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Research Paper

Entropy Analysis of Seasonal Groundwater Level Fluctuations for Delhi and Haridwar Regions of India Using Grace Satellite Data

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ABSTRACT

Groundwater monitoring and its spatio-temporal study require installation and management of ground-based observation wells on a large scale. The cost associated with such a study is generally high. An alternative to it is to use remote sensing data to manage groundwater resources in the least cost. There are only a few satellites which can provide gravity-based groundwater data. Gravity Recovery and Climate Experiment (GRACE) is a satellite which measures the change in gravity and is further used to study groundwater fluctuations. In the present study, groundwater fluctuations data (Product of GRACE satellite data) for Haridwar and Delhi region of India has been used to study the temporal and spatial variability using entropy theory. The temporal data from 2003 to 2016 has been used for both regions. The results suggested that the groundwater fluctuations are increasing in both regions of the study area. Results suggested that fluctuation of groundwater was high for the winter season of all years, but in the post-monsoon season, the fluctuation in between Delhi and Hardwar has been detected just about same Seasonal fluctuation in water level for both regions showed a maximum rise of 60 cm in water level and also maximum fall in the same range.

Keywords: Groundwater fluctuations; Entropy theory; GRACE

INTRODUCTION

Overexploitation of groundwater is one of the major causes of aquifer depletion in India and also throughout the world (Kumar et al., 2013; Sudheer et al., 2013). The availability of water in various water bodies like rivers, ponds, and reservoir are also decreasing at a much faster rate. The quantitative water budgeting of these water resources is generally very difficult due to the unavailability of data at the point of the study. Moreover, the collection of data at the study site, especially of groundwater table or its fluctuations, is generally time-consuming affair. Remote sensing satellites can resolve this problem since it can provide data in real-time. Remote sensors are capable of monitoring land as well as water resources of the earth and also of other planets and various asteroids. There are only a few satellites which have the capability to give real-time groundwater data. GRACE (Gravity Recovery and Climate Experiment) is one of such satellite which can provide real-time groundwater fluctuations data. The GRACE satellite plays an extreme role in describing the availability of groundwater and conditions of the aquifers. In the past few years, researchers have been investigated groundwater fluctuations using various remote sensing products.

Henry et al. (2009) studied the variability of groundwater storage and annual recharge of GRACE satellite data from 2002 to 2008 and investigated the level of groundwater data from 1982 to 2002 in the southern region of Mali, Africa using (Global Land Data Assimilation System) GLDAS model. Their results suggested that the GLDAS model predicted not accurate groundwater fluctuations, whereas GRACE satellite data produced significant results in groundwater storage. Some strategies have also been developed for improving groundwater storage (Hertig and Gleeson, 2012). Chambers (2006) used GRACE data to study the change in sea level. In his work, it was concluded that the change in sea level might be due to temperature variation or either by the salinity of the water. Altimetry data may also be used for detection of a change in the sea level. Contribution of human in the depletion of groundwater storage like loss of water steadily has been investigated by Joodaki et al. (2014). Forootan et al. (2014) worked on GRACE satellite data of groundwater storage from 2002 to 2011 for Iran region consisting of six basins using statistical techniques. It was investigated that high variability has been found between dataset. Scanlon et al. (2012) used GRACE satellite data coupled with groundwater-level data for evaluating the change in the groundwater storage from October 2006 to March 2010 for the California region, USA. In that study GRACE processing approach has been done for detecting the change in the groundwater storage. Further, Tiwari et al. (2009) studied on the fluctuation of groundwater storage of GRACE satellite data from 2002 to 2008 in the Northern region of India using Hydrological model, i.e. GLDAS model (Global Land Data Assimilation System) and Community Land Model (CLM). They had got a good correlation between the models. The results also suggested that the territory of groundwater disappeared at a very high rate i.e. 54 9 km^3/year in between dataset from 2002 to 2008. In the present study, entropy theory has been used on GRACE data of Haridwar and Delhi region to estimate temporal variability in groundwater table fluctuations. Entropy theory has also been used to study randomness in these regions.

STUDY AREA AND DATA COLLECTION

Two most populous cities of India, namely Delhi and Haridwar has been selected to study the groundwater fluctuations using GRACE data. Haridwar and Delhi have latitudes and longitudes of 29^0 56' N & 78^0 9' E and 28^0 36' N & 77^0 13' E respectively. The study area has been shown in Fig.1.

