11 Seasonal Ground Water Fluctuation Monitoring Using GRACE Satellite Technology Over Punjab and Haryana During 2005–2015

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Abstract

Optimum management of natural resources is critical for sustainable growth and development. Under rapidly increasing population and industrialization, the groundwater depletion rate is way more than that of the groundwater recharge rate in India. The situation is more alarming in North-West India, where the amount of precipitation is quite low for irrigation purpose. In the present study, groundwater fluctuation in Haryana and Punjab has been monitored during 2005–2015 using GRACE satellite data. Since 2002, Gravity Recovery and Climate Experiment (GRACE) satellite provided an estimation of various components of Earth's gravity field as it provides gravity data at $1° \times 1°$ resolution for the estimation of terrestrial water storage change, i.e. surface water and groundwater. The land surface variable has been used to infer how Terrestrial Water Storage (TWS) is contributing to canopy water and soil moisture. In the present study, the groundwater storage change of the Punjab and Haryana was monitored by computing storage changes in GRACE TWS, GLDAS land surface state variables with the terrestrial water balance approach. The results indicate that the Groundwater fluctuation follows the cyclic yearly pattern with highs corresponding to the monsoon. Computed groundwater mean depletion thickness over Haryana was found 1.13 cm and for Punjab is 0.92 cm during 2005–2015 in the study area. There are clear signals of yearly and seasonal variation in the groundwater as well as the impact of the extreme event on the groundwater change. The impact of cumulative water loss through Evapotranspiration (ET) on the groundwater has also been analyzed, which shows a positive correlation with the groundwater fluctuation.

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A. K. Taloor et al. (eds.), *Water, Cryosphere, and Climate Change in the Himalayas*, Geography of the Physical Environment, https://doi.org/10.1007/978-3-030-67932-3_11

Keywords

GRACE · TWS · Noah model · Groundwater recharge · Remote sensing

11.1 Introduction

Because of overexploitation, diminishing freshwater accessibility is because of informal extraction and inappropriate administration of water resources. In the coming decades, India is going towards a significant freshwater emergency in the period of a quickly evolving atmosphere. The groundwater resources are depleting at an alarming rate globally and particular in north-west India over the last two decades (Georgakakos and Graham 2008; Xu et al. 2012; Bhat et al. 2019; Taloor et al. 2019; Haque et al. 2020; Kumar et al. 2020; Sood et al. 2020a).

India is the seventh-biggest nation on the planet in terms of the zone and second as far as populace with 1200 mm/y normal precipitation. Due to irregularity in rainfall and groundwater overexploitation, the depletion of groundwater level surges abruptly (Joshi and Tyagi 1994; Briscoe and Malik 2006; Kumar et al. 2005; Moore and Fisher 2012; Rodell et al. 2009; Jasrotia and Kumar 2014; Gautam et al. 2017; Jasrotia et al. 2019; Sood et al. 2020b; Khan et al. 2020). In states like Haryana and Punjab water level depletion is comparatively faster than any other states of India (Waters et al. 1990; Engman 1991; Gontia and Patil 2012; Kumar et al. 2008; Meijerink 1996; Sander et al. 1996; Siebert et al. 2010; Adimalla and Taloor 2020; Adimalla et al. 2020; Kannaujiya et al. 2020; Sarkar et al. 2020; Taloor et al. 2020; Singh et al. 2020). There is a need for appropriate scientific methods for sustainable water resource utilization and geospatial technology is rapidly gaining its applications in the monitoring and mapping of water resources in the last few decades. GRACE data is a very useful tool for identifying the impact caused by extreme climate events like drought and floods (Jin and Feng 2013; Tapley 2004; Andersen and Hinderer 2005; Longuevergne et al. 2013; Phillips et al. 2012). GRACE data are capable of identifying seasonal and long-term variation in TWS and quite useful for hydrological model development. The information of TWS variations of recent decades is quite important for the study of water and its temporal changes. In this study, GRACE RL05 products and Global Land Data Assimilation System (GLDAS) Noah LSM (Betts et al. 1997; Chen et al. 1996; Koren et al. 1999; Ek 2003; Rodell et al. 2004) products, combined with a data record of the Central Ground Water Board (CGWB) India, were used to determine the long-term TWS over the state of Haryana and Punjab. This study insights useful guidance for sustainable management of water resources and futuristic planning and research to improve groundwater storage for the future.

