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Assessing climate change impacts on water footprint of crop production and crop yield: a case study of the Wu River basin, Taiwan

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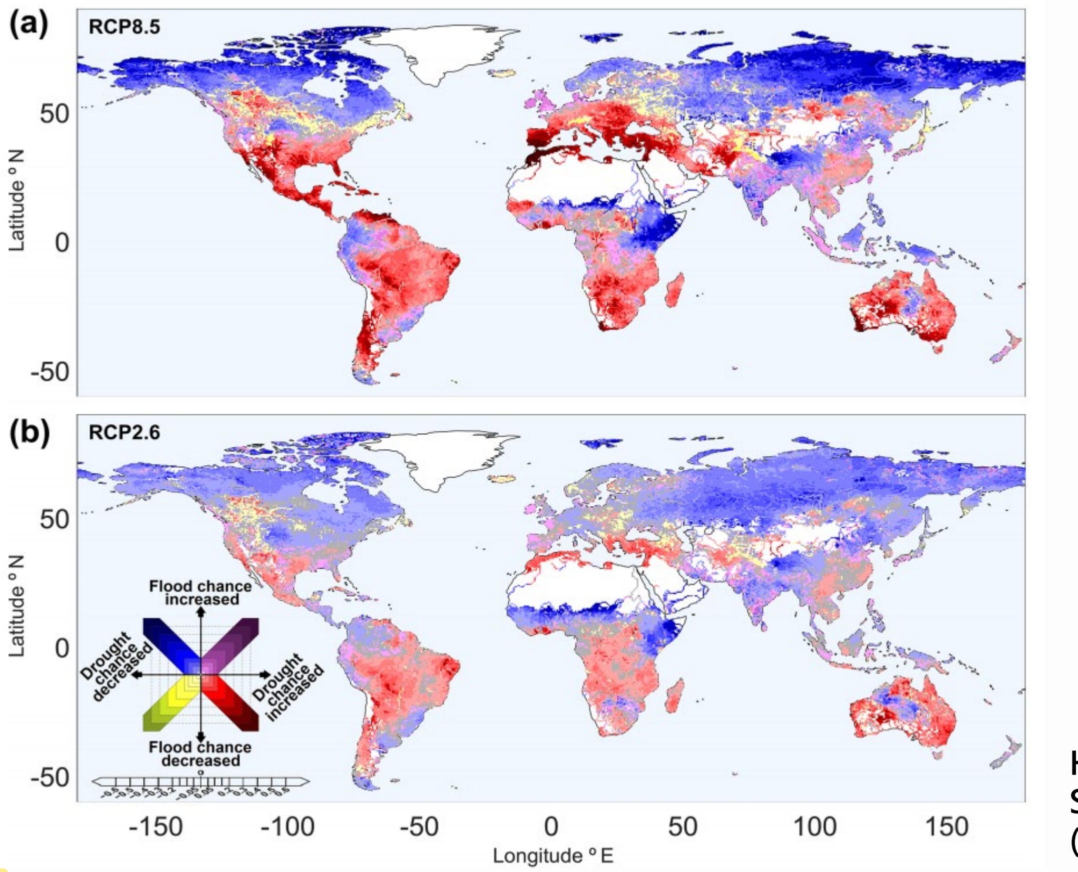
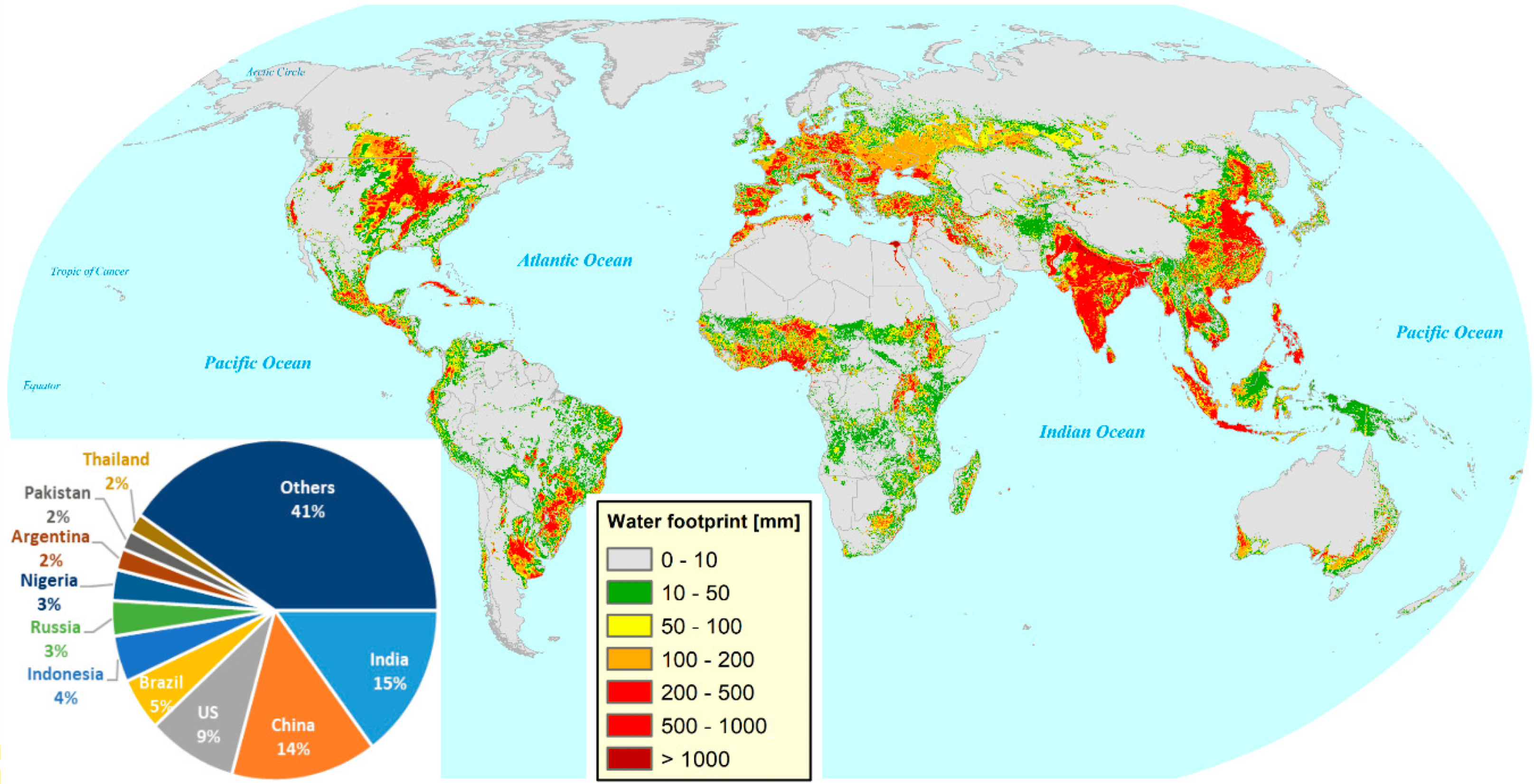
Increasing frequency of drought and flood under climate change



