A Comparative Assessment of Ground Water Resources using GRACE and Ground Data in Highly Populated Regions of Haryana, India

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Abstract

Ground water sustainability is a key component of the water resource management which further includes timely recharge and sustainable extraction of water from the aquifer. Whereas, with the excessive usage of groundwater in the densely populated areas, the availability of surface water and aquifer systems face a potent threat of reduction in level. In the current study, an assessment of ground water storage (GWS) is conducted for whole Haryana between 2010 to 2020. Further the study was deepened down to do a comparative assessment between two contrasting districts of the Haryana state in India (i.e. Faridabad, highly industrial and urbanized and Yamunanagar with mostly open and less urbanized) to identify the significant factor influencing the depletion. A decadal change is observed to attain the said goal using different datasets including gravity recovery and climate experiment (GRACE), rain fall (RF), and tube well-based ground data. The GRACE data is pre-processed before the analysis for enhanced results. The outcome is probed in two sets emphasizing on both (i) seasonal change (pre-monsoon, monsoon, post monsoon) for each year and (ii) change in each season for successive years. It was noted that Faridabad being more populated and industrialized than Yamunanagar undergo a greater reduction in ground water level. GWS data indicates that the Faridabad region experiences a more notable drop, with a rate of -4.73 ± 0.19 cm/year compared to Yamunanagar at a rate of -1.89 ± 0.57 cm/year. Another finding indicates a relatively higher depletion for the seasonal change for each year than seasonal change of a year. It signifies that urbanization contributes more to the declining of the groundwater in lieu of the meteorological effect. With the decrease in ground water level at an alarming rate if the concerned issues are neglected and no necessary mitigation plans are implemented, the state may face an issue of severe ground water shortage to a point where recovery is no longer possible in near future.

Key words Satellite, Water Depletion, GRACE, groundwater, Haryana.

Introduction

Groundwater, a constantly changing system, is located beneath the Earth surface (Adeleke, et al., 2015). Groundwater is influenced by various factors including land use land cover pattern, land use change pattern, soil properties, meteorological events, population demands for water, groundwater utilization pattern and groundwater recharge (Kumar, 1997; Adeleke, et al., 2015; Chowdhury and Paul, 2020). Among these controlling elements affecting groundwater's situation and fluctuations, recharge stands out as a crucial parameter that demands comprehensive assessment for groundwater resource management (Kumar, 1997). Frequent failure of monsoon, uneven rainfall distribution, and overexploitation of groundwater are gradually causing groundwater depletion in many parts of India (Chowdhury and Paul, 2020).

There has been an increase in demand for groundwater in the last few decades due to the rapid growth of population, increased industrialization, and agricultural intensification leading to imbalance in which the recharge rate of groundwater is very low to consumption rate of groundwater (Sathiyamoorthy et al., 2023). This results in groundwater depletion at a very faster pace which leads to water scarcity as the time progresses.

Remote sensing provides a wide-range of observations at different scales related to water resources in the space-time distribution mode (Hsin-Fu et al., 2008). Satellite-based Land Surface Models allow direct monitoring of regional variations in stored water leading to more precise estimation of groundwater resources. Determination of terrestrial water storage change is now possible by integrated study of GRACE (Gravity Recovery and Climate Experiment) and Global Land Data Assimilation System (GLDAS) (Rodell et al., 2007).

It has been observed that GRACE-based storage changes are in agreement with those obtained from GLDAS simulations. Rodell et al. (2007) used GLDAS outputs (soil moisture and snow water equivalent) as auxiliary information to isolate groundwater storage anomalies from GRACE Total Water Storage (TWS). Regional studies related to ground water depletion using GRACE data has been reported in various part of the Globe (Rodell et al., 2007; Rodell et al., 2009; Chen et al., 2014; Chen et al., 2016; Chatterjee et al., 2020; Singh et al., 2023) however, local studies comparing GWS of two contrasting locations in Haryana (i.e. Faridabad dominated by industrialization, urbanization and high population demand for water, and Yamunanagar dominated by open area, less industrial setups, mostly rural anatomy, and less population demand for water) is not available. Again, the ground-based observations have rarely been compared with GRACE observations for these two locations.