11.2 Study Area

The present study has been carried out in Haryana, Delhi and Punjab, India (Fig. 11.1). lies between 27° 39′ and 30° 35′ N scope and somewhere in the range of 74° 28′ and 77° 36′ E longitude. It has four primary topographical highlights viz. (i) The Yamuna-Ghaggar plain shaping the largest (piece of the state is likewise called Delhi doab comprising of Sutlej-Ghaggar doab (between Sutlej in the north in Punjab and Ghaggar stream coursing through northern Haryana). (ii) Ghaggar-Hakra doab (between Ghaggar waterway and Hakra or Drishadvati stream which is the paleochannel of the sacred Sarasvati River) and Hakra-Yamuna doab (between Hakra waterway and the Yamuna). (iii) The Shivalik hills towards the upper east the Bagar tract semi-desert dry sandy plain toward the southwest. (iv) The Aravalli Range in the south. The Haryana is very sweltering in summer at around 45 °C and mellows in winter. The most sweltering months are May and June and the coldest December and January. The atmosphere is dry to semi-dry with normal precipitation of 354.5–530 mm. The dirt qualities are impacted to a restricted degree by the geography, vegetation and parent rock. The Punjab is separated into three particular areas based on soil types viz.

southwestern, focal and eastern. The most extreme temperatures, for the most part, happen in mid-May and June. The temperature stays over 40 °C in the whole locale during this period. Punjab encounters its base temperature from December to February and the average yearly precipitation of Punjab is 500 mm.

11.3 Data and Methodology

The GRACE satellite data downloaded from http://grace.jpl.nasa.gov/data/get-data/ to study the TWS changes from 2005 to 2015 in the state of Punjab, Haryana and Delhi. The monthly soil moisture anomalies (at a spatial resolution of

