Challenges and opportunities for the integrated management of surface and groundwater resources in the Indus basin of Pakistan

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“Water resources management in the Indus basin of Pakistan - challenges and opportunities”
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The Indus basin is a trans-boundary basin consisting of Pakistan (53%), India (33%), China (8%) and Afghanistan (6%)

It is one of the largest irrigation systems of the world. It is experimental laboratory for studying and solving the typical irrigation water related problems

Global warming, trans-boundary conflicts, improved living standards and industrialization is putting more stress which demands strategic planning of these precious water resources
Irrigated Agriculture in Indus Basin

Harrapan civilization 2300 B.C. to 1500 B.C. (Fahlbusch et al., 2004)

During the 2nd millennium, various Mughal emperors constructed limited canal systems to irrigate dry lands along the Ravi, Chenab and Sutlej rivers (Thatte, 2008)

The systematic development of irrigation canals with weir-controlled structures started during British rule in 1850, when the 395 km long Upper Bari Doab canal (UBDC) was constructed.
Indus basin irrigation system of Pakistan “by default” delivers scarce water quantities at all hierarchies.

The objective of the colonial policy was rather to extend the agriculture to all the areas of Indus basin where agriculture can boom.

This would hence keep the rural population engaged in agriculture, avoid conflicts, protect against drought and hence secure the colonial rule (Narain, 2008). Molinga (1998) named this irrigation system as “protective irrigation’ by the British in the Indian sub-continent.
‘Wara’ means turn and ‘Bandi’ means fixation. Thus, warabandi means fixation of turns (Bandaragoda, 1998).

It is a system of water distribution which is designed in a way that every farmer receives a predetermined share of water with respect to the size of his land-holding (Malhotra et al., 1984).

Available quantity of water, whatever it is, is intended to be allocated to farmers in equal proportion to their Culturable Command Area, and not to some of the farmers to meet their total demand.
Colonial rule is over and farmers are out of protective irrigation system mantra.

After the green revolution, rice and sugarcane have emerged as important cash crops (Jurriens et al., 1996)

Farmers were found to respond to this scarcity by engaging in water thefts, tampering the outlets, exchanges in warabandi times, and most importantly supplementing canal irrigation with tubewell irrigation (Narain, 2003)

Around 0.8 million small capacity private tubewells are installed by the farmer to supplement irrigation water supplies (GOP, 2008)
The groundwater is not only providing more than 50% of the total crop water requirements in the Indus basin (Shah, 2007) but has become an integral part of the irrigated agricultural environment in the Indus Basin.
It is often neglected until undesirable effects start to develop. Use of poor quality GW in conjunctive water management in the absence of proper soil-water-crop management strategies is posing great risks to the agriculture production (Minhas and Bajwa, 2009).
Hydrological Modeling for Water Resources
WEAP, developed by the Stockholm Environment Institute, is a tool for water resources planning, which incorporates supply and demand issues in addition to quality and ecosystem preservation, as required by an integrated approach to basin management.

System definition e.g., time frame, spatial boundary, system components

Constitution of ‘current accounts’ snapshot of actual water demand, resources and supplies for the system

Building scenarios based on future trends on hydrology, management strategies

Evaluating the scenarios costs, benefits, and environmental impacts
**Land Use**

**Crops:** Wheat, Rice, Sugarcane, Cotton, Maize

**Soils:** Loam, Clay Loam, Sandy Clay Loam, Clay Loam

**Soil Water Capacity, Maximum Infiltration Rate, Effective Precipitation, Surface Layer Thickness**
Hydrological Modeling

WEAP Model Setup

Climate

Precipitation, Reference Evapotranspiration or Calculate from Climatic Parameters (Min and Max Temp), RH, WS, Solar Radiation (Penman-Monteith Equation)

Irrigation

Irrigation Schedule, Fraction Wetted, Irrigation Efficiency, Losses to GW, Losses to Runoff
Hydrological Modeling

WEAP Model Setup

WEAP Calibration Parameters

- Irrigation scheduling (time, depth)
- Infiltration properties
- Crop coefficients
- Irrigation efficiencies
**Hydrological Modeling**

**SWAT Model** is used to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, river basins.

- Detailed farm management analysis
- Impact soil-water-conservation measures
- Supply analysis
- Physical based
- Public domain and have user friendly interface
SWAT Model is used to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, river basins.