In the current study, an assessment of ground water storage (GWS) is conducted for whole Haryana between 2010 to 2020. Further the study was deepened down to do a comparative assessment between two contrasting districts of the Haryana state in India (i.e. Faridabad, highly industrial and urbanized and Yamunanagar with mostly open and less urbanized) to identify the significant factor influencing the depletion. A decadal change from 2010 to 2011 is observed to estimate the Ground water Storage anomalies using different datasets including GRACE, rain fall (RF), and tubewell-based ground water level data. The outcome is examined in two sets emphasizing on both i) seasonal change (pre-monsoon, monsoon, post monsoon) for each year and (ii) change in each season for successive years.

Materials and Methods

Study Area: Haryana is an Indian state located between 74° 29’-77 ° 35’ E longitude and 27°39’ -30°35’ N latitude that is northern part of the country with area of 44,212 Sq Km. The census of 2011 shows that Haryana has a population of about 2,53,51,462.

Haryana has four main geographical features which are Yamuna-Ghaggar Plains, Lower Shivalik Hills to the northeast in foothills of Himalayan. The Bagar region semi-desert dry sandy plain in North West of Haryana, Hisar. The Aravali Range's northernmost low rise isolated non-continuous outcrops in the south. The fertile Ghaggar Plain, a segment of the

Indo-Gangetic Plain, occupies most of the state's territory. Haryana experiences primarily three seasons; the winter (October–February), summer (March–June) and the monsoon season (July–September). Haryana is hot in summer at around 45 °C (113 °F) and mild in winter. It witnesses the highest temperatures in May and June, and lowest in December and January. The climate is arid to semi-arid with an average rainfall of 354.5 mm (Singh et al., 2022). Around 29% of rainfall is received during the months from July to September as a result of the monsoon, and the rest of the rainfall occurs between December and February, primarily due to the western disturbance as per Dept. of Agriculture, Haryana.

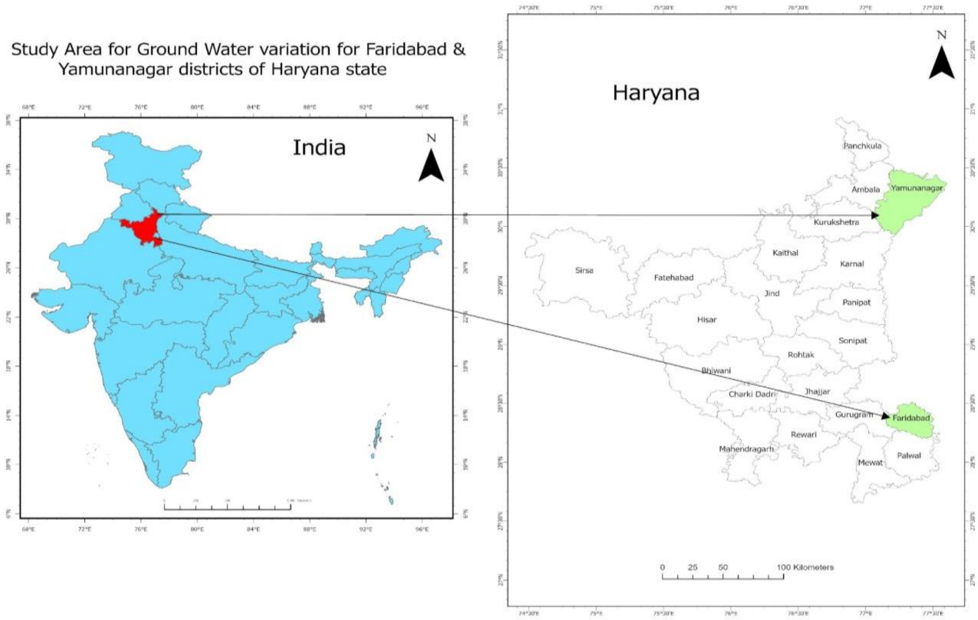

Fig. 1 Map of India showing the location of the state Haryana and inset figure shows the study region for Faridabad and Yamunanagar districts of Haryana.