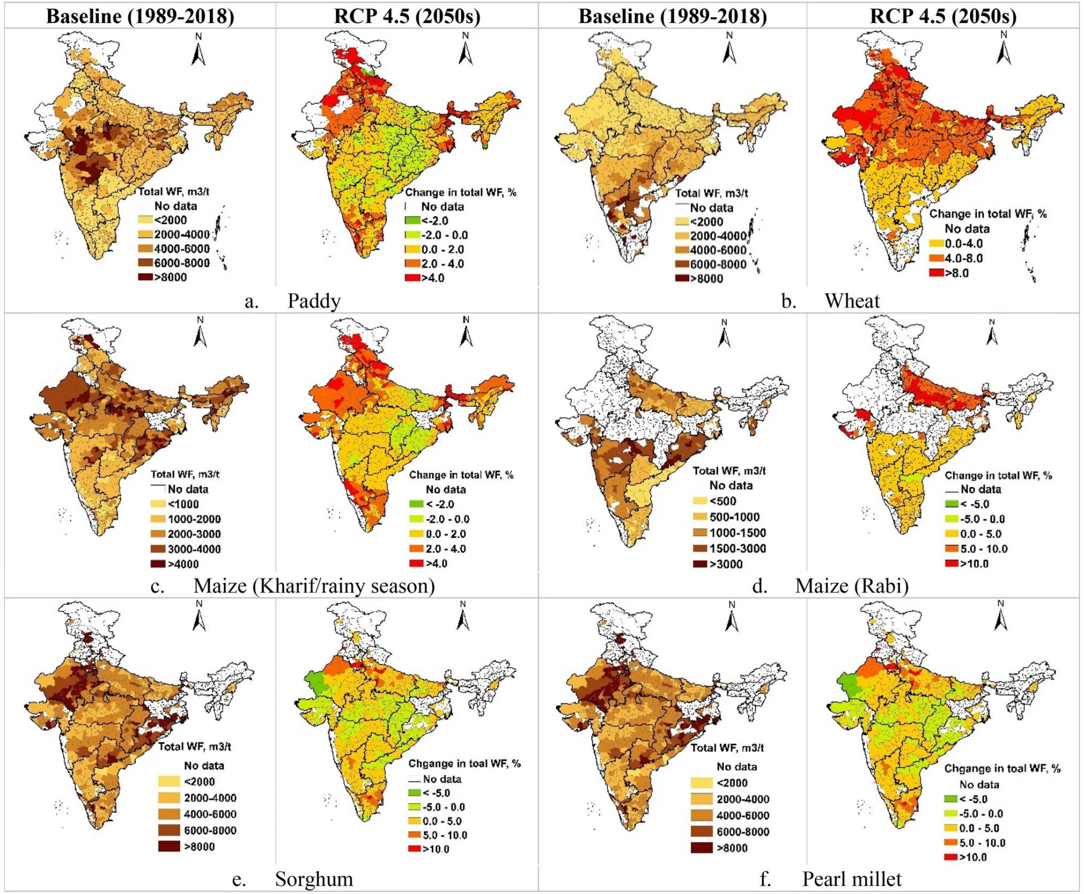
Hydrology and Earth System Sciences (Asadieh et al., 2017)

Water footprint of crop production in the world



Hydrology and earth system sciences
(Mekonnen & Hoekstra, A. Y. 2011)

Impact of water footprint under climate change: a case of India



Scientific Reports
(Mali et al., 2021)

