Critical analysis of hydrological mass variations of northwest India

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Abstract. With current climate change, water availability is a huge concern. Ground-water (GW) is depleting at a steep rate globally and more specifically in Northwest India. Estimation and analysis of GW availability would be of great use for formulating a proper water management plan for the future. The study is carried out in the north-western part of India with the aim of generating a time series for total water storage (TWS) using different remote sensing and model-based data like GRACE, Landsat, MODIS. From the time series, it is clear-cut that, the TWS is showing a declining trend and this might be due to depletion of groundwater as, other variables like precipitation, evapotranspiration, soil moisture (obtained from MERRA-2 and CFSR data) are not showing any negative trend during the study period (2002 - 2021). Also, from the change detection analysis of land use land cover maps and crop yield statistics of water-intensive crops it can be concluded that croplands in the study area are increasing denoting the usage of water for irrigation at a large scale. Thus, better management of the groundwater is required for avoiding severe water scarcity in the future.

Keywords: GRACE, TWS, ground water, change detection, crop yield

1. Introduction
Groundwater is an essential resource for agricultural, industrial, and domestic water use and it’s a primary source of freshwater [1]–[4]. GRACE (Gravity Recovery and Climate Experiment) data has played a key role in understanding the TWS, which integrates different compartments of water storage like surface water, soil moisture, and groundwater. Many studies have been carried out on GRACE to understand the status of groundwater [5]–[9], drought [10], urban groundwater variability [11] and solid earth [12]. Ahmed et al., (2021) has demonstrated the impact of anthropogenic activities on groundwater in Morocco and the need for taking sustainable measures. The major economy of India is from the agriculture industry and the production of water-intensive crops like paddy, wheat, cotton, sugarcane, has been suggested as one of the major reasons for groundwater depletion in the country, specifically north-western states [14]. Water intensive crops can cause a great impact on the rivers by reducing their run-off from the catchment and drawing large amount of groundwater resources (WWF, 2007)[15], [16]. Different climatic variables also influence TWS like, temperature, evapotranspiration rate, and precipitation. Another factor is population density, as it will exert stress on the available
water resources in an area [17]. The study aims to analyse the behaviour and the Spatio-temporal trend of TWS from 2002 to 2021.

2. Study Area
The study area (figure 1) lies between 22°N to 30°N and 72°E to 84°E, covering the north western part of India (Rajasthan, Haryana, Punjab, Uttar Pradesh and Delhi). The region receives an average rainfall of 700mm annually and has rivers like Yamuna, Chambal, Son, etc., The groundwater in the region is withdrawn continuously for the purpose of irrigation exceeding the recharge rate [1], [2] which leads to depletion of groundwater in the region.

![Study Area Map](image)

**Figure 1.** Study Area Map

3. Data and Methodology

3.1. Data
GRACE dataset (JPL GRACE Mascon solution) acquired for the study period (April 2002 to September 2021) has gridded monthly global water storage/height anomalies at 0.5-degree resolution. The crop yield data was obtained from National informatics centre’s (NIC) area productive statistics report, and the land use land cover (LULC) acquired from decadal and MODIS’ (Moderate resolution Imaging Spectroradiometer) MCD12Q1 products respectively. Other variables like temperature, evapotranspiration, precipitation, and soil moisture are analysed for the region with the help of MERRA-2 (Modern Era-Retrospective Analysis for Research and Analysis) Reanalysis data (temperature – evapotranspiration) and CFS (Climate Forecast System) Reanalysis data (precipitation – soil moisture) in climate engine. The resolution of MERRA-2 and CFS datasets are 0.5x0.625 degrees and 0.2 degrees respectively.
3.2. Methodology
The methodology (figure - 2) adopted for this study is as follows, GRACE data had gaps which were filled with the estimated seasonality and trend after which, the time series and spatial trend were analysed. LULC change detection analysis was carried out for the years 1985 – 2005; 2002 – 2021 with the decadal LULC map and MODIS MCD12Q1 products respectively. More importance was given to the features which got converted to croplands and built up. Then, the crop yield trend was derived from statistical analysis of the water-intensive crops (cotton, rice, sugarcane, and wheat) of the study area. Other variables such as temperature, evapotranspiration, soil moisture and precipitation were analysed in the climate engine research app.

![Methodology Flowchart](image)

**Figure 2. Methodology Flowchart**

4. Results
The time series plot of GRACE data (figure 3a) clearly shows a declining trend in the TWS of the region, it is around +1cm in 2002 and significantly drops to -2 cm in 2021. The Spatio-temporal trend (figure 3b) of the TWS data depicts the strong drop in the parts of Rajasthan and Punjab. From the change detection analysis (figure 4) carried out for the year 2002 and 2021, the increase of croplands especially in the parts of Rajasthan can be witnessed which could be a reason for the negative trend of TWS as groundwater is extracted at a large scale for crop production. During 1985 – 2005, 66% barren lands, 21% scrublands, 9% waterbodies and 2% forest have been converted into croplands. Whereas, during the study period (2002 - 2021), 56% scrublands and 42% grasslands have been converted to croplands. Also, the crop yield data explicitly shows a rise in the water – intensive crops in the study area which is another crucial reason for groundwater depletion.

![GRACE Time series](image)

![Spatio-temporal trend of TWS](image)

**Figure 3.** (a) GRACE Time series, (b) Spatio-temporal trend of TWS in the study area
Figure 4. Change Detection Analysis (a) LULC Change detection map (1985 - 2005) (b) LULC Change detection map (2002 - 2021) (c) Graph showing the change of LULC (1985 - 2005) (d) Graph showing the change of LULC (2002 - 2021)

Figure 5. Annual Crop yield Trend in North-western states of India (a) Cotton (b) Rice (c) Wheat (d) Sugarcane
5. Discussion

GW depletion in north-western India has been exceeded over 150 percent, especially in the major crop-producing states like Haryana, Punjab, Rajasthan, and Uttar Pradesh as the groundwater abstraction is far more than its recharging pattern [18]. The annual crop yield trend for the period 2002-2018 in the north-western part of India (Haryana, Punjab, Uttar Pradesh and Rajasthan and Delhi) has been demonstrated and the statistics show a positive trend for four water intensive crops, cotton (figure 5a), rice (figure 5b), wheat (figure 5c) and sugarcane (figure 5d). The cotton yield in three states is increasing and Punjab stands the highest with 4.273 bare/ha of crop for the year 2018 while Rajasthan is showing a continuous growth and Uttar Pradesh has a decreasing trend and yield of 0.477 bare/hectare in 2018. The rice production is increasing in all the parts and the yield is highest in Punjab with 4.313 t/ha and lowest in Uttar Pradesh with 2.687 t/ha. In the case of wheat and sugarcane production, Rajasthan and Haryana stand at top with an annual yield of 6.639 t/ha and 86.62 t/ha respectively. Also, the other influencing factors of TWS such as, temperature, precipitation, evapotranspiration are not showing a negative trend (figure 6), denoting the decrease of GW as the reason for declining trend in TWS from GRACE. This study provides an outline of the declining trend in the GW availability of the region and future studies can be done using in situ GW data which will explicitly show the depletion of GW in the area.
6. Conclusion
In all the crop yield plots, it is obvious that the crop production in north-western part of India is gradually increasing resulting in a growing trend of croplands (water-intensive crops) which is evident in the LULC maps also. Thus, it can be concluded that the declining trend of TWS, is due to over-exploitation of groundwater in the region for the purpose of irrigation. On the other hand, population is shooting up and demands are escalating for food, land and water resources which urges for a better management of natural resources in order to lead a sustainable living.

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