Faridabad is the most populous city in the Indian state of Haryana and a part of Delhi National Capital Region. It is located between 28°21’-28°21’N latitude 77°20’-77°29’E longitude. The river Yamuna forms the eastern district boundary with Haryana which is the prominent geographical characteristic of the region. Faridabad has a borderline hot semi-arid climate just short of a dry-winter humid subtropical climate. The city features the three typical Indian seasons - The "hot" or pre-monsoon season lasts from late March to late June and is typified by sweltering and arid conditions that begin very dry but latterly turn humid. The "wet" or monsoon season is sweltering and often dangerously humid with frequent but erratic heavy rainfall. Following the retreat of the monsoon is the "cool" or winter season with warm and sunny weather producing by far the most comfortable conditions. As per 2011 census, Faridabad district counted population of 18,09,733, whereas the population reached 23,04,024 in 2021 census leading to population growth rate over the decade 2011–2021 was 27.31%. This gives it a ranking of 266th in India (out of a total of 640).

Yamunanagar is an Indian state of Haryana and located between 30°17N - 30°12N latitude and 77°27E - 77°12E longitude. The Yamuna River flows through the district of Yamunanagar. The district also distinguishes the Yamuna system from the Satluj river system. The Yamuna River flows into the district from its northeastern edge, entering through a narrow passage in the Siwaliks. It is a perennial river. The district also gets occasional winter rains from cyclones. Rainfall is predominantly associated with the rainy season. The district has Shivalik hills and foot hill rolling plain in the north and north- east, and flood – plain along the Yamuna River in the east and south- east. The important rivers/ streams of the district are Yamuna, Sarasvati, Chautang, Rakshi, Somb, Boli, etc. Average Rainfall of Monsoon – 891 mm. The most rainfall is recorded in Chhachhrauli and Bilaspur tehsils in Haryana. They are known as "The Cherapunjjis of Haryana". The Loo wind usually prevails from May to June. Fog is common in December, January and February. As per 2011 census, Yamunanagar district counted population of 12,14,205, whereas the population reached 13,44,524 in 2021 census leading to population growth rate over the decade 2011–2021 was 10.73%. This gives it a ranking of 266th in India (out of a total of 640).

Datasets and Methodology: In the current study, a decadal change in groundwater conditions/storage (2011 to 2020) is observed for the two districts of Haryana (Yamunanagar and Faridabad). To attain the said goal different datasets are used including gravity recovery and climate experiment (GRACE), Soil Moisture Content (GLDAS), rain fall (RF), and tube well-based ground data. The GRACE data is made available by three centers: (i) Center for Space Research at University of Texas, Austin (CSR) (ii) Jet Propulsion Laboratory at California Institute of Technology and (iii) Deutsch's Geo Forschungszentrum (GFZ). The monthly data for our research area is obtained from CSR consisting of spherical harmonics Clm and Slm which are used in the derivation of gravity anomalies of a region. The multidimensional data is available in the NetCDF format and can be downloaded from the mentioned URL; https://www2.csr.utexas.edu/grace/RL06_mascons.html whereas, Global Land Data Assimilation System (URL; https://ldas.gsfc.nasa.gov/gldas) is used to obtain the other significant modelled parameters like precipitation and soil moisture content for the estimation of Ground water Storage variations. The methodology followed for the estimation of change in groundwater storage is as shown in Figure 2.

