Linking Climate to Water Security: Case Studies from the Western Desert of Egypt and the Ganges Delta Region of Bangladesh

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Introduction

- Effects of climate change
  - Temperature
  - ET
  - Rainfall
  - Sea level

- Water demand is increasing
  - Population
  - More food
  - Industrial growth

Threat to Freshwater availability

Affects societal growth

Water Stress
Two Regions with Different Climatic Conditions

- Arid climate in Siwa Oasis, Egypt (Western Desert region of Egypt)

- Monsoon sub-tropical climate in Ganges Delta of Bangladesh
Effects of Climate Change in Siwa Oasis
Siwa Oasis, Western Desert, Egypt

- Located in northwest of Egypt with an area of 1,200 km²
- Elevation from 0 to -25 m from MSL
- Agriculture is primary activity with olives and date palms as cash crops
- Only source of water is non-renewable Nubian Sandstone Aquifer System (NSAS)
- Absence of groundwater management since 1960 caused excess water use
- Six salty lakes formed (73 km² in 2000)
Cross-Sectional View of NSAS in Siwa

- **Lower Salinity** (300-700 ppm)
- **Moderate Salinity** (< 3,000 ppm)
- **Higher Salinity** (5,000-8,000)
- **Lower Salinity** (300-700 ppm)

- **Post Nubian Aquifer (PNA)**
- **Aquitard**
- **Nubian aquifer System (NAS)**

- **Shallow wells**
- **Deep wells**

- **Springs**

- **Land Surface Elevation (-18 m AMSL)**

- **Land Surface Elevation (-1000 m AMSL)**
Problems in Siwa Oasis

- Increased salinity in groundwater from Nubian Sandstone Aquifer together with excess crop water use
- Decreased revenue
Water balance in Siwa (MCM/year)

- Total withdrawal (MCM/year)
- Crop water irrigation MCM/year
- Total water use (MCM/year)
- Domestic use MCM/year

Excess water use

<table>
<thead>
<tr>
<th>Year</th>
<th>Total withdrawal</th>
<th>Crop water irrigation</th>
<th>Total water use</th>
<th>Domestic use</th>
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<td>1960</td>
<td>69.4</td>
<td>18.1</td>
<td>235</td>
<td>42.3</td>
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<td>1990</td>
<td>67.8</td>
<td>291</td>
<td>308.14</td>
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<td>291</td>
<td>89.3</td>
</tr>
</tbody>
</table>
Egyptian Government Initiative (2016): Reclaim 1.5 Million Acres in the Western Desert

- Attract people from over-populated areas
- Cultivate strategic crops to address food security concerns
- Cultivate economic crops for export as source of income
- Increase investment and job opportunities
- 30,000 acres to be cultivated in Siwa with best management practices
Questions

- What is the irrigation water demand in Siwa under climate change?
- Is this amount sustainable based on water availability in the non-renewable Nubian Aquifer System?
Cultivated Crops

Cash Crops
- Olives – 20%
- Date Palms – 20%

Food Security
Alternate crops – 60%

Summer
Maize and vegetables

Winter
Wheat, Barely, Bean, Onion, and vegetables
Crop Water Irrigation

Crop water demand with leaching allowance to minimize salinity

\[ IR = \frac{ET_c - R}{(1 - LR) \times E} \]

IR - irrigation requirement (mm/day)

\( ET_c \) - crop evapotranspiration (mm/day)

R - effective rainfall (mm/day)

LR - leaching requirement

E - irrigation efficiency
Data

• Monthly meteorological data from Coordinated Regional Climate Downscaling Experiment (CORDEX)

• Four models to project water use from 2020 to 2100

• Two emission scenarios; RCP 4.5 and RCP 8.5
<table>
<thead>
<tr>
<th>Institute</th>
<th>Regional Climate Model (RCM)</th>
<th>Global Climate Model (GCM)</th>
<th>Model</th>
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<tbody>
<tr>
<td>Swedish Meteorological and Hydrological Institute (SMHI)</td>
<td>Rossby Centre regional climate model (RCA4)</td>
<td>Centre National de Recherches Météorologiques (CNRM-CM5)</td>
<td>155 km</td>
</tr>
<tr>
<td>Koninklijk Netherlands Meteorological Institute (KNMI)</td>
<td>Regional Atmospheric Climate Model (RACMO22T)</td>
<td>EC-EARTH consortium (EC-EARTH)</td>
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<td>210 km</td>
</tr>
</tbody>
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Downloaded models for RCP 4.5 and RCP 8.5

http://www.cordex.org/
Monthly average ETo between historical and observed data (1981-2005)
Results