Research goals

Water footprint

Calculate the blue, green, grey water footprint of crop production

Crop yield

Simulate by SWAT

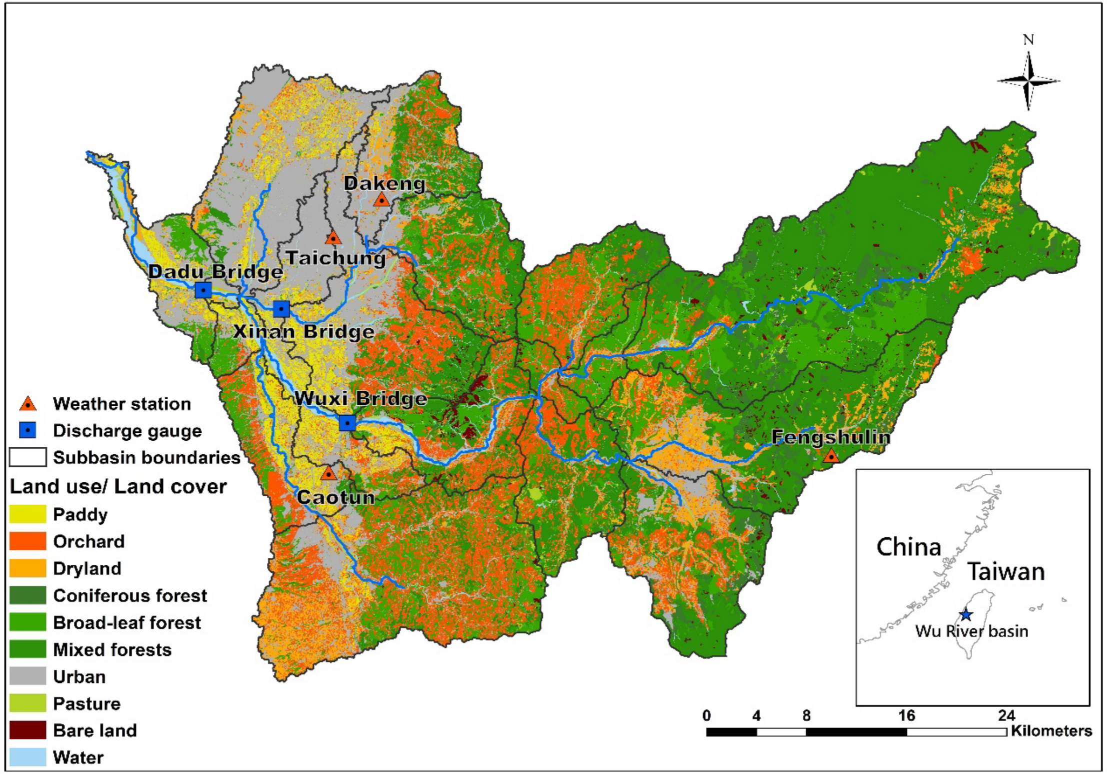
Climate change

Assess the impact of climate change

Adaption suggestion

Provide the suggestion for climate change adaption

Study area: Wu River basin



Located in central Taiwan, a crucial source of irrigation water for Taichung and Changhua counties

