Monitoring Groundwater Storage Changes From Gravity Recovery and Climate Experiment (GRACE) satellites

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Tuesday 15th May 2018
Training School on Ground Penetrating Radar
Rome, Italy
Dr. Mohammad Shamsudduha ("Shams") is a Research Fellow at UCL Institute for Risk and Disaster Reduction (IRDR) and the Project Manager of a UK Government-funded international consortium project, GroFutures (Groundwater Futures in Sub-Saharan Africa).

Shams has a Ph.D. in Hydrogeology from UCL Department of Geography and joined IRDR in March 2012 where he has been working on a number of research projects largely on issues around ‘water risks’ across the world. Over an extended academic career, Shams has received training and degrees from various universities around the world (Australia, Bangladesh, UK and USA). Shams has more than 12 years of experience in conducting research, largely collaborative and interdisciplinary in nature, with universities, research institutes, government departments, and non-governmental organisations. Shams has co-developed a decade long, successful research partnership with organisations in Bangladesh. Under GroFutures, Shams is expanding his research arena within the Sub-Saharan Africa that includes Ethiopia, Tanzania, Niger and Nigeria. Additionally, Shams has published over 28 research articles in peer-reviewed, international journals, and is currently serving as an Associate Editor for the journal of Climate Risk Management.
Shams research interests revolve around ‘water risks’ at local to global scales. Shams’ specific research interests include:

- **Risks of water and food insecurity**: resilience of terrestrial water resources to sustain irrigated agriculture and fresh drinking-water supplies in South Asia and Sub-Saharan Africa.
- **Risk to public health and food-grain production**: associated with chronic exposure to toxic metals (e.g. Arsenic) in untreated groundwater-fed water supplies in Asian Mega-Deltas.
- **Impacts of changes in global climate and land-use**: on groundwater replenishment and risks of rising sea levels, and more frequent and extensive flooding on livelihoods of dwellers in low-lying deltas in South and Southeast Asia.
Training School on Ground Penetrating Radar for civil engineering and cultural heritage management

Roma, Italy, May 14-18, 2018

Tuesday, 15 May 2018

➤ Use of GPR and complementary geophysical techniques in civil engineering (with a main focus on roads, bridges and groundwater resource monitoring)

| 14:00 - 15:30 | M. Shamsudduha | Groundwater resource monitoring using complementary geophysical techniques. Examples of data analysis and interpretation. |
Monitoring Groundwater Storage Changes From Gravity Recovery and Climate Experiment (GRACE) satellites
Background: Distribution of water on Earth

- Oceans: 96.5%
- Saline groundwater: 0.93%
- Saline lakes: 0.07%
- Freshwater: 2.5%
- Surface water and other freshwater: 1.3%
- Groundwater: 30.1%
- Glaciers and ice caps: 68.6%
- Lakes: 20.1%
- Ice and snow: 73.1%

Background: Distribution of water on Earth

**Distribution of aquifers on Earth**

Background: Global Use of Groundwater

**Agricultural water supply**

**Domestic water supply**

**Industrial water supply**

**Groundwater:** 1/3rd of all global freshwater withdrawal

Background: Groundwater Use in Bangladesh

Groundwater provides 98% of Bangladesh’s drinking water supplies.

There are 10-12 million tubewells in Bangladesh.

A typical hand-operated tubewell (No.6) in Bangladesh
Groundwater provides 80% of the irrigation water supplies in Bangladesh

How secure is the groundwater storage?

Is groundwater abstraction in balance with recharge?

Total no of shallow irrigation wells: 1.2 million (2006-07)

Boro rice field in northwest Bangladesh is being irrigated with groundwater
Groundwater has an important role in the environment: it replenishes streams, rivers, and wetlands and helps to support wildlife habitat; it is used as primary source of drinking water and also in agricultural and industrial activities.

Groundwater is the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers.

http://www.groundwater.org/
Groundwater monitoring involves in situ, satellite and airborne observations and laboratory analysis of quality variables. A groundwater monitoring programme includes both groundwater quantity (e.g. groundwater level) and quality monitoring networks.

www.fao.org/gtos/doc/ecvs/t03/t03-groundwater-report-v05.doc

Groundwater-level recording in Tanzania

Groundwater-level monitoring by UCL’s Groundwater Penetrating Radar technology (Source: Lai Bun Lok)

Groundwater storage changes by GRACE
“The first thing I tackled in the 1970s was the task of computing the orbits of satellites very accurately to support satellite altimetry missions. We reached the point that we could compute orbits that had an accuracy of a few centimeters” – Byron Tapley

Tapley’s computations hit a glitch that he couldn’t fix. He observed that the satellite orbits varied seasonally!

