Impact of Agricultural Intensification on the Water Resources in a Semi-Arid Catchment in India

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With

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Agriculture Intensification Vs Water Resource depletion
Why This Study?

- An Integrated model capable of simulating surface and subsurface hydrologic processes is required
- **SWAT**
  - Simple and robust model available in the public domain
  - Conceptual model that is highly efficient in simulating stream flow and sediment transport
  - GIS integrated versions makes the incorporation of spatial data simpler
- **Objective**
  - Apply ArcSWAT to study the groundwater scenario
  - Study the impact of excessive groundwater extraction for irrigation
SWAT Model Description

SWAT

Land Phase

Channel Routing Phase
ArcSWAT Model Land Phase Components

- Soil surface
- Root zone
- Shallow aquifer
- Deep aquifer
- ET
- Precipitation
- Effective Precipitation
- Revap
- Percolation
- Recharge to deep aquifer
- Irrigation
- Surface runoff
- Lateral flow
- Return flow
- Groundwater extraction
Review of SWAT

• Reasonably accurate results for the stream flow simulation (Ficklin et al., 2009; Ghaffari et al., 2010; Dessu and Melesse, 2012)

• Groundwater component
  • Compatible with the surface components, requiring only minimum readily available inputs from the field (Arnold et al., 1993)
  • Two control volumes: Shallow and Deep aquifer
  • Major drawback: Lumped model is used for the groundwater component (Sophocleous et al., 1999).

• SWAT + MODFLOW
  – Distributed modelling of the groundwater component taking recharge information from SWAT (Sophocleous et al., 1999, Kim et al., 2008).
  – Not available for ArcSWAT
Methodology

- ArcSWAT (v.2009) was selected
- Groundwater processes considered in ArcSWAT was assumed to be satisfactory for the analysis
- Identified some problems when ArcSWAT is applied to simulate large scale groundwater extraction from deep aquifer
ArcSWAT Model Components

- Soil surface
- Root zone
- Shallow aquifer
- Deep aquifer

**Maximum initial storage is limited to 3000 mm**

Mathematical relation:

\[ S_{Deep_i} = S_{Deep_{i-1}} + R_i - I_{irr_i} \]

*Insufficient to meet the high irrigation demand*
ArcSWAT with Additional Water Balance Component

ArcSWAT

Soil surface

Root zone

Shallow aquifer

Effective Precipitation

Precipitation

Revap

Percolation

Irrigation

Surface runoff

Lateral flow

Return flow

Recharge to deep aquifer

Groundwater extraction

Deep aquifer

Recharge

ArcSWAT with Additional Water Balance Component

Recharge
Deep Aquifer Water Balance Model

- $R$ and $Irr$ : from ArcSWAT (at HRU level)
- Irrigation source: Source outside the basin

- Change in deep aquifer water table depth

$$\nabla \Delta WT = \sum R_i \cdot A_i - \sum Irr_i \cdot A_i \cdot \varepsilon_i$$

$$s \cdot \sum A_i$$

$\varepsilon_i = $ Irrigation efficiency

$A_i = $ Area of the $i^{th}$ HRU in the sub-basin

$s = $ Aquifer specific yield in the sub-basin
Study Area

Malaprabha Catchment in India
Study Area Description

- Climatology: Tropical humid to semi-arid
- Agricultural watershed
- Major crops: paddy, sugarcane, oil seeds, cereals and pulses, mostly irrigated
  - DES statistics shows that the net irrigated area and groundwater irrigated area have almost doubled in the last three decades.
- Geology: Greywacke/Argillite, pink granite, basalt
- Agriculture intensification multiplied the irrigation demand
- Large scale groundwater extraction for irrigation
- Drastic groundwater table depletion
Database for the Model

- **DEM**: ASTER DEM of 30m resolution
- **Soil map**: NBSS & LUP (Nagpur)
- **Land use/Land cover map**: Landsat-7 ETM+
- **Rainfall**: Multi-site rainfall data from DES, Bangalore
- **Weather data**: DES, Bangalore
- **Stream flow**: WRDO, Bangalore
- **Groundwater table fluctuation**
Crop management practices were manually defined

Irrigation is enabled when plant stress reaches 0.95

Irrigation source: Source outside the basin

SCS-CN method $\rightarrow$ Surface runoff

Hargraves method $\rightarrow$ Potential evapotranspiration

Specific yield $= 3\%$ (following CGWB)