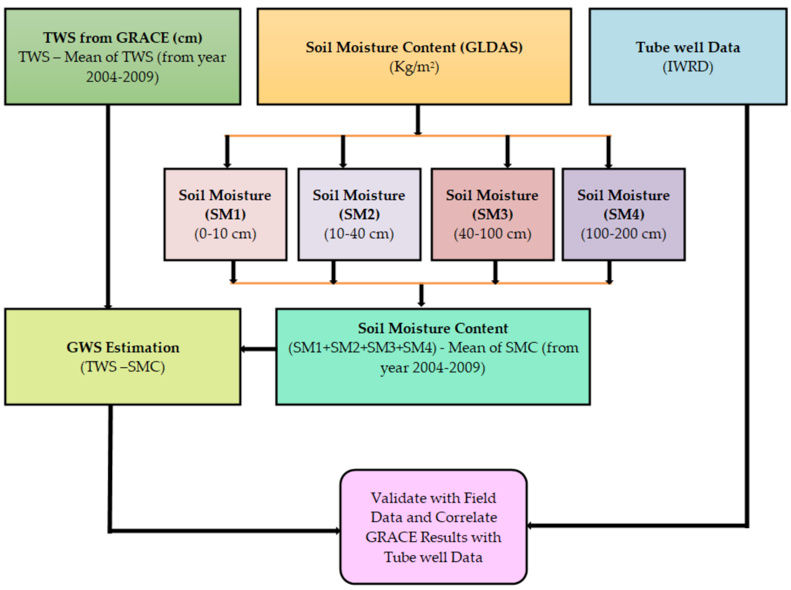

Fig. 2 Flowchart showing methodology for the estimation of Ground water storage change.

The GRACE data available is pre-processed; decorrelation filtering (Swenson and Wahr, 2006) and Gaussian smoothening at 300km (Jekeli, 1981) is done for enhanced results. The Terrestrial Water Storage anomalies are obtained by subtracting the TWS of each month from the mean of TWS (January 2004 to December 2009). Likewise, the Soil Moisture anomalies are calculated by subtracting the SMC (GLDAS) from the mean of SMC (January 2004 to December 2009). Further, the soil moisture is subtracted from the TWS (Rodell et al.2007) to evaluate the GWS as mentioned in the Eq. 1.

$$\Delta GWS = \Delta TWSGRACE - \Delta SMGLDAS \quad \text{Eq. 1}$$

The outcome is probed in two sets emphasizing on both (i) seasonal change (pre-monsoon, monsoon, post monsoon) for each year and (ii) change in each season for successive years.

Results

Analysis of GRACE data and Observations: The study was done for the time period of 2010-2020 for Faridabad and Yamunanagar districts of Haryana state. Rain fall (RF) data, GRACE-derived TWS, soil moisture content (SMC) and estimated GWS data and trend of GWS change for Yamunanagar (Figure 4) and Faridabad (Figure 5) regions have been analyzed. The Figure 4 shows the variation of ground water storage over the years calculated using GRACE data. Overall, Haryana's groundwater levels are decreasing, but Faridabad experiences a more substantial depletion rate in comparison to Yamunanagar (Figure 4). By examining the work done, it was found that the depletion rate of Faridabad district is much more than Yamunanagar district of Haryana owing to more urbanization in the district as supported by the greater population growth rate for the former district which is 27.31%.

Lesser ground water usage has been seen in the time period of 2010 to 2011 in comparison to the upcoming years. After a detailed yearly analysis of data with respect to seasonal variations, indicated that GWS in Yamunanagar varies from -22cm to -6cm in the time duration 2010-2011. However, it has been noted that there is a variation of between -36 cm and -25 cm for Faridabad during the same duration. Further, a drastic change of -37 cm is seen for Faridabad in the last years of our research i.e. 2019-2020 whereas a minute change is recorded for Yamunanagar. GWS data indicates that the Faridabad region experiences a more notable drop, with a rate of -4.7.3 ± 0.19 cm/year compared to Yamunanagar at a rate of -1.89 ± 0.57 cm/year.