Area: 2,026 km^2

Annual total precipitation : 2,092 mm

Average annual flow : 115.83 m^3/s

Paddy fields: 4%

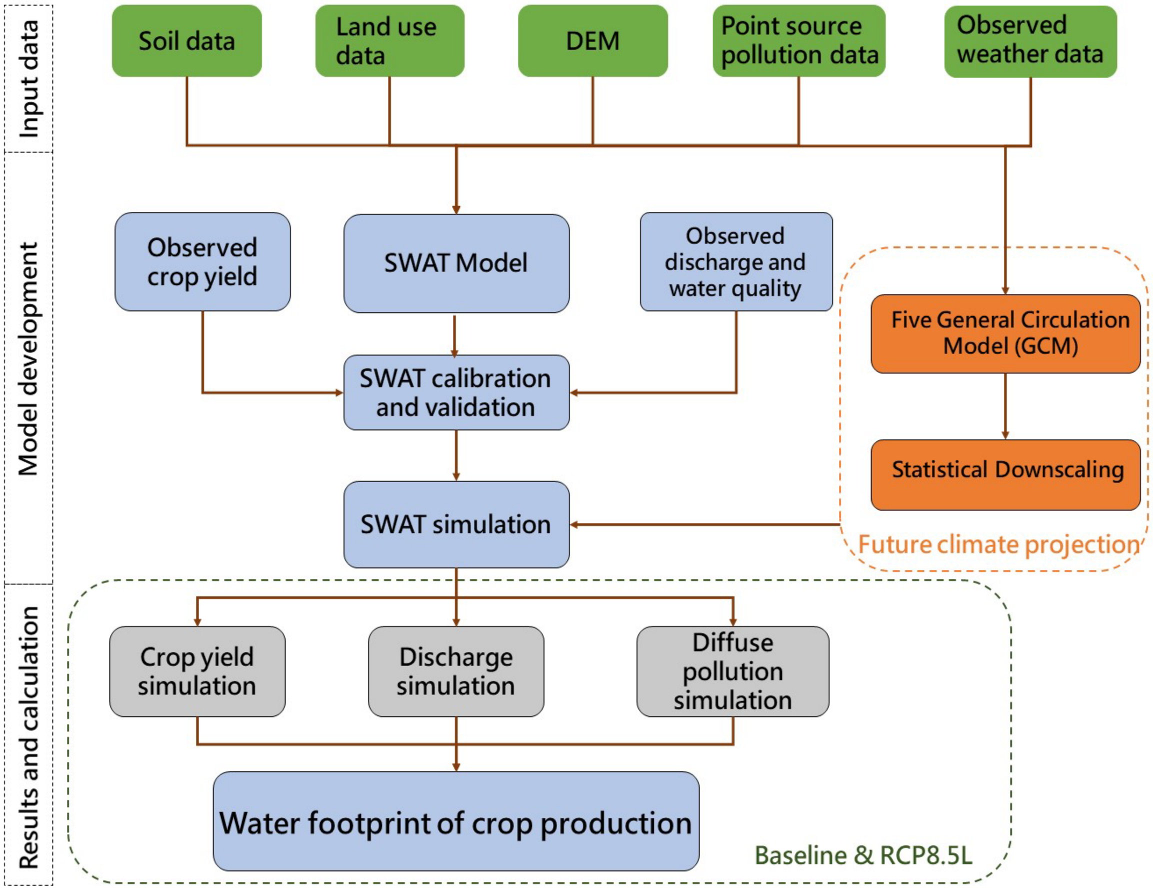
Drylands: 17%

Orchard: 6%

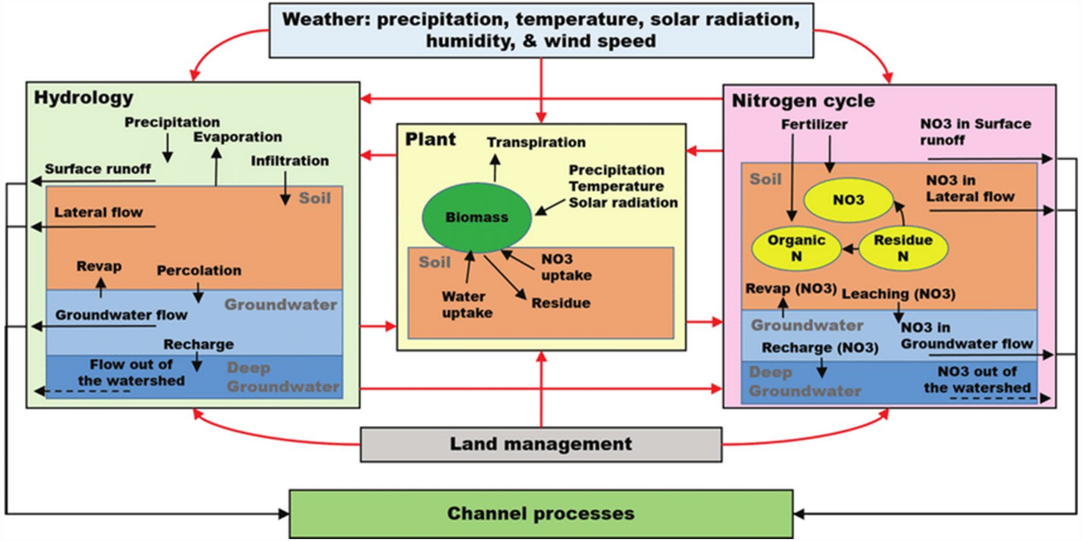
Forest: 51%

Urban: 19%

Material and Method



Method: SWAT2012



(Lee et al., 2017)

The SWAT model, a watershed-scale hydrological model, has been widely utilized globally for analyzing the impacts of human activities and climate change on diffuse pollution and crop yield

Method: Water footprint (1/2)

Blue water footprint

Major source of irrigation: streamflow, ponds, groundwater, etc.

Green water footprint

Rainwater stored in the root zone of soil

Grey water footprint

The amount of fresh water needed to dilute pollutants to maintain water quality standards

The TWN water standard:
suspended solids: 25 ppm,
nitrate: 10ppm
total phosphorus: 0.05ppm.

Method: Water footprint (2/2)

