Impacts of Climate Change on Coastal Aquifers in Northern Oman

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Outline

• Brief Overview of Literature
• Groundwater Models Jamma and SLC aquifers
• Climate Change Scenarios
• Results and Discussion
• Conclusions
Literature Review (Case studies)

- The level of negative impacts (changing of recharge patterns and sea level rise - SLR) depends on the level of stress the aquifer is experiencing. Shallow coastal aquifer are at greatest risk (Danielopol et al., 2003; Holman, 2006; Kumar, 2012; and Werner at al., 2013).

- Sherif and Singh (1999) investigated climate change effect on seawater intrusion coastal aquifers (Nile Delta aquifer in Egypt and Madras aquifer in India). The results show that a 0.5 m rise in the Mediterranean Sea level will cause additional intrusion of 9.0 km in the Nile Delta aquifer, but only 0.4 km in the Bay of Bengal (Madras aquifer). [the impact is site specific and depends on the level of development that the aquifer experiences]

- Carneiro et al. (2010) simulated effects of SLR and changes in recharge to the quantity and quality of groundwater on a coastal Saïdia aquifer in Morocco under three IPCC scenarios up to year 2099. They found that the freshwater volume reduced by 50 - 60 % with respect to the base condition, due to the decline in recharge (decrease in recharge).
Literature Review (Case studies)

- A study by Ferguson and Gleeson (2012) found that coastal aquifers are more vulnerable to groundwater extraction than to predicted SLR under different cases of hydrogeologic conditions and population densities. Only aquifers with very low hydraulic gradients (seaward direction) are more vulnerable to SLR.

- Reviewing the literature shows that the effect of climate change on groundwater resources is a site specific based on geological and hydrological settings along with the level of development of the aquifer.
Jamma Aquifer and Samail Lower Catchement

- Located on southeast Batinah-coast of Oman, about 50 km west of Muscat.
- Coastal plain part of Wadi Al Fara catchment (A = 295 km²)
- Heavy abstraction, consequently seawater intrusion since early 1980.

Projected Coordinate System:
WGS 1984 UMT Zone 40N
Projection: Transverse Mercator
Central Meridian: 57.00
Latitude of Origin: 0.0
Source: Landsat
Jamma: Model Set-up

- Two layers, $\Delta x, \Delta y = 30$ m.
- 952 rows and 610 columns.
- The total number of active cells = 655,390 cells.

(a) Boundary conditions
(b) Location of abstraction wells
(c) Hydraulic conductivity zones
(d) Location of observation wells

- The model performs well regardless the limitation of data availability.
- ME = -0.04 m, MAE = 0.9 m, and the model efficiency (NSE) is 0.96.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (m/d)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKL1Z1</td>
<td>35</td>
<td>Hydraulic conductivity of Zone 1 in Layer 1</td>
</tr>
<tr>
<td>HKL1Z2</td>
<td>8</td>
<td>Hydraulic conductivity of Zone 2 in Layer 1</td>
</tr>
<tr>
<td>HKL2Z1</td>
<td>20</td>
<td>Hydraulic conductivity of Zone 1 in Layer 2</td>
</tr>
<tr>
<td>HKL2Z2</td>
<td>0.3</td>
<td>Hydraulic conductivity of Zone 2 in Layer 2</td>
</tr>
<tr>
<td>Rech</td>
<td>1.80247E-06</td>
<td>Recharge from precipitation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water balance</th>
<th>In</th>
<th>Out</th>
<th>In - Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³/day</td>
<td>%</td>
<td>m³/day</td>
</tr>
<tr>
<td>Inflow from sea</td>
<td>171,702</td>
<td>68.3</td>
<td>0</td>
</tr>
<tr>
<td>inflow from south</td>
<td>79,288</td>
<td>31.5</td>
<td>0</td>
</tr>
<tr>
<td>Pumping wells</td>
<td>0</td>
<td>0</td>
<td>243,695</td>
</tr>
<tr>
<td>ET</td>
<td>0</td>
<td>0</td>
<td>7,829</td>
</tr>
<tr>
<td>Recharge</td>
<td>534</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>251,524</td>
<td>100</td>
<td>251,524</td>
</tr>
</tbody>
</table>
## Jamma: Climate change and SLR data

<table>
<thead>
<tr>
<th></th>
<th>ET0</th>
<th>Precipitation</th>
<th>SLR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2050</td>
<td>2070</td>
<td>2050</td>
</tr>
<tr>
<td></td>
<td>mm/day</td>
<td>mm/year</td>
<td>m</td>
</tr>
<tr>
<td>RCP2.6</td>
<td>7.15</td>
<td>7.15</td>
<td>81</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>7.34</td>
<td>7.33</td>
<td>76</td>
</tr>
<tr>
<td>RCP6.0</td>
<td>7.50</td>
<td>7.57</td>
<td>81</td>
</tr>
<tr>
<td>RCP8.5</td>
<td>7.85</td>
<td>7.92</td>
<td>93</td>
</tr>
</tbody>
</table>

