Socio-Hydrological Storylines under Deep Uncertainty: Applying DAPP and ABM to Compound Water Stress and Subsidence

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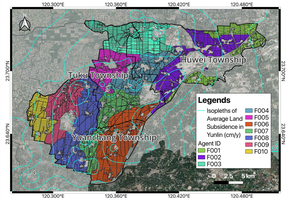
Abstract

To address water management challenges from climate change and land subsidence in Yunlin, this study develops an integrated Climate-Hydrology-Social-Crop (CHSC) model to evaluate policy robustness. The framework combines WthGen climate scenarios, GWLF streamflow modeling, and System Dynamics for water supply analysis, alongside a Tank Model for groundwater table. An Agent-Based Model (ABM) simulates social decision-making, coupled with AquaCrop for yield and income assessment. Finally, Dynamic Adaptive Policy Pathways (DAPP) are employed to map adaptation strategies based on 1) groundwater table 2) canal water deficit 3) agricultural income.

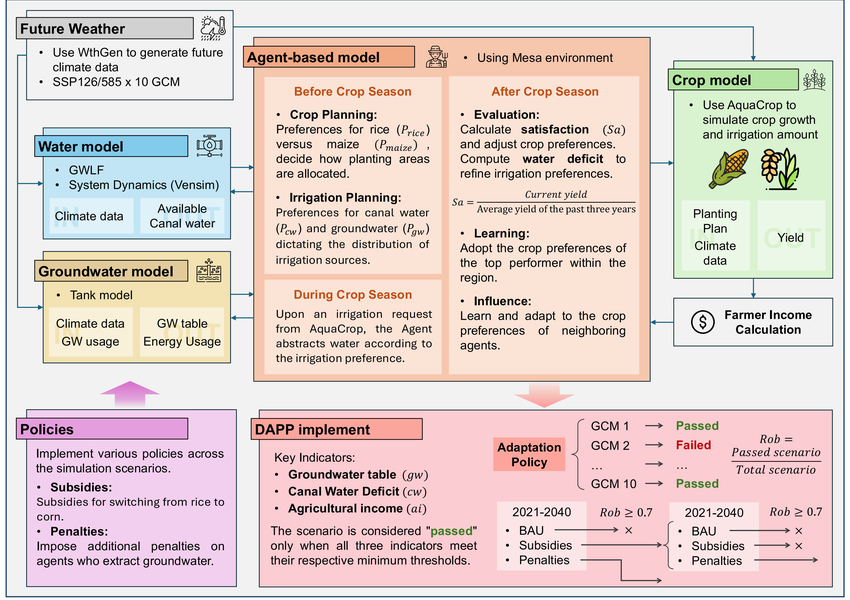
The CHSC model identifies robust water management strategies amidst uncertainty. Results show that early penalty and subsidy interventions create cumulative effects that steer systems toward long-term stability. This proactive approach fosters a resilient equilibrium, reducing the need for intensive, high-cost management in the later century.

Geographical Background

This study focuses on the **Huwei-Tuku-Yuanchang** corridor in Yunlin County, covering a total agricultural area of approximately **12,467 hectares** and discretized into **10 agents**. As a major production zone for **paddy rice, maize** and **peanuts**, the region's heavy reliance on groundwater irrigation has made it a primary land subsidence hotspot, serving as a critical site for evaluating agricultural adaptation policies.



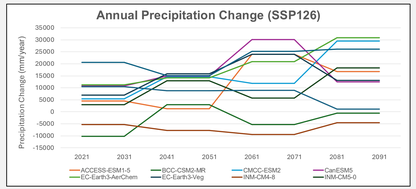
Methods

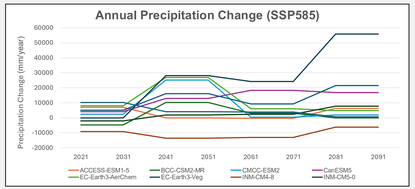


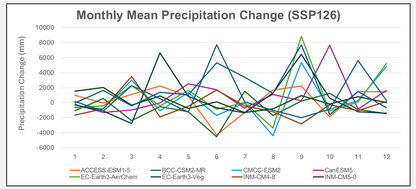
Results

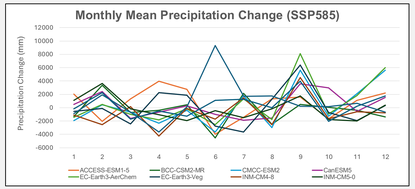
Future weather scenario

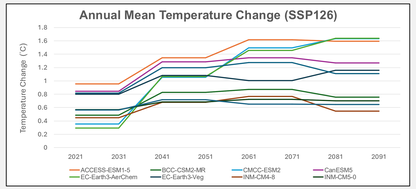
Following baseline fitting, 10 GCMs were selected to simulate future climate trends. Under both SSP126 and SSP585, **annual precipitation** shows an overall upward trend—with SSP585 exhibiting a more pronounced increase—though model divergence highlights ongoing uncertainty. **Seasonally**, rainfall surges in February/March and September but consistently declines in April, October, and November, signaling more extreme dry-wet cycles. Meanwhile, **temperatures** maintain a continuous upward trajectory; while SSP126 projections show a slight stabilization or decline by the late century, SSP585 exhibits rapid and unabated warming.