$$WF = WF_{blue} + WF_{green} + WF_{grey}$$

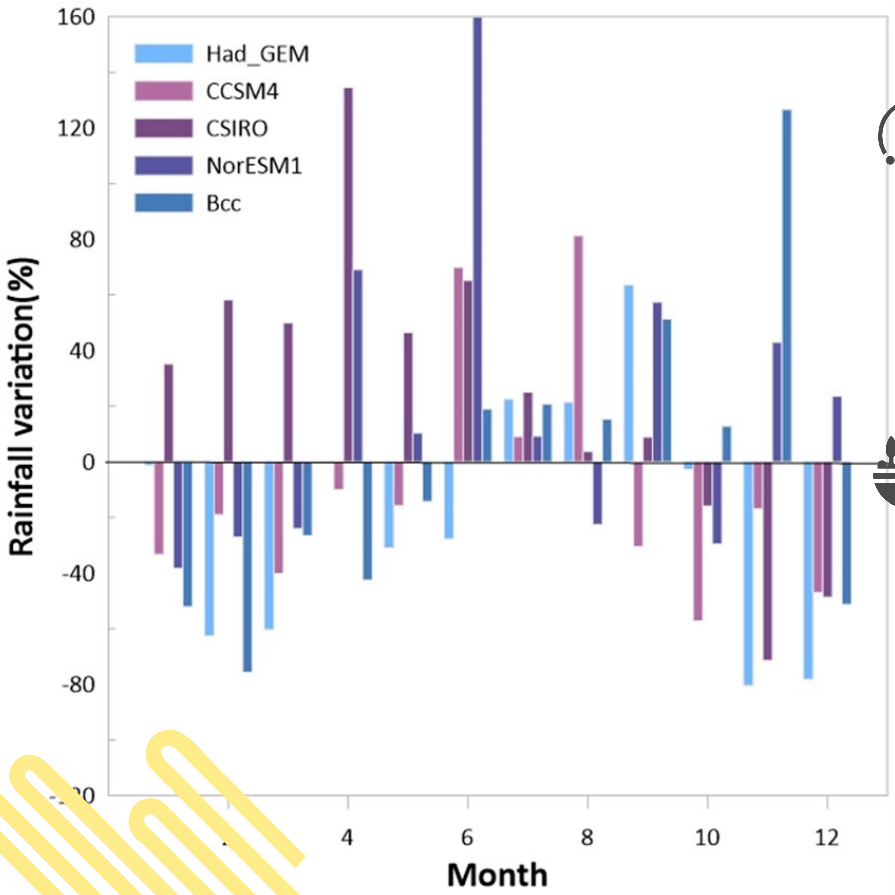
$$WF_{blue} = \frac{IR}{Y}$$

$$WF_{green} = \frac{\min(ET_{crop}, P_e) \times A}{Y} \times 10$$

$$WF_{grey} = \frac{L}{C_{max} - C_{nature}} / Y$$

WF: total water footprint of the crop (m^3/ton)
WF_{blue}: blue water footprint of the crop (m^3/ton)
WF_{green} :green water footprint of the crop (m^3/ton)
WF_{grey}: grey water footprint of the crop (m^3/ton)
IR: irrigation water (m^3)
Y: crop yield (ton)
A: cropping area (ha)
ET_{crop}:crop evapotranspiration (mm)
P_e:effective rainfall (mm)
L: The diffuse pollution during the crop cultivation process (kg)
C_{max}:the maximum diffuse pollution concentration acceptable in rivers (kg/m^3)
C_{nature}:the natural background output (kg/m^3)

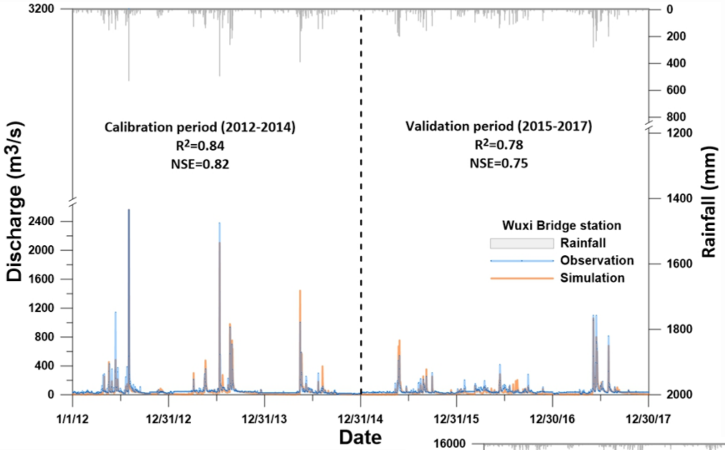
Method: Climate change scenarios



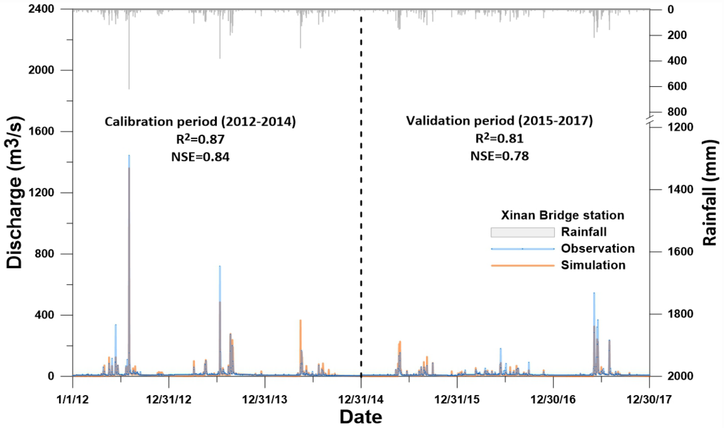
Five GCMs: HadGEM2-AO, NorESM1-ME, CSIRO-Mk3-6-0, CCSM4, and bcc-csn1.1n

Average decrease of approximately 12% during the dry season and increase of about 18% during the wet season.

