concentrated, and the spatial heterogeneity is significant.
- Under the SWAT-NSGA-II Decision Support Framework, TN and TP can be reduced by 24.15% and 29.59%, respectively.

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Thank you !

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