Groundwater from space for the Mashreq region

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Motivation

- Study of hydrology is important for science and society
- Traditional hydrological studies using models and ground observations are limited in space and time
- Satellite sensors can cover large areas and over long periods of time
- This is specifically true for groundwater that has limited in-situ monitoring
Study Area – Mashreq region

Countries
1 Bahrain
2 Egypt
3 Iraq
4 Jordan
5 Kuwait
6 Lebanon
7 Oman
8 Palestine
9 Qatar
10 Saudi Arabia
11 Sudan
12 Syria
13 UAE
14 Yemen

Large River Basins
1 Tigris–Euphrates
2 Nile

Mashreq region includes 14 countries with roughly 7 million km²

sources: https://www.hydrosheds.org/
GRACE (Gravity and Climate Experiment)

• Launched in March of 2002 - characterize variations in Earth’s gravity.

• GRACE applications in water resources
  – Changes on runoff and groundwater on land masses.
  – Exchanges between ice sheets or glaciers and the ocean.

• Products
  – GRACE: 2002-2017
  – GRACE follow-on: 2018 - present
Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow On

Conventional based remote sensing cannot sense water below the centimeters of

GRACE 2002-2017

GRACE-FO 2018

Launched 22 May 2018

GRACE and GRACE Follow On are unique in their ability to monitor water at all levels, down to the deepest aquifer

Source: Matt Rodell, NASA
Changes in Terrestrial Water Storage Anomalies (TWSA) for Mashreq region

Changes in TWSA for the time period between April 2002 and June 2017
Terrestrial Water Storage Anomalies seem to increase (become more negative) over Mashreq region (decreasing water storages)

Estimate change: -3.18 cm/year
Northeastern Mashreq region (Jordan, Iraq, Syria, and Lebanon) experienced very high rate of negative changes in TWS.

Kuwait, Saudi Arabia, and Qatar also have high rate of negative TWS.
Compared with TWSA of Nile (-1.02 cm/year), TWSA of Tigris-Euphrates River basin is significant reduction with a rate of -8.22 cm/year.
• Lower precipitation initiates a requirement to withdraw water from aquifers
• This results in an aquifer loss that is much greater than recharge and this accumulates
• The surface water deficit is quantified by drought indices – dependent on precipitation
• Increase in population and agricultural activities increase withdrawal during drought periods
Relationship between natural climate variability and TWSA – Case study of Tigris-Euphrates

Meteorological drought (SPEI Standardized Precipitation Evapotranspiration Index) over Tigris-Euphrates from 1985-2020 at three scales (SPEI24, SPEI48, and SPEI60).

Significant reduction in TWSA is associated with natural drought. However, human activities may accelerate this process after 2015 (wetness increases but TWSA still low).

Note 1: The drought datasets are derived from the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS)

Note 2: for a comparison between TWSA and drought index, TWSA is standardized
Since Tigris-Euphrates is a transboundary river, changes in water resources may caused by upstream countries.

Comparison between drought duration and drought severity for Qadisiyah River basin during 2015-18. The drought conditions inside Iraq and outside Iraq (upstream countries) are significantly different (SPI). In Iraq, there is a wet period but not for upstream basin.
Hydrological Simulation using Soil Water Assessment Tool

**SWAT Input**
- Precipitation
- Temperature
- Wind Speed
- Solar Radiation
- Relative Humidity
- Land Use
- Soil
- Topography

**Spatial-Temporal Analysis**

**SWAT**

**SWAT Output**
- Runoff/Soil erosion/Water quality for HRU
  - Daily
- Runoff/Soil erosion/Water quality for Subwatershed
  - Monthly
- Runoff/Soil erosion/Water quality for Reach segment
  - Yearly
### Table 1 Calibration parameters