Irrigation efficiency $= 0.4$ for flood irrigation (Narayanamoorthy, 2006)
Model Sensitivity Analysis for the Basin

- LH-OAT method in ArcSWAT is used for sensitivity analysis
  - Each parameter is divided into sub-ranges
  - Each sub-range is sampled only once
  - Output shows the influence of the parameter changed

- 14 parameters related to flow and groundwater

- Sensitive parameters are
  - RCHRG_DP (Deep aquifer percolation coefficient)
  - EPCO (Plant uptake compensation factor)
  - CN2 (Curve number)
Model Calibration for the Basin

- Sensitive parameters were manually calibrated for stream flow as well as the groundwater table fluctuation

<table>
<thead>
<tr>
<th>Rank</th>
<th>Parameter</th>
<th>Calibrated value</th>
<th>Range for good simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RCHRG_DP</td>
<td>0.01-0.8</td>
<td>0 – 0.8216</td>
</tr>
<tr>
<td>2</td>
<td>EPCO</td>
<td>1</td>
<td>0 – 0.888</td>
</tr>
<tr>
<td>3</td>
<td>CN2</td>
<td>CN2-20 to CN2+5</td>
<td>CN2-20 to CN2+24*</td>
</tr>
<tr>
<td>4</td>
<td>ALPHA_BF</td>
<td>0.01</td>
<td>0.01-0.9</td>
</tr>
<tr>
<td>5</td>
<td>SOL_K</td>
<td>2.19-4.86</td>
<td>-23.6 to 22.5 (%)*</td>
</tr>
<tr>
<td>6</td>
<td>GW_delay</td>
<td>31</td>
<td>0 – 46.34</td>
</tr>
<tr>
<td>7</td>
<td>CH_K2</td>
<td>5.0</td>
<td>0 - 4.75</td>
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<tr>
<td>8</td>
<td>CH_N2</td>
<td>0.03</td>
<td>0 – 0.029</td>
</tr>
<tr>
<td>9</td>
<td>GWQMN</td>
<td>Default value</td>
<td>0 – 979.2</td>
</tr>
<tr>
<td>10</td>
<td>SOL_AWC</td>
<td>0-3 times the observed values</td>
<td>-24.9 to 24.3(%)*</td>
</tr>
<tr>
<td>11</td>
<td>GW_revap</td>
<td>0.2-0.5</td>
<td>0 – 0.495</td>
</tr>
<tr>
<td>12</td>
<td>SURLAG</td>
<td>4</td>
<td>0.056 – 9.98</td>
</tr>
<tr>
<td>13</td>
<td>REVAPMN</td>
<td>Default values</td>
<td>0 – 99.43</td>
</tr>
<tr>
<td>14</td>
<td>ESCO</td>
<td>0.1</td>
<td>0 – 0.9951</td>
</tr>
</tbody>
</table>

* Parameter changes are with respect to the calibrated values
Model Calibration and Validation for Streamflow

\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (o_i - m_i)^2} \]

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\[ NSE = \frac{1}{N} \sum_{i=1}^{N} (o_i - m_i)^2 \]

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Correl. Coeff.</td>
<td>0.963</td>
<td>0.961</td>
</tr>
<tr>
<td>RMSE</td>
<td>41.34 (M.cu.m)</td>
<td>18.10 (M.cu.m)</td>
</tr>
<tr>
<td>NMSE</td>
<td>0.074</td>
<td>0.075</td>
</tr>
<tr>
<td>NSE</td>
<td>0.925</td>
<td>0.923</td>
</tr>
</tbody>
</table>

\( o_i \) = Observed data  
\( m_i \) = Model output  
\( N \) = Total number of observations  
\( \sigma_{obs} \) = Standard deviation of the observed data
GWT Depletion in the Basin During the Calibration Period
Summary & Conclusions

- ArcSWAT was used to study the impact of excessive water extraction on the groundwater resources.
- ArcSWAT is clubbed with a water balance model to overcome the limitation on the maximum initial storage in the deep aquifer.
- The model was applied to the Malaprabha catchment in India.
- The model was found to be giving very good estimate of the stream flow.
- The groundwater table simulation shows drastic groundwater table depletion due to the excessive groundwater extraction in the semi-arid parts of the catchment.
- The model is helpful to get a general picture of the groundwater scenario in the area.
Acknowledgement
We acknowledge METI and NASA for providing the ASTER GDEM data used for this study.

Thank you for your attention