Ultimately, the study region of Faridabad reveals a more significant Ground Water Storage (GWS) depletion in contrast to Yamunanagar, further providing validation for the results shown in Figure 4. In figures 5 and 6 it is seen that higher rainfall is received in Yamunanagar than Faridabad. Thereby, in Yamunanagar there is lesser depletion but also more replenishment of ground water. Whereas, along with more extraction of ground water in Faridabad due to urbanization there is lesser rainfall so there is more depletion. But the state of Haryana received close to the normal annual rainfall throughout the study period from 2010 to 2020 therefore the decline is less affected climatologically. Rather it is highly dependent on the increased population and urbanization.

It is well supported with the statistics mentioned in Table 1 depicting inflation in the built-up area of 7.96 sq.km. and 2.27 sq.km. for Faridabad and Yamunanagar respectively.

Similarly, an increase of 172.5 sq.km. of built-up land is majorly responsible for the depletion of Ground Water Storage in Haryana state. Therefore, the results obtained suggest that the more likely cause of ground water depletion is the unsustainable ground water abstraction for irrigation and other anthropogenic uses. The Ground Water Storage is declining at an alarming rate in Faridabad considering a decrease of 61.7 percent over the decade of 2010-2020. Moreover, it was also observed that Haryana underwent a decrement by 71.36 percent over the decade of 2010-2020. Also, it has been examined that the values of Ground Water Storage (GWS) derived using GRACE data and the wells sample data collected from ground have in common for Yamunanagar district (Figure 7), whereas for Faridabad district (Figure 8) it is totally varied. This can be understood from the fact that there were only few samples of ground sample data and which were also not throughout the districts and hence leading to so much of variations for Faridabad district particularly.

Table 1. Year wise Change in Built Up Area (Sq. km) for the districts Faridabad and Haryana.

District	Year 2017	Year 2020	Change in Area
Yamunanagar	116.27	118.55	2.27
Faridabad	188.1	196.06	7.96