- Evapotranspiration
- Surface flows
- Biomass
- Water quality
- Pollution (point/non-point)
Hydrological Modeling

SWAT Model Setup

DEM
1kmX1km
(http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info)

Land use
1kmX1km
(http://free.vgt.vito.be)

Soil types
FAO digital soil map of the world (FAO, 2008).

Outlet locations

Climatic stations
Hydrological Modeling

SWAT Model Setup

Establish Stream Network

SWAT uses DEM to create streams
Hydrological Modeling

SWAT Model Setup

Establish Sub-basins

SWAT created 132 sub-basins

After sub-basins, HRUs are created

HRUs are unique combination of land use, soil type and slope
Hydrological Modeling

SWAT Model Setup

Land Use

Land Use Classes: 27
Hydrological Modeling

Land Use

SWAT Model Setup

Land use

Look up table

Database (crop.dbf)
Hydrological Modeling

SWAT Model Setup

Soil Types

Soil types: 48
Hydrological Modeling

SWAT Model Setup

Soil Map

Look up table

Database (usersoil.dbf)
Hydrological Modeling

SWAT Model Setup

Establish HRUs

HRU: 2459
Hydrological Modeling

SWAT Model Setup

SWAT Calibration Parameters

- Irrigation scheduling (time, depth)
- Infiltration properties
- Crop coefficient
- Soil water holding capacity
- Root depth
- Flow data
- Groundwater capillary rise (REVAP from shallow aquifer)

There were over 100 runs to calibrate the model
Hydrological Modeling

Results

Irrigation demand = 176 bcm
Canal water supplies = 44 bcm
Ground water supplies = 45 bcm

Irrigation Network Losses (52 bcm) -> Mean Annual Canal Diversion (96 bcm)

Canal Supplies at Farm gate (44 bcm) -> Field Channel Losses (8 bcm)

Irrigation Water at Farm gate (89 bcm) -> Irrigation Water at Field level (81 bcm)

Groundwater Contribution (45 bcm) -> Rainfall (19 bcm)

Water Available for consumptive use (100 bcm)
Average ETp (Indus) = 1667 mm
ETp (Sindh) = 1828 mm
ETp (Punjab) = 1554 mm
Average irrigation (Indus) = 932 mm
Irrigation (Sindh) = 867 mm
Irrigation (Punjab) = 977 mm
REVITALIZING IRRIGATION IN PAKISTAN

Role of groundwater in irrigated agriculture of Pakistan- A GIS and remote sensing approach
Introduction

Study area

Irrigated area: 197,009 ha
No. of Distributaries: 17
Climate: Semi - arid
Precipitation: 250 mm yr\(^{-1}\)
Evapotranspiration (ETc): 1300 mm yr\(^{-1}\)
Withdrawals 1 to 1.5 km\(^3\)
One cannot manage what one does not measure is an old adage that is valid today for groundwater management in Pakistan.

Lack of groundwater management institutions, undefined groundwater management policy and no priority to regulate groundwater abstraction has already questioned sustainability of groundwater use in Pakistan.

Moreover there is no information available on groundwater abstraction at a high spatial resolution.
Methods

- Water available at head of distributaries (canal water) – gross Irrigation
- Water available at root-zone (canal water) – net irrigation
- Water available at root-zone (groundwater) – IGWnet

Daily inflow data from PMIU

After losses in irrigation network and farmer’s fields (36 %) (Hussain et al. (2011))

Using GIS and remote sensing techniques
Methods

Groundwater use IGWnet

\[ \text{IGWnet} = \text{Actual Evapotranspiration} - \text{Net Irrigation} - \text{Rainfall} \]


\[ \text{IGWgross} = \text{IGWnet} / \text{Irrigation efficiency} \]


Irrigation efficiency = 63 %

Hussain et al. (2011)
Methods

Actual evapotranspiration (ETa)

The Surface Energy Balance Algorithm for Land (SEBAL; Bastiaanssen, 1995) was selected for modeling ETa.