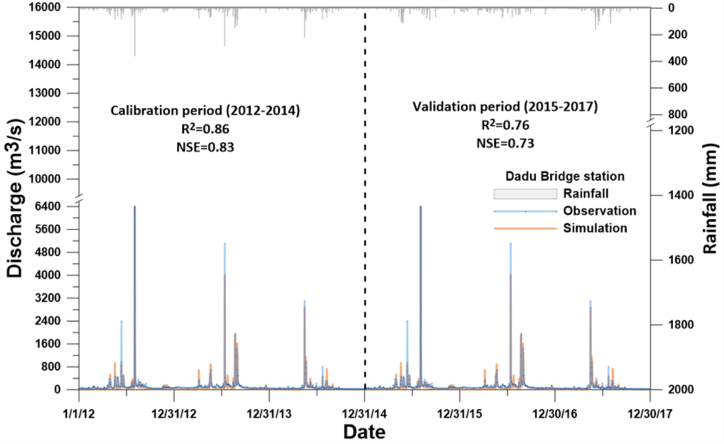
SWAT Calibration: Discharge



Wuxi Bridge station



Xinan Bridge station

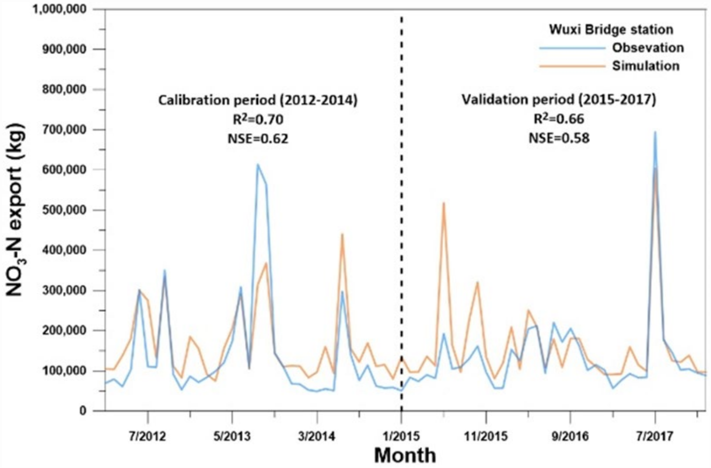


Dadu Bridge station

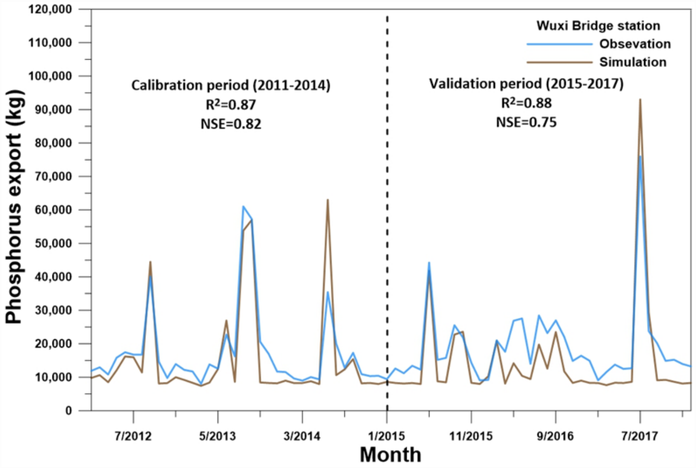
Calibration: R^2 >0.8 and NSE>0.7

Validation: R^2 >0.75 and NSE>0.73

SWAT Calibration: Diffuse pollution



NO_3-N

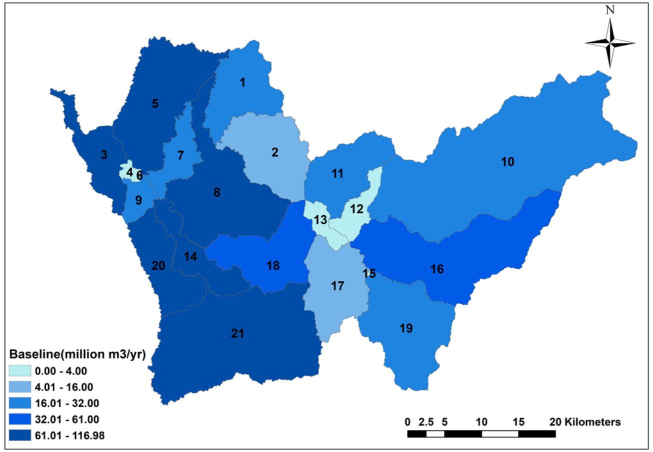


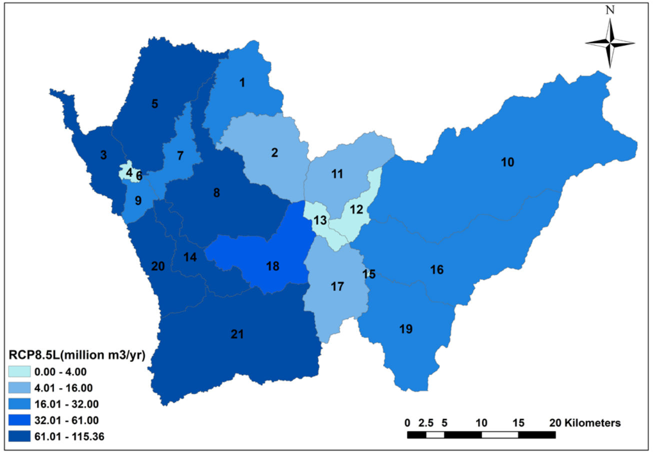
TP

The monthly nitrate calibration and validation results: R^2 >0.65 and NSE>0.5

The monthly phosphorus calibration and validation results: R^2 >0.8 and NSE>0.75

Spatial variations in blue-green water footprint

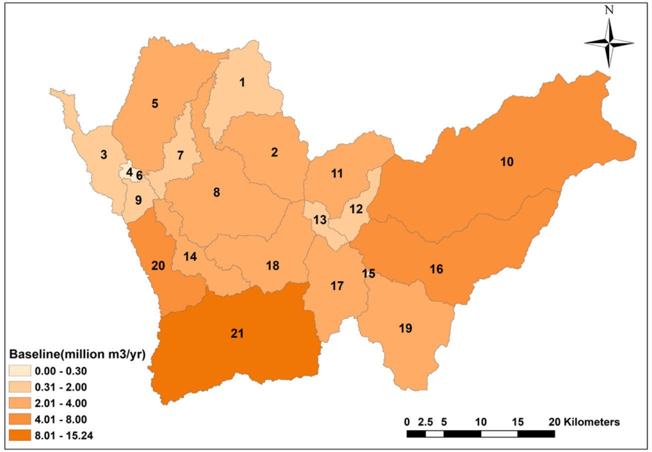


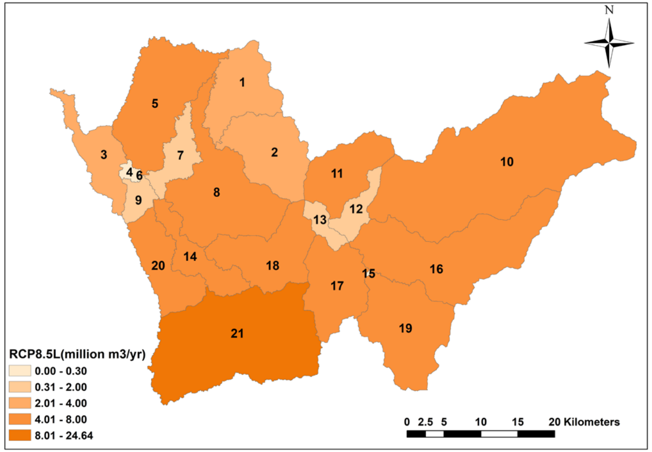