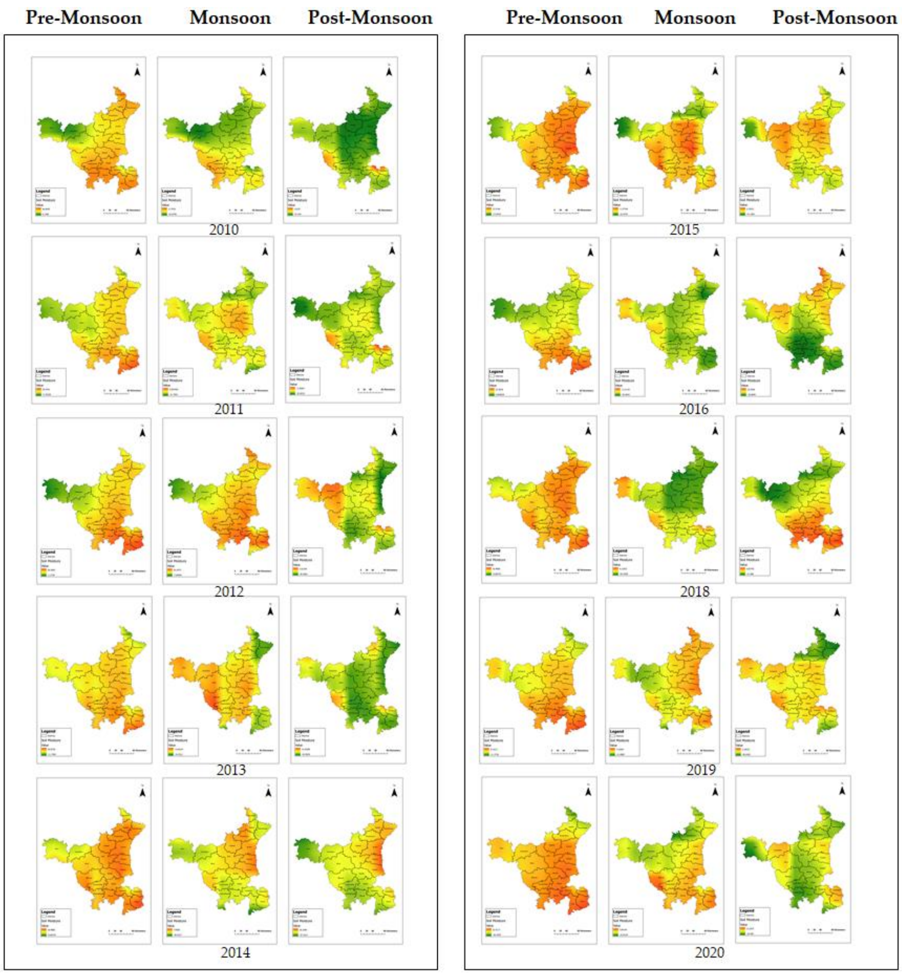

Fig. 3 Monthly GLDAS soil moisture content, year wise anomalies from the period of 2010 to 2020 in Yamunanagar and Faridabad districts of Haryana.