Overview over the satellite overpasses selected for modeling ETa using SEBAL

<table>
<thead>
<tr>
<th>Data set</th>
<th>Layer</th>
<th>Spatial Resolution</th>
<th>Temporal resolution</th>
<th>Linear interpol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD11L2</td>
<td>Land surface temperature and emissivity</td>
<td>1 km</td>
<td>overpass</td>
<td>No</td>
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<tr>
<td>MOD13A2</td>
<td>Vegetation Indices</td>
<td>1 km</td>
<td>16day</td>
<td>Yes</td>
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<td>MOD15A2</td>
<td>LAI</td>
<td>1 km</td>
<td>8day</td>
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<td>MOD09Q1</td>
<td>Surface Reflectance</td>
<td>250 m</td>
<td>8day</td>
<td>Yes</td>
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</table>
**Methods**

**Land use land cover classification**

- **MODIS NDVI 250mX250m**
- From TERRA and AQUA
- Temporal resolution is 8 days

[https://lpdaac.usgs.gov/get_data/data_pool](https://lpdaac.usgs.gov/get_data/data_pool)

Total 273 images were downloaded
Results

Actual evapotranspiration (ETa) - Results

Apr 2006-07

ETa
High : 115 mm
Low : 12 mm

0 3 6 12 18 24 Kilometers

N

Water for a food-secure world
www.iwmi.org
### Results

#### Actual evapotranspiration (ETa)

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<td>Wheat-Cotton</td>
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<td>45</td>
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<td>2</td>
<td>Wheat-Rice</td>
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<td>9</td>
<td>7</td>
<td>7</td>
<td>10</td>
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<td>3</td>
<td>Wheat-Fodder</td>
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<td>21</td>
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<td>18</td>
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<td>4</td>
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<td>28</td>
<td>29</td>
<td>29</td>
<td>26</td>
<td>25</td>
</tr>
</tbody>
</table>

**Land use land cover classification (%):**

- **Desert**: \(\text{ETa}\%\)
- **Fodder-Fodder**: \(\text{ETa}\%\)
- **Olive/Date-Fall**: \(\text{ETa}\%\)
- **Wheat-Cotton**: \(\text{ETa}\%\)
- **Wheat-Fodder**: \(\text{ETa}\%\)
- **Wheat-Rice**: \(\text{ETa}\%\)
Results

Average ETc for Kharif season = 5.1 mm/day
Average Irrigation Depth for Kharif season = 2.2 mm/day

Average ETc for Rabi season = 2.6 mm/day
Average Irrigation Depth for Rabi season = 1.6 mm/day
## Results

### Water accounting

<table>
<thead>
<tr>
<th>Name</th>
<th>GrossID (mm)</th>
<th>NetID (mm)</th>
<th>RF (mm)</th>
<th>ETa (mm)</th>
<th>GWnet (mm)</th>
<th>GWgross (mm)</th>
<th>ETp (mm)</th>
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</thead>
<tbody>
<tr>
<td>Direct WC</td>
<td>858</td>
<td>309</td>
<td>227</td>
<td>689</td>
<td>153</td>
<td>225</td>
<td>1313</td>
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<tr>
<td>Bakhushah</td>
<td>688</td>
<td>248</td>
<td>227</td>
<td>690</td>
<td>215</td>
<td>316</td>
<td>1313</td>
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<tr>
<td>1L_Disty</td>
<td>657</td>
<td>237</td>
<td>227</td>
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<tr>
<td>4R_Disty</td>
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<td>5R_Disty</td>
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<td>7R_Disty</td>
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<td>8R_Disty</td>
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<tr>
<td>9R_Disty</td>
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<td>227</td>
<td>535</td>
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<tr>
<td>Hakra_left</td>
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<td>227</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>649</strong></td>
<td><strong>234</strong></td>
<td><strong>227</strong></td>
<td><strong>676</strong></td>
<td><strong>215</strong></td>
<td><strong>317</strong></td>
<td><strong>1313</strong></td>
</tr>
</tbody>
</table>

**Water accounting**

- **Rainfall, 33%**
- **Irrigation, 35%**
- **Groundwater, 32%**
Annual net irrigation for Hakra canal command area is only 215 mm

Farmers located at head of distributaries get more share as compare to middle and tail
Results

Groundwater use IGWnet

Annual net groundwater use for Hakra canal command area is only 234 mm

Farmers located at head of distributaries use more share as compare to middle and tail
Conclusions and Recommendations

Surface water supplies are not sufficient to meet the crop water requirement even if field application efficiency is increased near to 100%.

Groundwater contribution is significant but still it is not able to meet the potential evapotranspiration.

Water scarcity moves along the canal reach. Farmers at the head of canal commands receive more canal water as compare to farmers at the tail end reaches.
Thank You