Modeling impact of Agricultural Water Management Interventions on Watershed Hydrology and various Ecosystem Services

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Presentation outlines

• Present and future water availability
• Challenges and opportunities
• Need for Agricultural water management interventions

Showing case-studies

• Kothapally watershed, Andhra Pradesh, Southern India
  – Modeling brief
  – AWM Impacts
• Garhkundar watershed, Bundelkhand region, Central India
  – AWM Impacts

• Up-scaling scenario: Osman Sagar catchment
• Conclusions
Annual precipitation on Earth surface = 110,305 Km$^3$ (90,000-120,000 Km$^3$)
Total runoff returning back to Ocean = 38,230 Km$^3$ (34.7 %)
Expected ET from Earth surface = 72,075 Km$^3$ (65.3 %)
Total ET reported (in current figure) = 71,300 Km$^3$

Source: Rockstrom et al., 1999
Type of water resources

- Blue water resource: Water available in rivers, groundwater aquifers and reservoirs

- Green water resource: Water stored as soil moisture
Green water is dominating in global food production compared to blue water.

Source: Rost et al., 2008; Rockstrom et al., 1999
Food demand in 2050 will be doubled than the current requirements
Fresh water requirement in 2050 also will be doubled but...

From where the additional fresh water will come or any alternate source/solutions?
Option-1: Expanding the agricultural land!

*Crop and pasture lands have already crossed its thresholds limits*
1. Climate change
2. Ocean acidification
3. Ozone depletion
4. N cycle
5. P Cycle
6. Fresh water use
7. Land use
8. Biodiversity loss
9. Aerosol loading
10. Chemical pollution
Option-2: Opportunities to expand water resources availability in crop lands!

Example India case

Source: CWC, Government of India
# Groundwater Use Status in India

<table>
<thead>
<tr>
<th>Details</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Agricultural Land</td>
<td>142 Million ha</td>
</tr>
<tr>
<td>Rainfed area</td>
<td>~ 60%</td>
</tr>
<tr>
<td>Irrigated area</td>
<td>~ 40%</td>
</tr>
<tr>
<td>Surface water irrigated area</td>
<td>21 Million ha</td>
</tr>
<tr>
<td>Groundwater irrigated area</td>
<td>27 Million ha</td>
</tr>
<tr>
<td>Total groundwater withdrawal (1960)</td>
<td>25 Km$^3$</td>
</tr>
<tr>
<td>Total groundwater withdrawal (2009)</td>
<td>250-300 Km$^3$</td>
</tr>
<tr>
<td>Number of bore wells (1960)</td>
<td>1 Million</td>
</tr>
<tr>
<td>Number of bore wells (2009)</td>
<td>20 Million</td>
</tr>
</tbody>
</table>

Garg and Wani, 2012
Option-3: Sustainable Intensification, Watershed-based Land Use Planning, Increased Efficiency of Resources

- Land
- Water
- Energy
- Nutrients
- Labor
- Chemicals
Agriculture generally increases provisioning ecosystem services at the expense of regulating and cultural ecosystem services.

**Ecosystem Services**
- **Provisioning:** Crop, Timber, Meat, Mineral, Fish
- **Regulating:** Soil formation, Pollination
- **Supporting:** Erosion control, GW recharge
- **Cultural:** Tourism, Aesthetic

Gordon et al., 2009
Rainfed agriculture: a large untapped potential

- Current farmers’ yields are lower by 2 to 5 folds than the achievable yields
- Vast potential of rainfed agriculture needs to be harnessed

Wani et al., 2012
ICRISAT led consortium developed AWM interventions in Kothapally watershed from 1999 onwards
Agricultural Water Management Interventions

**In-situ intervention**
- Land form treatment (BBF)
- Contour cultivation
- Bunds and field bunding
- Mulching and no-tillage

**Ex-situ Interventions**
- Check dam, farm ponds
- Mini percolation pits
- Gully control structures
- Loose boulders
Field-based soil and water conservation measures (in-situ practices) enhances green water availability

