GRACE Anomalies to Assess Groundwater Sustainability in Maharashtra, India.

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GRACE MISSION



The GRACE mission will have two identical spacecrafts flying about 220 kilometers apart in a polar orbit 500 kilometers above the Earth.



GRACE will be able to map the Earth's gravity fields by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system.



It will provide scientists from all over the world with an efficient and costeffective way to map the Earth's gravity fields with unprecedented accuracy.



The results from this mission will yield crucial information about the distribution and flow of mass within the Earth and it's surroundings.







GRACE TWS Anomalies

• GRACE monitor changes in gravity

- Changes in gravity are attributed to changes in terrestrial water storage (TWS)
- NASA provides
 - monthly TWS data at approximate resolution of 1 by 1 degree.
 - the anomaly data for each month
- •The anomaly is the difference between raw value and a baseline value for a pixel.
- The baseline value is the average value for a period Jan 2004 to Dec 2009.
- If anomaly of Jan 2011 is +5 cm, then the pixel value is 5 cm above the baseline.
- •The difference between two temporal pixels (e.g. between Jan 2011 and Jan 2012) will provide the change during the time interval.
- Peak Anomalies can inform sustainability of groundwater
- Low anomalies can inform adequacy of groundwater

Using GRACE Anomalies to determine Sustainable use of Groundwater?

- **1**. Estimate Groundwater Anomalies from TWS Anomalies
- 2. Identify highest GW anomaly for in a year
 - In Indian states, it's post-monsoon. In Maharashtra, its October or November.
 - Note that
 - In some years it was in October and in others it was in November. This is due to delays in Monsoon.
 - In some years, the maximum anomaly was negative indicating a dry year.
- 3. Then regress peak-anomalies, and test if the slope is statistically different to zero
 - If insignificant, then the aquifer is 'always' recovering during post monsoon. The groundwater use is sustainable
 - If rising positive slope and significant, it reflects a wet rainfall sequence or wide annual rainfall variability
 - If negative groundwater use is unsustainable. There's a need for MAR and/or better groundwater consumption pattern.
- 4. Sustainability does not imply groundwater adequacy



Regions of Maharashtra

Rainfall Variability 2002-2016

High rainfall in Konkan & Goa, probably skews State's statistics.

Except for Konkan & Goa, other regions receive less rainfall than the State.

Average rainfall is low in Marathwada, but the coefficient of variation is high

Variation in Vidarbha is also higher than that of the State

To minimize the impact of high variation local storage and demand management are essential in these two regions.

	Max	Min	Average	SD	CV
Maharashtra					
State	1411	876	1138	185	0.16
Konkan & Goa	3842	2192	3149	525	0.17
Madhya					
Maharashtra	1181	630	878	166	0.19
Marathwada	1039	533	724	169	0.23
Vidarbha	1520	796	1080	229	0.21

Peak Anomalies

Vidarbha recorded both extremes of peak anomalies, resulting highest CV.

In Vidarbha, and Konkan, the peak anomaly was less than the baseline value in 2004 and in 2015 respectively.

Peak Anomalies were recorded as follows:

- Maharashtra Nov 2008
- Konkan Oct 2007
- Madhya Maharashtra Oct 2013
- Marathwada Nov 2016
- Vidarbha Nov 2016

	Max	Min	Average	SD	CV
Maharashtra State	20.8	3.3	11.1	5.4	0.49
Konkan	14.5	-1.1	8.6	4.6	0.53
MadhyaMaha	18.9	5.0	11.9	4.4	0.37
Marthwada	20.2	3.4	11.2	5.5	0.49
Vidarbha	27.6	-3.9	10.7	9.3	0.87

Low Anomalies

In Vidarbha, despite the average is minimum, the CV is the highest.

On the average, depletion of groundwater in other regions are approximately the same, except in Vidarbha

It is likely, that the aquifers in Vidarbha has the poorest storage capacity.

Low Anomalies were recorded as follows:

- Maharashtra June 2004
- Konkan June 2007
- Madhya Maharashtra June 2007
- Marathwada May 2016
- Vidarbha Jul 2009

Onset of groundwater scarcity will be earlier in Marathwada than in other regions.

	Max	Min	Average	SD	CV
Maharashtra State	-0.4	-14.1	-10.2	4.3	-0.42
Konkan	-2.2	-20.7	-12.5	5.8	-0.47
Madhya					
Maharashtra	-0.6	-18.7	-11.3	5.2	-0.46
Marthwada	-1.3	-14.3	-10.7	4.0	-0.37
/idarbha	3.7	-15.6	-7.8	7.0	-0.89

Storage Capacity of Aquifers (cm)

By subtracting the max peak anomaly from minimum low anomaly recorded, minimum possible aquifer storage can be estimated.

Among the regions, Vidarbha shows maximum possible storage.

	Max
Maharashtra State	34.8
Konkan	35.2
Madhya Maharashtra	37.6
Marthwada	34.5
Vidarbha	43.2

Maharashtra Groundwater Behavior



Konkan



Annual low and peak anomalies are not changing significantly.

Groundwater use is sustainable.

✓ Noting the negative anomaly in 2015, it may be interpreted that Konkan aquifers, despite being in a high rainfall region, may not recover fully every year.

Peak anomalies are significantly correlated with rainfall

Low anomalies are not correlated with previous monsoon.

 Withdrawals are independent of groundwater stored during monsoon

Madhya Maharashtra



Marathwada



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Vidarbha



Conclusions

✓ Sustainability

- ✓ Sustainable use is not the same as adequate water for agriculture.
- ✓ Groundwater withdrawals in the region are independent of water stored during previous monsoon
- ✓ At the State level, there's increase in groundwater storage following monsoon.
- ✓ Among the regions, Vidarbha shows an increase in post-monsoon storage.
- ✓ None of the regions show a decline in storage.
- ✓ Groundwater extracted is replaced during monsoon.
- ✓ Therefore as a resource, groundwater is used sustainably in Maharashtra and regions.
- Improving adequacy and reliability of groundwater
 - ✓ The onset of groundwater scarcity may be in May.
 - ✓ Groundwater levels are fully recovered by October/November
 - ✓ The coefficient of variation of rainfall is high in Marathwada and Vidarbha.
 - ✓ Vidarbha has higher capacity to store water than the others. MAR may be promoted in this region.
 - ✓ Onset of groundwater scarcity will be earlier in Marathwada than in other regions.