Subbasins 3, 5, 8, 14, 20, and 21 exhibit blue and green water consumption exceeding 61 million tons/year in baseline scenario.

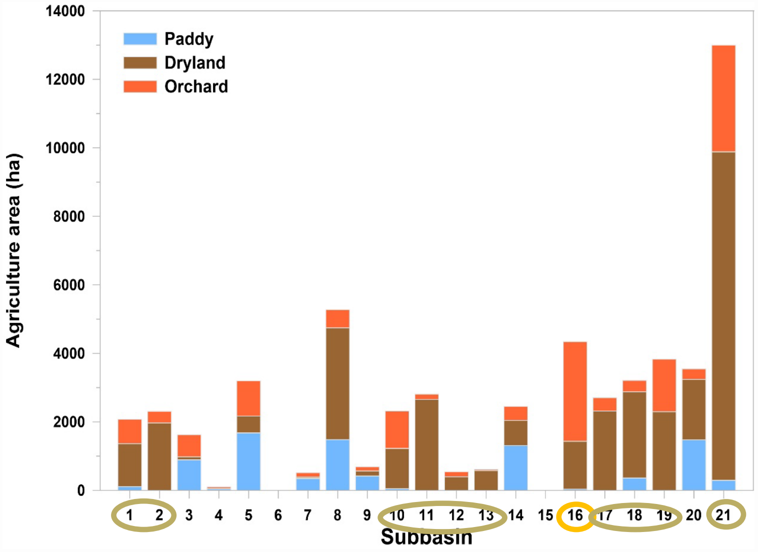
Most subbasins demonstrate marginal change in the range of blue and green water consumption.

Spatial variations in NO_3-N grey water footprint

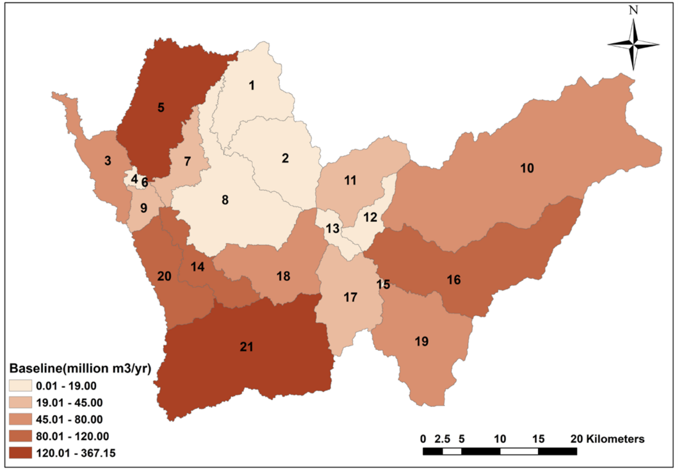




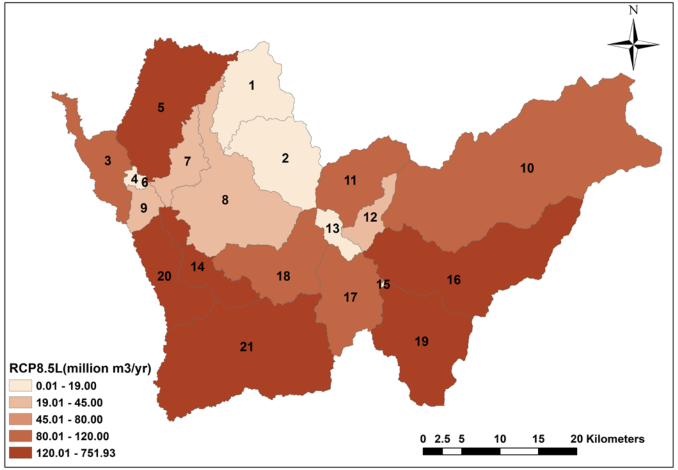
- Subbasins 10, 16, 20, and 21 in the upstream regions, where sweet potatoes and oranges predominate, exhibit higher nitrate nitrogen grey water demand in baseline scenario.
- Substantial increase in nitrate nitrogen grey water demand in field within the middle and upper stream subbasins, surpassing 4 million tons/year in RCP8.5 scenario.