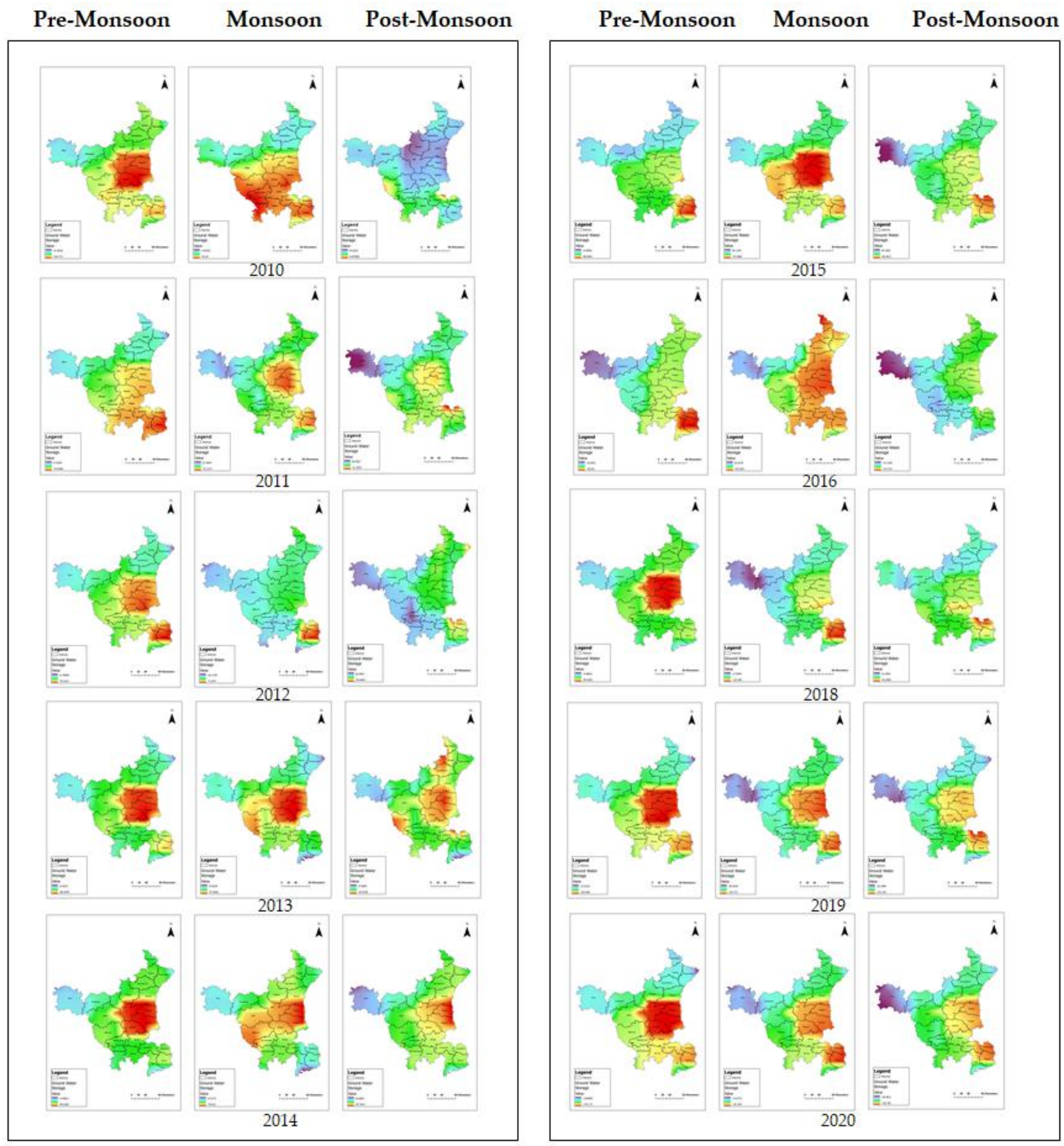

Fig. 4 Monthly GRACE / GLDAS gravity solution for total groundwater storage year wise from the period of 2010 to 2020 in Yamunanagar and Faridabad districts of Haryana.

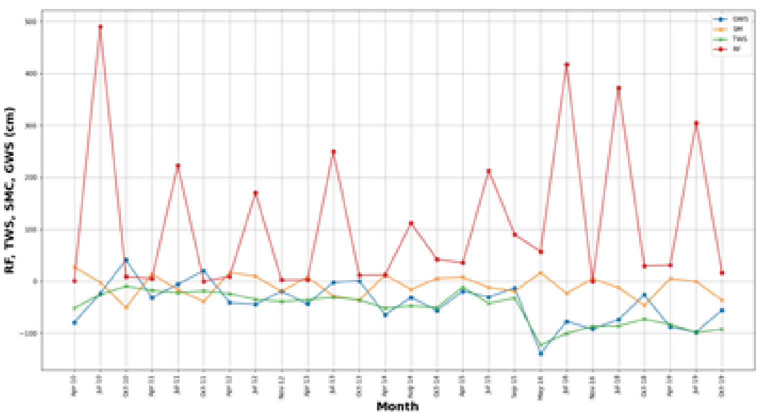

Fig. 5 Monthly time series of GRACE-derived total ground water storage, modeled soil water storage, estimated ground water storage and rainfall over Yamunanagar plotted as equivalent heights of water in centimeters.

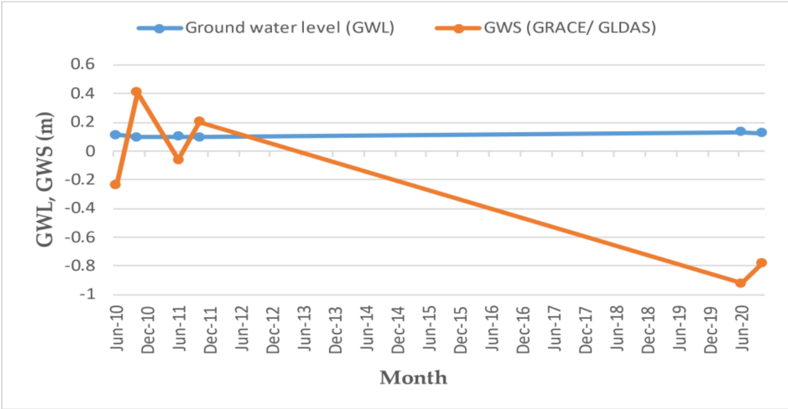

Fig. 6 Monthly time series of GRACE-derived total ground water storage, modeled soil water storage, estimated ground water storage and rainfall over Faridabad plotted as equivalent heights of water in centimeters.