- Contour cultivation
- Broad Bed and Furrow
- Cultivation across the slope
- Border strips
- Field bunds
- Conservation agriculture /min tillage
- Mulching
Ex-situ interventions help in recharging groundwater

How much??
Hydrological components at watershed scale

Rainfall = Surface Runoff + Groundwater recharge + ET + Change in soil moisture storage
Hydrological model SWAT is applied for analyzing impact of AWM interventions

**SWAT Input:**
- Digital Elevation model
- Soil Information
- Land use Information
- Meteorological Information
- Management Information
- Reservoir/Pond Information

**Model Calibration and Validation**

**SWAT Output:**
- Surface runoff
- Groundwater recharge
- Evapotranspiration
- Sediment Transport
- Nutrient Transport
- Soil moisture
- Water, N and P stress
- Crop Growth and yield

Water balance components:
Rainfall = Surface Runoff + Groundwater recharge
ET + Change in soil moisture storage
Monsoonal Water Balance at Kothapally: Jun to Oct

<table>
<thead>
<tr>
<th>Rainfall (mm)</th>
<th>Outflow (mm)</th>
<th>GW Recharge</th>
<th>ET (mm)</th>
<th>Other (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>60 (8%)</td>
<td>120 (16%)</td>
<td>540 (72%)</td>
<td>30 (4%)</td>
</tr>
</tbody>
</table>
AWM interventions reduced surface runoff by 30-60%
Check dam harvested water three to four times than their storage capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Amount of water Captured (m³)</th>
<th>Potential Storage capacity</th>
<th>Ratio to Potential storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>30242</td>
<td>8880</td>
<td>3.4</td>
</tr>
<tr>
<td>2001</td>
<td>18787</td>
<td>9980</td>
<td>1.9</td>
</tr>
<tr>
<td>2002</td>
<td>9768</td>
<td>11230</td>
<td>0.9</td>
</tr>
<tr>
<td>2003</td>
<td>23369</td>
<td>13030</td>
<td>1.8</td>
</tr>
<tr>
<td>2004</td>
<td>33494</td>
<td>13030</td>
<td>2.6</td>
</tr>
<tr>
<td>2005</td>
<td>35955</td>
<td>13030</td>
<td>2.8</td>
</tr>
<tr>
<td>2006</td>
<td>20987</td>
<td>13030</td>
<td>1.6</td>
</tr>
<tr>
<td>2007</td>
<td>41866</td>
<td>13030</td>
<td>3.2</td>
</tr>
<tr>
<td>2008</td>
<td>42531</td>
<td>13030</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Water harvesting potential is higher in *in-situ* practices than *ex-situ* interventions

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Annual Rainfall (mm)</th>
<th>Capacity of the check dams to store water (m³/ha)</th>
<th>Total water harvested by Check dams in one year period (m³/ha)</th>
<th>Total water harvested by Insitu practices in one year period (m³/ha)</th>
<th>Un-Harvested amount (m³/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>650</td>
<td>45</td>
<td>55</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>Normal</td>
<td>870</td>
<td>45</td>
<td>105</td>
<td>350</td>
<td>425</td>
</tr>
<tr>
<td>Wet</td>
<td>1210</td>
<td>45</td>
<td>175</td>
<td>650</td>
<td>1475</td>
</tr>
</tbody>
</table>
AWM interventions enhanced groundwater recharge by 50-80%
GW recharge starts with nearly 250 mm cumulative rainfall in SAT

![Graph showing the relationship between cumulative rainfall (mm) and change in hydraulic head (m).](image)
Groundwater availability in a given year also dependent on previous GW stages

- GW recharge during monsoon
- GW availability in beginning of monsoon

Dry year (following a wet year)

Dry year (following a dry year)

Normal year (following a wet year)

Normal year (following a dry year)
## Water balance in Kothapally watershed
No Int. vs. Max Int.