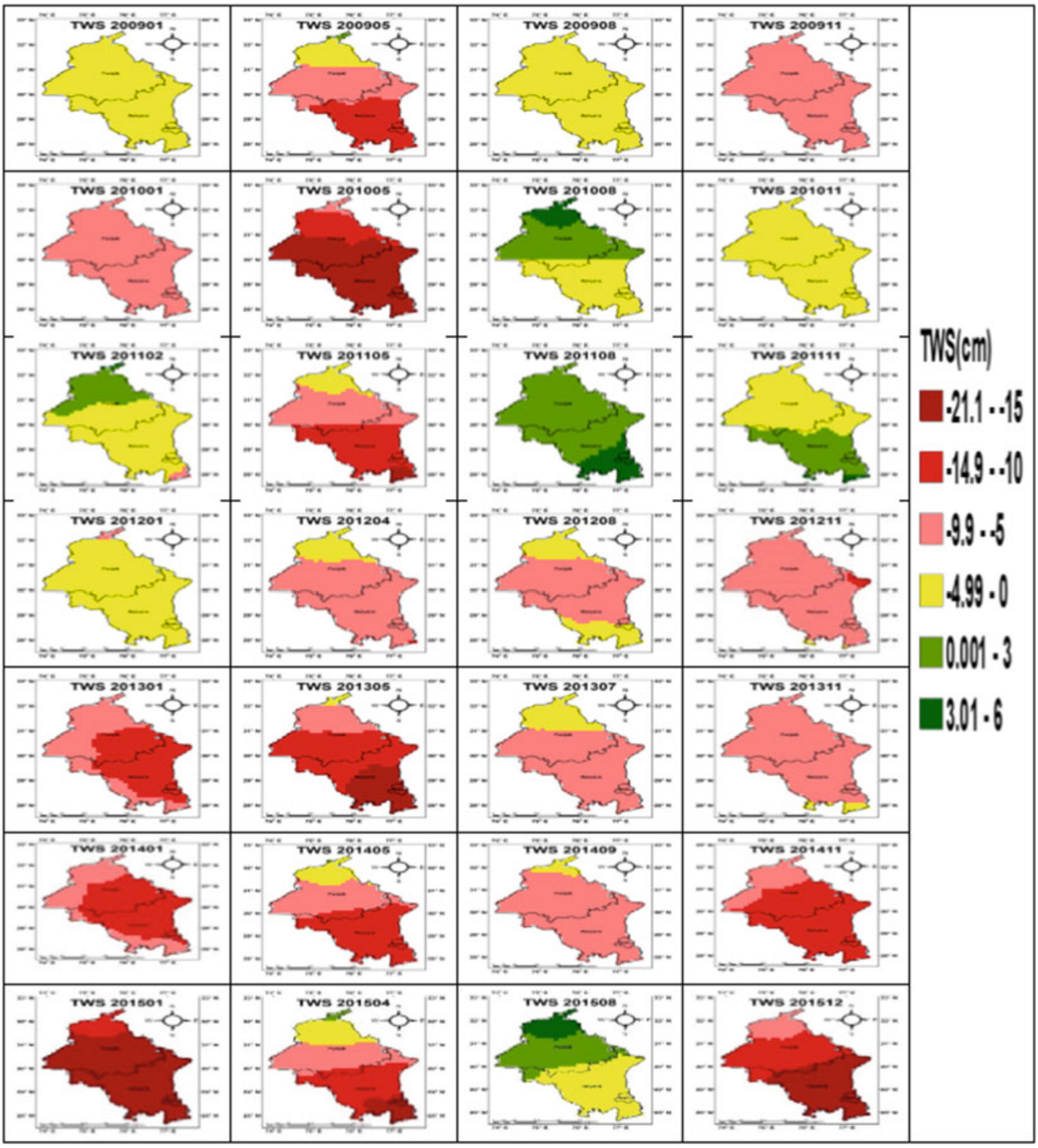

Fig. 11.1 Seasonal TWS spatial map over Haryana and Punjab from 2009 to 2015 (for winter January, May for pre-monsoon, August for monsoon and November for post-monsoon). **when satellite data is missing, we take adjacent month** (*Source* GRACE data)

1° × 1°) calculate the soil moisture. To independently evaluate groundwater storage change, there is a need to measure surface water storage change and expel it from GRACE perceptions. The GLDAS gauges used in the present study are from the Noah LSM (Ek 2003). The GRACE data provides the gravity mass anomalies to estimate TWS changes. These mass anomalies obtained by calculating the temporal variation in gravity which is expressed by monthly mean terrestrial water storage variation, equivalent water storage anomalies, as well as water height (Rodell and Famiglietti 2002; Rodell et al. 2004; Famiglietti et al. 2011; Rodell et al. 2009; Scanlon et al. 2012; Sun et al. 2012; Richey et al. 2015; Singh et al. 2017, 2019).

$$\mathrm{TWS}_t = \mathrm{SM}_t + \mathrm{SWE}_t + \mathrm{SW}_t + \mathrm{GW}_t, \quad (11.1)$$

Here TWS_t is the total terrestrial water storage, SM_t which is total soil moisture, SME_t is the snow water estimation, SW_t is the total surface water and GW_t is the total groundwater.

$$\Delta\mathrm{AW}_t = \mathrm{TWSA}_t - \Delta\mathrm{SWE}_t - \Delta\mathrm{SM}_t, \quad (11.2)$$

Here Δ is the time-mean variation of an individual parameter. Soil moisture anomalies derived from the NASA Global Land Data Assimilation System (GLDAS) as shown in Eq. (11.2). It isolates the contribution of groundwater storage changes to changes in total water storage. The reservoir storage changes applied in the state of Haryana, Delhi and Punjab along with soil moisture and previously described data

$$\Delta\mathrm{GW}_t = \mathrm{TWSA}_t - \Delta\mathrm{SWE}_t - \Delta\mathrm{SM}_t - \Delta\mathrm{SW}_t, \quad (11.3)$$

Here $\Delta\mathrm{SW}_\mathrm{t}$ is surface water anomaly for an individual month, Whereas errors in the GWS calculated using the parameters; TWSA, SM, SWE and SW (Rodell et al. 2004).

We compared our GRACE derived GWS variations with groundwater level (observed by monitoring dug wells and tube wells; data obtained from CGWB website).

11.4 Results and Discussions

The analysis of satellite data showed a continuous water deficit in Haryana and Punjab from 2009 to 2015 (Fig. 11.1). From winter to premonsoon, the depletion rate of TWS was 8–10 cm, while it was 5–8 cm after the monsoon. However, the rate of recharge during the monsoon was 10–13 cm. In the year 2010, 2011 and 2015, the month of August showed good recharge during monsoon because of heavy rainfall (Tables 11.1 and 11.2).