Spatial variations in TP grey water footprint

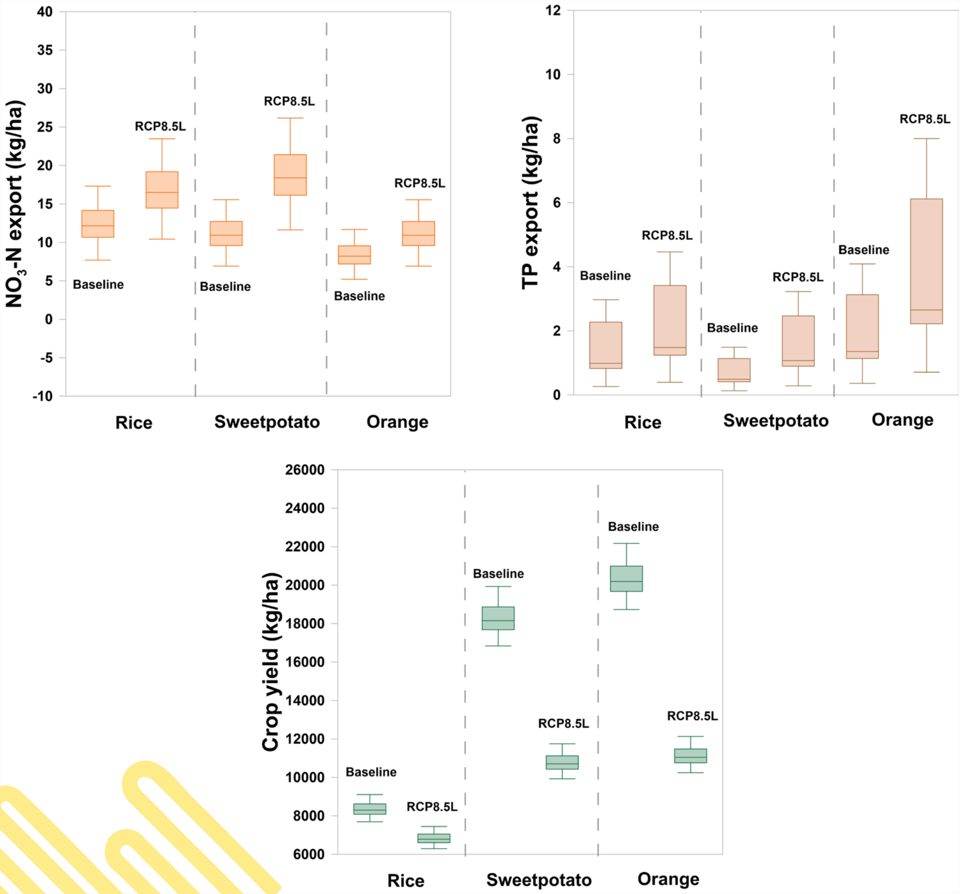


Total phosphorus grey water demand in subbasins 5, 14, 16, 20, and 21, where agriculture predominantly involves sweet potatoes and oranges cultivation .



Significant increase in total phosphorus grey water demand in the middle and upper stream subwatersheds, especially in larger orchard cultivation areas .

Diffuse pollution and Crop yield under climate change



The diffuse pollution will be increased by 33%~116% across different crops under climate change.

The crop yield will be decreased by 18%~45% across different crops under climate change.

Comparison with world water footprints

	Crop	Wu river	World				
			10th percentile	20th percentile	25th percentile	50th percentile	Average
Blue-Green water footprint (m^3/ton)	Rice	7456	599	859	952	1476	1486
	Sweet potato	354	203	219	224	249	330
	Orange	369	303	333	343	383	510
NO3-N Grey water footprint (m^3/ton)	Rice	145	71	129	162	215	187
	Sweet potato	60	14	50	50	50	53
	Orange	42	14	15	16	42	49

(Mekonnen & Hoekstra, 2014)

Paddy fields exceed the global average water footprint 5 times, primarily due to intensive irrigation practices in Taiwan.

The nitrate grey water footprint for each crop is nearly equal to the global average.

Proposed solutions for cultivation adaptation

Crop conversion

Evaluate the crop conversion in the middle and upper subbasin.

Increase nutrient use efficiency

Assess the crop growth demand during the growth period.

Fertilizer application

Adjust the fertilizer application practices (e.g., timing, amount, types)

Evaluate the impact of climate change

Identify the hotspots of variations under various climate change scenarios.

Conclusions

Variation in water footprints in Taiwan

- The water blue-green water footprint of paddy fields are approximately **5 times** higher than other rice field regions in the world.
- Grey water footprint will surge by approximately **33% to 116%** under climate change scenarios.

Impact of climate change in Taiwan

- Sweet potato and orange cultivation showed the most significant increase in nutrient export, potentially **surpassing 50%.**
- Crop yield are anticipated to decline by **18% to 45%.**

Cultivation adaptation is needed in the future

- For examples: Effective water resource management, strategic allocation, and conversion of crop types that consume less water and generate less nutrient exports.

Thank you for your attention

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