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>SWAT default value</th>
<th>Final Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>r__CN2.mgt</td>
<td>(-0.4 - 0.4)</td>
<td>-0.05</td>
<td>SCS runoff curve number factor</td>
</tr>
<tr>
<td>r__SOL_AWC(..).sol</td>
<td>(-0.3 - 0.3)</td>
<td>0.1</td>
<td>Available water capacity of the soil layer</td>
</tr>
<tr>
<td>r__ESCO.hru</td>
<td>0.1 - 0.95</td>
<td>0.3</td>
<td>Soil evaporation compensation factor</td>
</tr>
<tr>
<td>r__RCHRG_DP.gw</td>
<td>0.0 - 0.9</td>
<td>0.1</td>
<td>Deep aquifer percolation fraction</td>
</tr>
<tr>
<td>r__ALPHA_BF.gw</td>
<td>0.05 - 0.5</td>
<td>0.2</td>
<td>Baseflow alpha factor (days)</td>
</tr>
<tr>
<td>r__SURLAG.bsn</td>
<td>0 - 10</td>
<td>0.2</td>
<td>Surface runoff lag time</td>
</tr>
<tr>
<td>v__GWQMN.gw</td>
<td>0 - 2500</td>
<td>940</td>
<td>Threshold depth of water in the shallow aquifer required for return flow to occur (mm)</td>
</tr>
<tr>
<td>v__GW_REVAP.gw</td>
<td>0.05 - 0.5</td>
<td>0.1</td>
<td>Groundwater &quot;revap&quot; coefficient</td>
</tr>
<tr>
<td>v__GW_DELAY.gw</td>
<td>25 - 350</td>
<td>125.7</td>
<td>Groundwater delay (days).</td>
</tr>
<tr>
<td>r__SOL_K(..).sol</td>
<td>(-0.2 - 0.2)</td>
<td>-0.1</td>
<td>Saturated hydraulic conductivity.</td>
</tr>
<tr>
<td>v__SMTMP.bsn</td>
<td>(-2 - 2)</td>
<td>0.01</td>
<td>Snow melt base temperature.</td>
</tr>
<tr>
<td>v__CH_K2.rte</td>
<td>0 - 100</td>
<td>24</td>
<td>Effective hydraulic conductivity in main channel alluvium.</td>
</tr>
<tr>
<td>v__CH_K1.sub</td>
<td>10 - 150</td>
<td>103.7</td>
<td>Effective hydraulic conductivity in tributary channel alluvium</td>
</tr>
<tr>
<td>v__CH_N1.sub</td>
<td>0 - 0.3</td>
<td>0.01</td>
<td>Manning's &quot;n&quot; value for the tributary channels.</td>
</tr>
<tr>
<td>v__SFTMP.bsn</td>
<td>(-5 - 5)</td>
<td>0.7</td>
<td>Snowfall temperature (°C)</td>
</tr>
<tr>
<td>v__SMTMP.bsn</td>
<td>(-5 - 5)</td>
<td>4.5</td>
<td>Snow melt base temperature.</td>
</tr>
<tr>
<td>v__SMFMX.bsn</td>
<td>0 - 10</td>
<td>4.0</td>
<td>Maximum melt rate for snow during year (occurs on summer solstice)</td>
</tr>
<tr>
<td>v__SMFMN.bsn</td>
<td>0 - 10</td>
<td>0.1</td>
<td>Minimum melt rate for snow during the year (occurs on winter solstice)</td>
</tr>
<tr>
<td>v__TIMP.bsn</td>
<td>0 - 1</td>
<td>0.8</td>
<td>Snow pack temperature lag factor.</td>
</tr>
<tr>
<td>v__SNOCOVMX.bsn</td>
<td>0 - 500</td>
<td>50.0</td>
<td>Minimum snow water content that corresponds to 100% snow cover</td>
</tr>
<tr>
<td>v__SNO50COV.bsn</td>
<td>0 - 1</td>
<td>0.1</td>
<td>Snow water equivalent that corresponds to 50% snow cover</td>
</tr>
</tbody>
</table>

Note: v_ means the existing parameter value is to be replaced by a given value, and r_ means an existing parameter value is multiplied by (1 + a given value). (..) means for different soil layers or months.

Parameters for the Soil Water Assessment Tool model

**Inputs**  
Discharge from in-situ sites from Ministry of water resources  
Rainfall  
Ministry of Water Resources of Iraq  
Other meteorological inputs are model derived by the SWAT community  
The period 1934-1979 was chosen as the period before dam construction in the region.
Map of Digital elevation model (DEM) for the Tigris River Basin

Land cover/use of the Tigris River Basin

SWAT-DEM delineated subbasins of the Tigris River Basin

Modeling of the Tigris River Basin using Soil Water Assessment Tool
Modeling of the Tigris River Basin using Soil Water Assessment Tool

Calibration and Validation for Almosul from 1934-1979, The Tigris River Basin

R²cal = 0.82 & NS = 0.79
R²val = 0.77 & NS = 0.72

Discharge (m³/sec)

Calibration

Validation

Months

95PPU  observed  Best_Sim
Modeling of the Tigris River Basin using Soil Water Assessment Tool

Calibration and Validation for Baghdad from 1934-1979, The Tigris River Basin

Calibration

Validation

R$^2_{cal}$=0.78 & NS=0.77
R$^2_{val}$=0.75 & NS=0.73

Discharge (m$^3$/sec)

Months

Calibration

Validation

95PPU observed Best_Sim
Conclusions

• Satellite-based datasets could provide unique opportunities to assess changes in groundwater resources at large scale.

• Mashreq region is an excellent example for applications of satellite-related products and models as in-situ data is scarce.
Thank you