Climate Change and Adaptation: Sustainable Water Management

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Food-Energy-Water in a Changing Scenario

Increasing groundwater depth in Gangetic Basin
Solutions

• More crop per drop or More nutrition per drop
  • Switching flood to drip irrigation
  • Improved irrigation water management
  • Participatory framework targeting the most vulnerable farmers
Major Crop Practice in India

- Irrigation affects water and energy cycle
- Land surface modelling must include irrigation
- Existing coupled models - demand driven irrigation with generic crop
- India-uncontrolled irrigation
- Paddy primary crop - submerged crop - water and energy balance mechanisms different
VIC-AMBHAS-IRR model

Forward-difference two-dimensional, one-layer groundwater model with governing equation:

$$\frac{\partial}{\partial x} \left( T \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( T \frac{\partial h}{\partial y} \right) = S_y \frac{\partial h}{\partial t} - q_r + q_p + q_b$$

Where: \( h \) = hydraulic head, \( T \) = aquifer transmissivity, \( S_y \) = aquifer storage coefficient, \( q_r \) = groundwater recharge, \( q_p \) = groundwater pumping, \( q_b \) = baseflow to rivers

- **aquifer is isotropic**, can be heterogeneous
- \( T \) recalculated at each time-step as the saturated aquifer thickness varies, according to:
  $$T = K (h - z_{base})$$
  where \( K \) = hydraulic conductivity, and \( z_{base} \) = elevation of the base of the aquifer

Joseph et al. (2022), ERL (revision)
Paddy Formulation

Concept from SWAT (Xie and Cui, 2011), MATCRO rice (Masutomi et al., 2016), Devanand et al. 2019

**Energy Balance:**

1) \( R_n = H + LE + G + S_{tw} \)

Where: \( S_{tw} = c_{pw} \rho_w d_w \frac{\partial T_s}{\partial t} \)

\( S_{tw} \) = heat flux stored in surface water,

\( c_{pw} \) = specific heat of water, \( \rho_w \) = density of water,

\( d_w \) = depth of water, \( T_s \) = surface temperature

2) **Surface albedo:** soil albedo replaced with albedo of water

**Water Balance:**

1) **Evaporation** - soil evaporation replaced with open water evaporation

\[ E = E_{\text{canopy}} + E_{\text{transpiration}} + E_w \]

2) **Seepage** -

\[ Q_{12} = 0.1\% \text{ of } Q_{12,\text{max}} \]

\( Q_{12} \) is the seepage from layer 1 to layer 2

Field tilling creates low permeability layer beneath the field, which cannot infiltrate at the maximum capacity

3) **Overbund flow** -

\[ R_{\text{over}} = \frac{(h_t - h_{\text{max}})}{\Delta t}, \quad h_t > h_{\text{max}} \]

\[ R_{\text{over}} = 0, \quad h_t \leq h_{\text{max}} \]

\( h_{\text{max}} \) is considered to be 300mm (Mishra et al. 2007)

4) **Ponded depth** -

\( h_t \) is the ponded depth at time step \( t \)

\[ \Delta h_w = (P + \text{irrig} - E_w - \text{infil}). \Delta t \]

\( h_{t+1} = h_t + \Delta h_w \), if \( h_{t+1} < 0 \) set \( h_{t+1} = 0 \)
Model Performances

Evaluation of Model Performance
Depth to GW simulated from flood, intermittent and drip irrigation
Irrigation water management

Seasonal Predictions (suitable crop for season)

Extended Range: 2-4 Weeks (Irrigation water Arrangements)

Decadal to multi-decadal projections: (Crop allocation for water and food security)

Weather Forecast: 3-7 Days (Irrigation Water Application)

Optimization Model

Objective: Minimize Water use

Decision Variable: Irrigation Water Application

1000 Rainfall Scenarios given Forecasts

Real-time Soil Moisture

Farm Scale Hydrologic Model

Constraint:
P(\text{Root Zone Soil Moisture} \leq \text{Water Stress Threshold}) = \alpha \ (\text{say 0.95})

Optimized Irrigation Water to be applied

Saves 10-30% water with no loss in the yield Patent filed; Roy et al. (2021), WRR
Extending with ERPAS

**Decision Variable (Irrigation Water) Search Space**

**Search based Optimization**

- **Limited Ensemble**
  - Forecasts
  - Days

- **Weather Generator: Hidden Markov Model**
  - Forecasts
  - Days

- **Large Ensemble Given Forecasts/Predictions**

- **Farm-scale Ecohydrological Model with Monte Carlo Simulations**

**Checking Probabilistic Constraints**

**Optimal Irrigation Water Management Plan for 3 Weeks**
Changes in RY (a, c, e and g) and savings in irrigation water use (b, d, f and h) w.r.t. the farmer’s method of irrigation scheduling, using the proposed framework with extended range forecast for (t+1)th to (t+7)th day, (t+8)th to (t+14)th day and (t+15)th to (t+21)th day reliability factor value (α): 0.95 in (a) and (b), 0.85 in (c) and (d), 0.75 in (e) and (f), 0.5 in (g) and (h).

Roy et al. (2022), Climate Services
Upscaling over a large region

Satellite Observations

- Different soil types
- Different crop types
- Farms with in-situ soil moisture sensors
- Rootzone soil moisture sensor
- Weather Forecast information

Simulation-optimization framework
Soil Moisture Prediction at Sites

- Site 1 and Site 2 (S1 and S2) – considered as “base sites”. Sites with similar soil types were taken as “test sites” → Site No. 6, 11, 14, 21 (S1*) and Site No. 15 (S2*)
- All these predictors: (LST, EVI, NDVI, Temperature, Precipitation, Background RZSM data scaled from RS observed SSM products) are extracted for the test sites
- Long Short-Term Memory model (LSTM) – predict the RZSM with these predictors
- Observed datasets for soil moisture is used to train the model

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<th>$s_w$</th>
<th>$s_h$</th>
<th>$s_{fc}$</th>
<th>$s^*$</th>
<th>$n$</th>
<th>$Z_r$</th>
<th>$K_s$</th>
<th>$\beta$</th>
<th>SWR</th>
<th>Soil Type</th>
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<td>Clay Loam</td>
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Water Savings and Change in Yield

S6

S15
Thank You