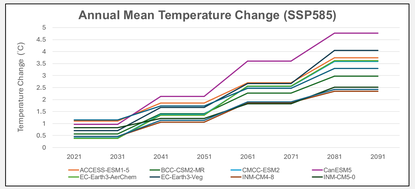






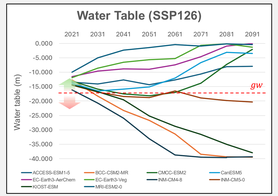


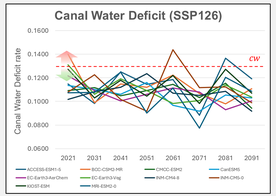


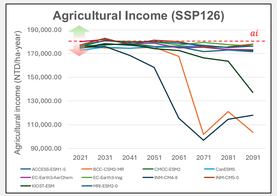


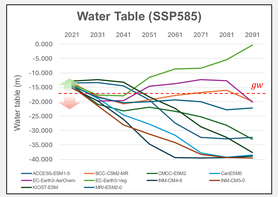
Future without adaptation policies

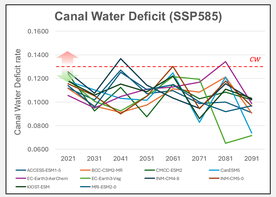
After selecting 10 GCMs through baseline fitting, the CHSC model was executed without adaptation policies. Results show that water tables remain low in both scenarios, with more severe depletion under SSP585. While canal water deficits improve alongside projected rainfall increases, agricultural income collapses in the mid-to-late century. This is primarily due to groundwater exhaustion from over-reliance.

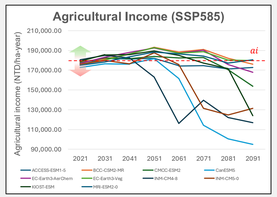








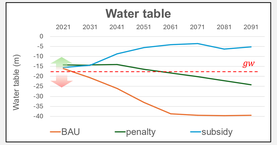


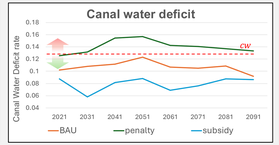


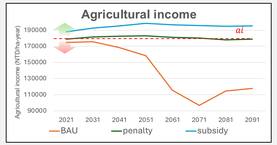
Results

Adaptation policies simulation in a scenario for example

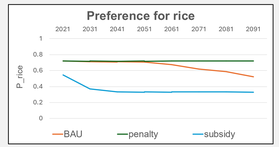
Using the CHSC model, this study compared policy impacts under the **INM-CM4-8 (SSP126)** scenario. The **subsidy policy** proved most effective, stabilizing groundwater, reducing canal water deficits, and maximizing agricultural income. While **penalties** initially slowed groundwater depletion, their efficacy vanished after 2050, inadvertently increasing canal water stress.

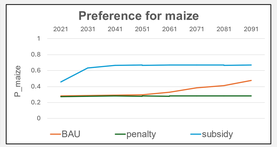






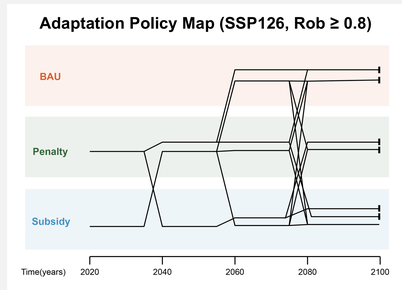
Farmer decision-making reveals that subsidies effectively incentivize a shift to maize, reducing irrigation needs and benefiting both groundwater and canal availability. Conversely, penalties curb extraction but fail to alter cropping preferences. As a result, farmers continue growing water-intensive rice, shifting pressure to canal systems and causing a mid-to-late century decline in water tables.

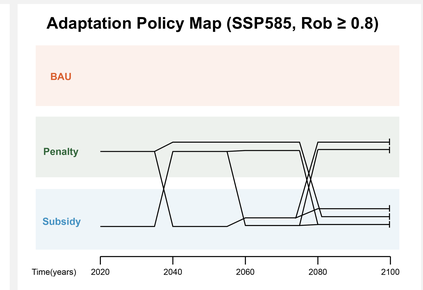




Adaptation policy map developed by DAPP

Integrating the CHSC model with the DAPP framework reveals contrasting adaptive pathways. In the **SSP126 scenario**, diverse policy options are available; **cumulative effects** from early interventions stabilize the system by the mid-to-late century, rendering further actions unnecessary. Conversely, pathways under **SSP585** are markedly restricted, requiring continuous, intensified intervention from the outset to the century's end to maintain safety thresholds. This underscores the lack of policy flexibility and the sustained adaptation costs inherent in high-emission scenarios.





Conclusions so far

- **Robust Decision-making Under Uncertainty:** Given the inherent uncertainties in agricultural water management, the CHSC model developed in this study provides a critical framework for policymakers to identify and implement **robust strategies** that remain effective across diverse future scenarios.
- **Cumulative Benefits and Long-term Stability:** Penalty and subsidy instruments enhance systemic robustness through **cumulative effects**. Early interventions can steer the system toward stability, potentially reducing the need for intensive management by the mid-to-late century.

Future work

- **Improve Model Realism**: Enhance the behavioral and physical accuracy of the simulation.
- **Inclusion of Multiple Physical Risks**: Incorporate a broader range of physical risk assessments, such as flooding, water quality degradation, and heatwaves, into the modeling framework.
- **Diversify Policy Options**: Add measures such as shifting planting dates and increasing water storage infrastructure (e.g., irrigation ponds).
- **Computational Efficiency**: Streamline the model to minimize computational costs.

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