Quantification of the seasonal mean of groundwater from TWS using Eq. (11.3) has been depicted in Fig. 11.2. In this study, the mean of January and February for the winter session, mean of March, April, and May for premonsoon season, mean of June–September for monsoon season and mean of November and December for the post-monsoon season have been considered. The same pattern for both the States viz. The Punjab, Delhi and Haryana were observed during the winter session, which is due to less rainfall and more groundwater extraction for cropland irrigation. The ET values were higher due to more moisture present in soil and crop. During the premonsoon season, less precipitation, high solar radiation, and more ET on the field results in the higher water extraction for domestic and irrigation uses. During the monsoon season, large amount of rainfall resulted in higher soil moisture, and higher amount of ET was also observed over cropland area where as the TWS from satellite data also showed increasing trends. However, estimated groundwater (GW) from Eq. (11.3) was low as compared to TWS, which may be due to soil characteristics. However, groundwater recharge was more in the post-monsoon season due to the lag of soil moisture percolation. The results show that due to continuous water depletion over the state of the Punjab and Haryana and decreasing trend were of the order of 0.92 and 1.3 cm, respectively (Fig. 11.3). The above trends are in agreement with Central Ground Water Board results (Fig. 11.4).

Table 11.1 Monthly rainfall (cm) over Punjab from 2009 to 2015

Year	2009	2010	2011	2012	2013	2014	2015
January	1.04	0.27	0.36	3.58	0.93	2.18	1.77
February	1.71	1.23	3.3	0.29	5.01	2.01	3.13
March	1.07	0.05	0.67	0.19	1.16	3.03	6.85
April	2.13	0.03	1.22	2.02	0.34	2.45	2.98
May	0.44	0.35	1.45	0.08	0.36	2.08	1.67
June	1.02	3.45	9.88	0.96	12.03	2.06	4.87
July	16.67	20.86	8.5	6.77	11.79	7.63	13.16
August	8.24	12.13	16.13	0.51	21.71	4.19	8.86
September	7.18	9.46	11.43	8.35	2.44	10.58	6.92
October	0.27	0.58	0.06	0.28	1.62	0.6	0.92
November	0.61	0.04	0.02	0.04	0.61	0.07	0.08
December	0.2	1.66	0.34	0.82	0.66	1.41	0.07

Source India Meteorological Department

Table 11.2 Monthly rainfall (cm) over Haryana and Delhi from 2009 to 2015

Year	2009	2010	2011	2012	2013	2014	2015
January	2009	2010	2011	2012	2013	2014	2015
February	1.04	0.27	0.36	3.58	0.93	2.18	1.24
March	1. 71	1.23	3.3	0.29	5.01	2.01	0.65
April	1.07	0.05	0.67	0.19	1.16	3.03	7.16
May	2.13	0.09	1. 22	2.02	0.34	2.45	3.47
June	0.44	0.35	1.45	0.08	0.36	2.08	0.84
July	1.02	3.45	9.88	0.96	12.03	2.06	4.41
August	16.67	20.86	8.5	6.77	11.79	7.63	13.25
September	8.24	12.13	16.13	10.51	21.71	4.19	8.94
October	7.18	9.46	11.43	8.35	2.44	10.58	3.2
November	0.27	0.58	0.06	0.28	1.62	0.6	0.37
December	0.61	0.04	0.02	0.04	0.61	0.07	0.23

Source India Meteorological Department

11.5 Conclusion

Annual average groundwater losses over Haryana and Punjab were of the order of 1.13 cm/yr and 0.92 cm/yr, respectively. The vast majority of the groundwater withdrawal from the study area because of an expansion in irrigation and evapotranspiration as these areas are thickly populated and widely inundated. The groundwater assets are experiencing critical pressure as they are not being energized at a similar rate as they are found on the earth surface. Compelling administration is urgently needed to draw harmony among discharge and recharge in the study area. Moreover, the monthly satellite information can be used for ideal water management purposes.