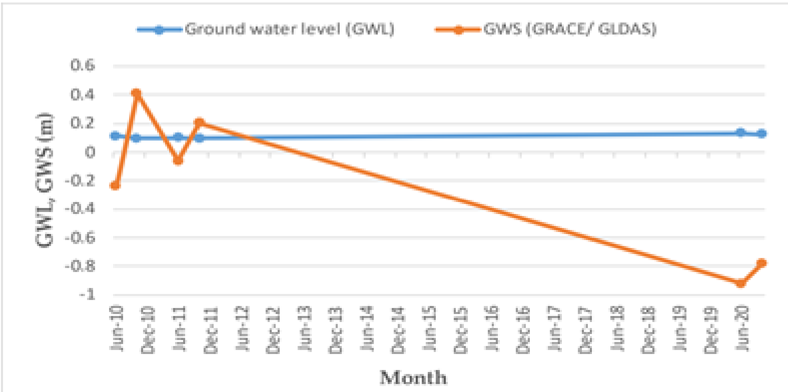

Fig. 7 Comparison between GRACE/GLDAS-derived GWS and wells observed ground water level in meters in Yamunanagar.

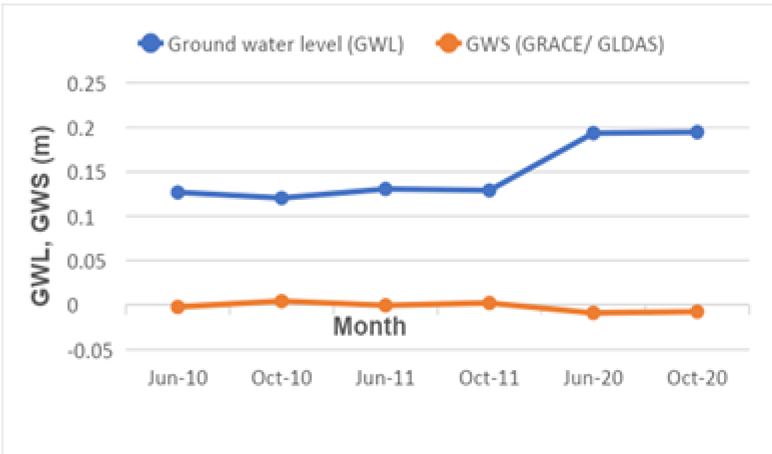

Fig. 8 Comparison between GRACE/GLDAS-derived GWS and Well Derived Ground water level (GWL) in meters in Faridabad.

Conclusions

Utilizing high-frequency GRACE satellite gravity data presents a cost-effective option for evaluating groundwater sustainability on a regional scale. Under circumstances where there is unavailability of water level data from wells, the GRACE gravity data facilitate the improved quantitative assessment, management of ground water supplies and to characterize the spatial and temporal variations of ground water depletion and restoration. To assess the groundwater storage (GWS) situation in densely populated and industrial areas of Faridabad and Yamunanagar, various types of datasets such as GRACE-derived TWS, RF, SMC and bore-hole data were parts of the study. From the results, we found an unavoidable contribution of seasonal (climatically influenced) change over GWS depletion and replenishment, but it is comparatively less than the influence of anthropogenic factors. The comparative analysis of the results illustrates more depletion in the Faridabad region at the rate of -4.73 ± 0.19 cm/year compared to the Yamunanagar region that shows a rate of depletion at -1.89 ± 0.57 cm/year. Overall, there is a depletion in entire Haryana state but some positive GWS values has been seen in rare parts of the state which is the limitation of the study as the GRACE data is available at global level and the cell size is larger. Whereas, the most adverse depletion rate is seen in the NCR region and a medium depletion rate is observed in the Northern and North-Western region of Haryana. Lastly, in the comparative analysis of GWS in Faridabad and Yamunanagar, it suggests that urbanization is the major factor responsible for more ground water depletion relative to climatic changes. If the Government of India does not implement an appropriate mitigation plan to ensure sustainable ground water usage, then the state of Haryana may face a severe shortage of ground water for agriculture and potable water in the future.

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