Annual water use (RCP 4.5)

Water use (m³/acre)

Year:
- 2020
- 2040
- 2060
- 2080
- 2100

Water use values:
- M1: 4117, 4278, 4206, 4244, 4386
- M2: 4048, 3937, 3705, 3868, 3647
- M3: 3589, 3678, 3536, 3614, 3647
- M4: 3736, 3937, 3868, 3937, 4158

Legend:
- M1
- M2
- M3
- M4
Annual water use (RCP 8.5)
Model Weighted Results

- Crop water use is around 4000 m$^3$/acre/yr by 2100 - RCP 4.5
- RCP 8.5 shows crop water use increasing to about 4700 m$^3$/acre/yr by 2100
Key Findings

• Crop water use from RCP 4.5 scenario shows sustainability with groundwater from the Nubian aquifer

• However, crop water use from RCP 8.5 scenario can affect non-renewable water from Nubian Aquifer increasing water scarcity in this region

• Given the uncertainty, some measures to reduce greenhouse gas emissions is warranted in the region to minimize potential climate change impacts
Effects of Climate Variability in the Ganges Delta of Bangladesh
Experiences water related challenges e.g., drought, flood, cyclones, water logging, river erosion, tidal actions

Limitations in quantity, quality, and timing of available water

Evaluate freshwater scarcity: lower end of Ganges Delta of Bangladesh
- Area ~42,000 km²
- Population 32.8 million

Major part of largest Mangrove ecosystem

Source: Farakka barrage: The Sunday Indian, Feb 17, 2012
Sundarbans: https://pritulmahmud.wordpress.com
Floods and Droughts

Source: Kyle Knight/IRIN

The Daily Star, August 2009

Key Question: How is climate variability affecting freshwater scarcity?
Key Variables

- Rainfall, temperature, ET (Bangladesh Meteorological Department)
- Actual ET => Complimentary relationship model
- Pre-barrage period (1949-1974)
Mean Annual ET

Change in ET volume from pre-barrage period

Significant increase in ET

- Mean Dry Season ET Volume
- Mean Wet Season ET Volume

Climate Pattern

Spatial variation of rainfall

Wet season

Dry season

Wet: June – Oct
Dry: Nov-May

Temporal variation of rainfall, temperature and ET

Highlighted years

Dry season rainfall (Nov-May)

Wet season rainfall (June-Oct)

Dry season ET (Nov-May)

Wet season ET (June-Oct)

Dry season temperature

W

D

Pre-barrage period (before 1975)

Post-barrage period (after 1975)

Period 1: Post-barrage with treaties and agreements (1975-1988)


Rainfall and Temperature

Increasing of Extreme temperature

Intensifying droughts and floods

Percentage of Stations

-110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100

Summer days>30°C Monthly min of daily T min Heating degree Days Cooling Degree days Monthly min of daily Tmax Monthly max of daily Tmin Consecutive dry days Consecutive wet days

Increase Significant Increase Decrease Significant Decrease

Increasing of Extreme temperature
Impact of Farakka Barrage on Stream Flows

Flow duration curve
High flow threshed -20%
Low flow threshed -70%

Dry season flow reduced 58%
Serious concerns in the period without a treaty
Dry season flow reduced 97%

Not much impact of rainfall and temperature changes on Ganges and Gorai River flows.
Key Findings

- Upper range of temperatures => increasing
- Significant increase of HDDheat and CDDcold => more energy is required to heat and cool the environment
- Increase of overall temperature, along with extreme values => serious influence on increasing ET
- Actual ET in the recent past shows about 110% volume increase compared to the pre-barrage period
- Study area => towards warmer climate => profound impact on surface water availability
Key Findings

- Longer consecutive dry and wet periods => affecting crop production
- Longer successive wet periods => reduce drainage capacity and produce floods
- Mean rainfall intensity is decreasing
- High rainfall intensity of short duration is increasing

Water-logged conditions due to limited drainage time.
Conclusions

Siwa Oasis, Egypt

- High economic activity and growth can increase greenhouse gases and can affect groundwater sustainability
- Moderate to slow economic growth needs to be promoted for sustainable supply of groundwater

Ganges Delta of Bangladesh

- Heading towards warmer climate => affecting water security
- Extreme temperature and rainfalls => increasing
- Vulnerable to droughts and floods