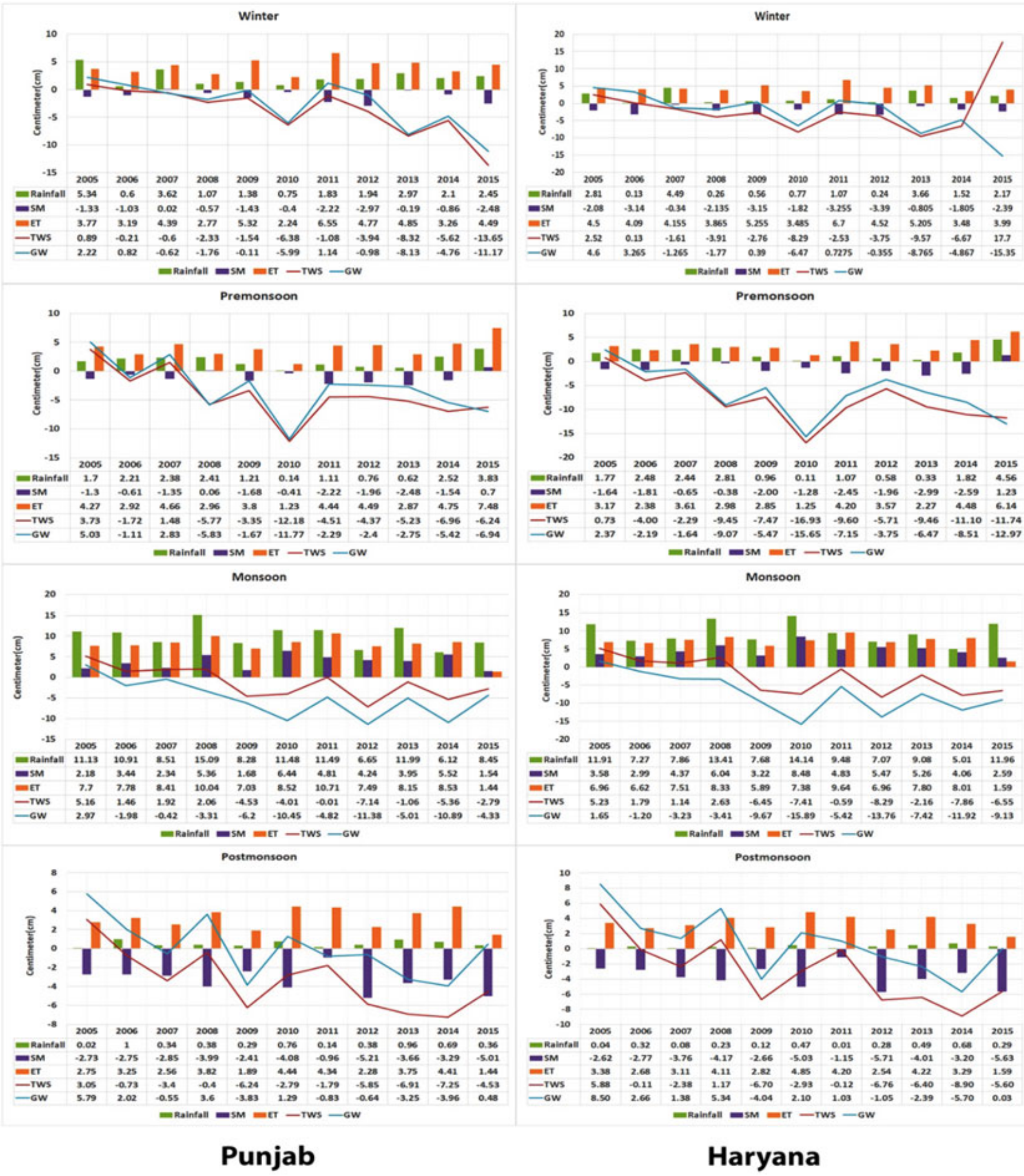

Fig. 11.2 Seasonal-mean calculated groundwater, TWS, SM and ET fluctuation over Punjab and Haryana State during 2005–2015 (*Source* India Meteorological Department)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Rainfall	5.03	4.54	4.12	5.91	3.37	4.18	4.45	2.82	4.65	3.19	4.27
SM	-0.50	0.24	-0.27	0.71	-0.70	0.96	0.77	-0.87	0.53	0.43	-0.21
ET	2.75	3.25	2.56	3.82	1.89	4.44	4.34	2.28	3.75	4.41	1.44
TWS	3.56	-0.16	0.06	-1.25	-4.16	-6.14	-1.76	-5.85	-4.78	-6.28	-5.90
GW	4.06	-0.40	0.33	-1.95	-3.46	-7.10	-2.53	-4.98	-5.31	-6.71	-5.68