<table>
<thead>
<tr>
<th>Hydrological Parameters</th>
<th>No Intervention stage</th>
<th>After AWM interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>143 (19 %)</td>
<td>60 (8 %)</td>
</tr>
<tr>
<td>ET (mm)</td>
<td>512 (68 %)</td>
<td>540 (72 %)</td>
</tr>
<tr>
<td>GW recharge (mm)</td>
<td>70 (9 %)</td>
<td>120 (16 %)</td>
</tr>
<tr>
<td>Change in SMC (mm)</td>
<td>25 (3 %)</td>
<td>30 (4 %)</td>
</tr>
</tbody>
</table>
Soil loss reduced by 3 to 5 folds after implementing AWM interventions.
Impact of water management interventions in Garhkundar-Dabar watershed, Bundelkhand region, Central India
Changing rainfall pattern in Jhansi, Bundelkhand, Central India
Hydrological components: Treated vs. non-treated
Cropping intensity in GKD watershed doubled

Singh et al., 2013
Up-scaling AWM interventions

*Scenario analysis for Osman Sagar catchment*
Upstream vs. downstream in Osman Sagar catchment

Upstream land use
Total geographical area (Osman Sagar catchment) = 75000 Ha
  Rainfed area = 42%
  Irrigated area = 8%
  Waste land = 23%
  Non Agriculture use = 23%
  Forest = 4%

Downstream user
Drinking water source for the Hyderabad (~ 8-10 % of domestic water demand of the city)

<table>
<thead>
<tr>
<th>Source</th>
<th>Inflow to OS reservoir</th>
<th>62 MCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses</td>
<td>Domestic use</td>
<td>30 MCM</td>
</tr>
<tr>
<td></td>
<td>Spillover at downstream</td>
<td>12 MCM</td>
</tr>
<tr>
<td></td>
<td>Evaporation</td>
<td>20 MCM</td>
</tr>
</tbody>
</table>
### Impact of AWM interventions

<table>
<thead>
<tr>
<th>Water Year</th>
<th>Parameters</th>
<th>Current stage</th>
<th>No Int.</th>
<th>Insitu</th>
<th>Exsitu</th>
<th>Max Int.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal years</td>
<td>Groundwater recharge (MCM)</td>
<td>96</td>
<td>82</td>
<td>83</td>
<td>104</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Potential irrigated area for growing second crop (km²)</td>
<td>125</td>
<td>100</td>
<td>105</td>
<td>135</td>
<td>128</td>
</tr>
<tr>
<td>Average annual rainfall:</td>
<td>Average yield of monsoon crop (ton/ha)</td>
<td>-</td>
<td>1.4</td>
<td>1.7</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>740 mm</td>
<td>Inflow to Osman Sagar (MCM)</td>
<td>56</td>
<td>73</td>
<td>70</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Total crop production in monsoon period (1000 tons)</td>
<td>-</td>
<td>21</td>
<td>27</td>
<td>25</td>
<td>27</td>
</tr>
<tr>
<td>Spillover releases</td>
<td>Spillover releases downstream to the Musi river (MCM)</td>
<td>1</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Soil Loss (ton/ha)</td>
<td>13</td>
<td>17</td>
<td>16</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Garg et al., 2012
Conclusions

- Rainfed areas have large untapped potential which could be harnessed thru improved land, water and nutrient management practices.
- Watershed management is suitable adaptation and mitigation strategies to address current and future food security issues.
- Micro (field) and meso (watershed) scale monitoring need to be intensified in different agro-ecological regions along with modeling effort for effective resource planning.
Further details of methodology and results, please refer...


Ramesh Singh, Kaushal K Garg, Suhas P Wani, R K Tewari, S K Dhyani (Forthcoming). Impact of water management interventions on hydrology and ecosystem services in Garhkundar-Dabar watershed of Bundelkhand region, Central India. *Journal of Hydrology* 2013
Thank You