**Note:** The evapotranspiration, precipitation and Sea level values of the current case are 4.5 mm/day, 60 mm/year and 0.0 m respectively.
Jamma: Saline water inflow into the aquifer

2050

2070

Change in inflow from the sea

Sealevel rise

Change in inflow from the sea (m³/d)

Sealevel rise (m)
Jamma: Intruded distance and salinized land area considering the 1500 ppm iso-concentric line (RCP8.5)

Deterioration is happening faster over the first 15 years.
Jamma: Salinity maps for Jamma aquifer considering RCP8.5 (2070)
Jamma: Water table contour maps for the current case and RCPs for 2050 and 2070
Consequences on the Farming Activities

Figure 31: Agricultural area in Feddans overlying the aquifer according to the salinity of groundwater

Figure 32: Agricultural area percentage wise overlying the aquifer according to the salinity of groundwater
Consequences on the Farming Activities, Cont’d

<table>
<thead>
<tr>
<th>Salt Concentration in the groundwater in g/L</th>
<th>Gross Profit OR/Feddan</th>
<th>Cropped area in Feddans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Croppe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d area</td>
</tr>
<tr>
<td>freshwater</td>
<td>1089</td>
<td>1,388</td>
</tr>
<tr>
<td>low salinity</td>
<td>803</td>
<td>164</td>
</tr>
<tr>
<td>moderate salinity</td>
<td>468</td>
<td>159</td>
</tr>
<tr>
<td>high salinity</td>
<td>431</td>
<td>292</td>
</tr>
<tr>
<td>very high salinity</td>
<td>0</td>
<td>592</td>
</tr>
<tr>
<td>Total area in Feddan</td>
<td></td>
<td>2,595</td>
</tr>
</tbody>
</table>

- Gross profit/feddan is **1089 OR/feddan** on average for a farm accessing groundwater with salinity lower than 1.5 g/L.
- Gross Profit goes down to **431 OR/feddan** if the groundwater salinity is comprised between 5 and 10 g/L.
- Beyond 10 g/L there is no possibility to grow food crops and gross profit is then nil (OSS, 2012).
Samail Lower Catchment Aquifer

- Located in Al-Seeb area.
- Covers an area of 59 km².
- Sensitivity analysis & calibration - PEST (32 piezometers).
- Calibrated results:
  - Correlation coefficient (R²) = 0.99
  - MAE = 0.63 m
  - RMSE = 0.70 m

Projected coordinate System:
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Source: Landsat
Samail: Model Set-up

Boundary conditions
- Constant Head
- GHB

Recharge zones
- Rech1
- Rech2
- Rech3
- Rech4
- Rech5
- Rech6
- Rech7
- Rech8

Pumping wells
- Water supply wells
- Irrigation wells

HK - Zone1
HK - Zone2

Observation wells
Samail Lower Catchment

No Flow

GHB

Constant Head

28-30 March, 2017
Al-Maktoumi-Gulf Water Conference - Manama
Samail: Water balance, simulated heads for base case, RCPs for the Samail Aquifer

<table>
<thead>
<tr>
<th>Water balance</th>
<th>In</th>
<th>Out</th>
<th>In - Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³/day</td>
<td>%</td>
<td>m³/day</td>
</tr>
<tr>
<td>Constant head</td>
<td>413</td>
<td>1</td>
<td>12,833</td>
</tr>
<tr>
<td>Pumping wells</td>
<td>0</td>
<td>0</td>
<td>21,343</td>
</tr>
<tr>
<td>ET</td>
<td>0</td>
<td>0</td>
<td>9,067</td>
</tr>
<tr>
<td>GHB</td>
<td>886</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Recharge</td>
<td>41,944</td>
<td>97</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>43,243</td>
<td>100</td>
<td>43,243</td>
</tr>
</tbody>
</table>

ET = 5 mm/day
Precipitation = 80 mm/year
Sea level values = 0

Note: Base case (2015):
Samail: Inflow across coastal boundary, hydraulic head contour maps

- Change in precipitation is small
- Effect of pristine groundwater flow
Conclusions

- The extent of the effect of climate change on groundwater aquifer is site specific. Stressed aquifers are highly vulnerable and severely affected. A need to categorize the aquifers in different groups to plan the mitigation tasks accordingly.

- The impact of the climate change is happening at rapid rate during the first few years which necessitate that mitigation actions have to be implemented as early as possible. Otherwise, late implementation will be less effective in mitigating the depleted resources and deteriorated quality which will definitely affects the farming community in large along with other purposes.

- Sea level rise found to be the main factor that significantly affects the coastal groundwater resources. This is because the change in rainfall rate as per the RCPs scenarios for north of Oman is small and the effect of ET is also low because of high extinction depth.

- Although, the aquifer systems that maintains a positive hydraulic gradient seaward direction (like SLC in this study) is not severely affected by the climate change, but improper development and management of those systems would definitely shift them to be more vulnerable to be adversely effected by climate change.
Acknowledgement

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