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Rainfall	4.89	3.14	4.00	5.28	2.92	4.98	3.61	2.61	3.72	2.55	5.56
SM	-0.22	-0.34	0.30	0.52	-0.62	0.95	0.49	-0.66	0.68	-0.07	0.22
ET	3.38	2.68	3.11	4.11	2.82	4.85	4.20	2.54	4.22	3.29	1.59
TWS	3.82	-0.41	-1.06	-1.84	-6.15	-8.82	-3.05	-6.76	-6.28	-8.73	-9.47
GW	4.04	-0.07	-1.35	-2.37	-5.53	-9.76	-3.54	-6.10	-6.96	-8.66	-9.69

Fig. 11.3 Annual mean groundwater depletions observed by satellite over Punjab and Haryana (*Source* GRACE data)

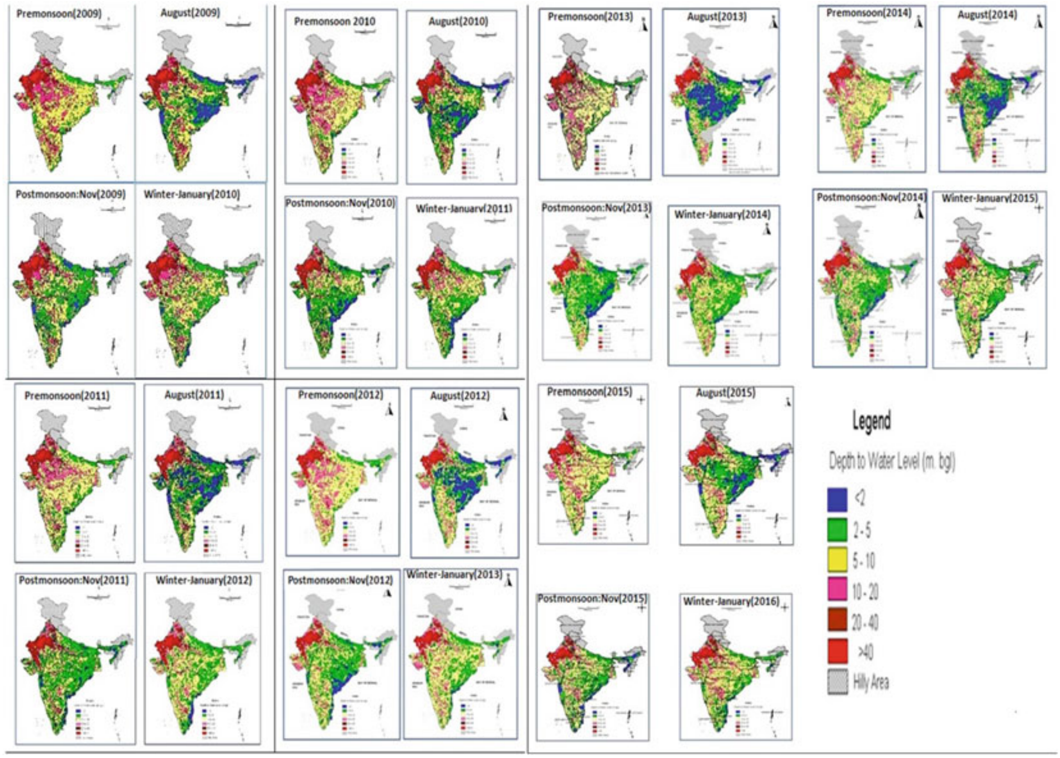

Fig. 11.4 Seasonal groundwater depth level observed by CGWB during 2009–2015 respectively (*Source* http://www.cgwb.gov.in/GW-Year-Book.html)

Acknowledgments The authors are highly thankful to the University of Allahabad, Prayagraj. India Meterology Department, Delhi; Head Department of Remote Sensing and GIS, University of Jammu, Jammu for encouragement and providing facilitating the present research work and especially thanks to NASA for providing GRACE & GLDAS Data set.

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