• these subtle shifts in Earth’s gravity occur primarily due to movement of water mass from one place to another on and under land, in the ocean, and in the atmosphere

• only satellite could measure these subtle, tiny shifts accurately enough to map Earth’s gravity in fine detail

The GRACE mission was led by B. Tapley (PI) of the University of Texas at Austin (USA) and Frank Flechtner (Co-PI) of the German Research Centre for Geosciences (GFZ)
GRACE, twin satellites launched in March 2002, are making detailed measurements of Earth’s gravity field which will lead to discoveries about gravity and Earth’s natural systems. These discoveries could have far-reaching benefits to society and the world’s population.

- Monthly gravity anomaly maps generated by GRACE are 1000 times more accurate than previous gravity maps.
During each 90-minute orbit, the distance between the GRACE satellites varies by about 2 kilometers (1.2 miles). Instruments aboard the satellites measure the separation to a precision of one micrometer (NASA graph by Robert Simmon and Kevin Ward, using GRACE data from the JPL Physical Oceanography DAAC).
Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE from April 2002 to March 2016

GRACE observes changes in water storage caused by natural variability, climate change and human activities such as groundwater pumping

Rodell et al. (2018)
\[ \Delta TWS = \Delta ISS + \Delta SWS + \Delta SMS + \Delta GWS \]

- Fluid mass changes represent total terrestrial water storage changes (\(\Delta TWS\)) after removing atmospheric mass variations and ocean tides.

\[ \Delta GWS = \Delta TWS - [\Delta ISS + \Delta SWS + \Delta SMS] \]

- How good is the estimation of GRACE-derived \(\Delta GWS\)?

Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin

M. Shamsudduha,¹ R. G. Taylor,¹ and L. Longuevergne²

Received 1 June 2011; revised 20 October 2011; accepted 5 January 2012; published 10 February 2012.

Water Res. Resour.
One of the largest sedimentary basins in the world

Area: \(~300,000\) km\(^2\)

Subtropical monsoon climate - highly dynamic hydrological system
Dense network of surface water and groundwater monitoring stations
Datasets used in the study of $\Delta$GWS in the Bengal Basin:

- $\Delta$GWS & $\Delta$SWS constrained by observations at 236 & 298 monitoring stations
- $\Delta$SMS constrained by simulated soil moisture from LSMs: CLM, NOAH, VIC

Background picture shows irrigation of Boro rice in Bangladesh

Shamsudduha et al. (2012)
Groundwater Storage in the Bengal Basin

\[ \Delta GWS = \Delta TWS - (\Delta SWS + \Delta SMS + \Delta ISS) \]

<table>
<thead>
<tr>
<th>Observed</th>
<th>GRACE</th>
<th>Observed</th>
<th>LSMs (GLDAS)</th>
<th>Nil</th>
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Graph showing seasonal storage anomaly (cm) and monthly rainfall (mm) over the months from January to December.
Validation of GRACE-derived $\Delta GWS$

**GRACE data:** CSR and GRGS

**SMS data:** NOAH, VIC, CLM

**SWS data:** observational

**GWS data:** observational

**An updated analysis:**

**Bengal Basin GWS anomaly**

- GRACE ensemble GWS
- Borehole–GWS $[Sy=0.10]$
Groundwater Storage in the Bengal Basin

An updated analysis:

Bengal Basin (Bangladesh)

- GRACE-TWS
- Simulated SMS
- Simulated SWS
- GRACE-GWS
- Precipitation

Graph showing time series data for different parameters with trend lines.
Groundwater is the largest store of freshwater (~30%) on Earth; surface water storage represents ~1%

Groundwater sustains drinking, irrigation and industrial water supplies in many countries around the world

Monitoring of groundwater storage and quality is critical to sustainable resource development (i.e. water & food security)

Groundwater-level or storage change can be measured by various techniques including spaceborne GRACE satellites (basin scale) and GRP techniques (local scale)

Without monitoring impacts of human use and climate change on groundwater would be challenging to assess

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