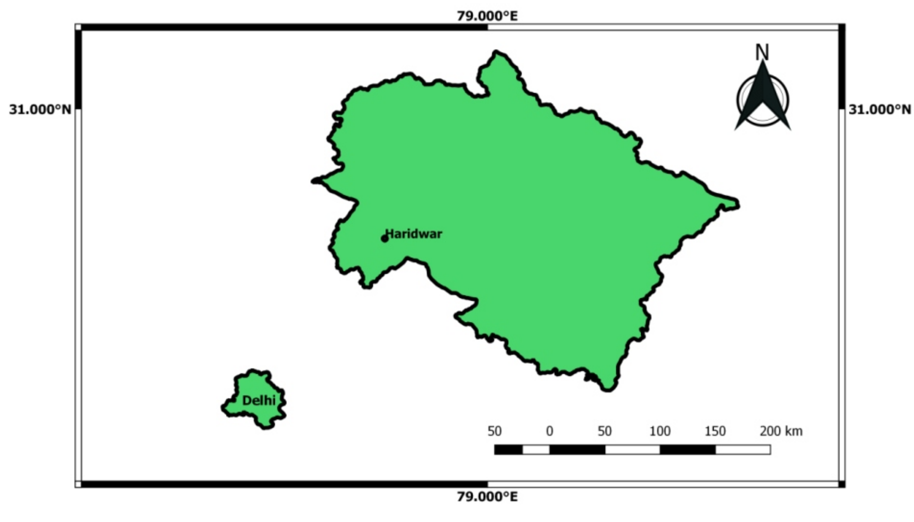

Fig.1. Study area map

The GRACE satellite data between 2003 to 2016 has been for groundwater fluctuation has been collected from JPL website NASA. In this study, variability in groundwater has been studied on a seasonal basis. The seasons are based on Indian Metrological Department (IMD) norms which are shown in Table 1.

Table.1 Monthly distribution of seasons as per IMD norms

Seasons	Months
Winter	January – February
Pre-Monsoon	March – May
Southwest monsoon	June – September
Post-Monsoon	October – December

GRACE satellite data is used in the present study. The GRACE satellite was built for detecting the change in gravity in a subsurface environment which can also detect fluctuations in groundwater storage. GRACE satellite was launched (Tapley et al., 2004) by NASA (National Aeronautics and Space Administration) and the German Aerospace Centre in March 2002. GRACE satellite was planned for five years of life span and it consists of two satellites i.e. GRACE-1 and GRACE-2. Further specifications of GRACE satellite are shown in Table 2.

Table 2. GRACE satellite specifications

Joined mission	NASA and the German Aerospace Center
Two grace satellite	GRACE 1 and GRACE 2
Mission type	Gravitational science
Launched on	17 March 2002
Initial altitude	500 km at a near-polar inclination of 89°
Launch mass	487 kg (1,074 lb) each
Dimensions	1.942 × 3.123 × 0.72 m (6.4 × 10.2 × 2.4 ft)

ENTROPY THEORY

Entropy theory was introduced by Shannon in l948 and the principle of maximum entropy was given by Jaynes (1957). Using entropy theory, variability or randomness in the dataset can be extracted. It minimizes the biasness or error in the system when the data having missing values. Entropy approach has been used in this paper to study the variability in fluctuation in the groundwater table change. The discrete form of entropy H(x) is given (Shannon, 1948; Mishra et al., 2009) as follows

$$H(x) = -\sum_{k=1}^{K} p(x_k)\log_2\left[p(x_k)\right] \quad \ldots(1)$$

where, k = time interval of K event; x_k = Event corresponding to the interval k; $p(x_k)$ = Probability of x_k

Apportionment Entropy

It is used to find out the temporal changes on monthly basis in the dataset and it varies between zero to $\log_2(12)$ and it is given by

$$AE = -\sum (r_i / R)\log_2 (r_i / R) \quad \ldots (2)$$

where, R = summation of all months (i.e. 12 months) ; p_i = Rainfall probability i.e. r_i / R ; i (no. of months) = 1, 2, 3…, 12

Mean Disorder Index

It is used in temporal scale and well as spatial scale and if the value of disorder index (DI) is high it means variability will be high. Mean Disorder Index is described as follows…

$$Mean \quad Disorder \quad Index = \frac{1}{N}\sum_{i=1}^{N} DI \quad \ldots (3)$$

where, N is the entropy length in time series; DI = Disorder Index

Marginal Disorder Index (MDI)

Marginal disorder index (MDI) may be defined as when the disorder index is calculated by marginal entropy called MDI and it is done on monthly and seasonally basis of data.

$$DI(Disorder \quad Index) = Maxi. \quad Possible \quad Entropy - Actual \quad Entropy \quad in \quad Series \quad \ldots (4)$$

RESULTS AND DISCUSSION

Groundwater depletion is a direct indicator of either low rainfall condition or overexploitation of aquifer resources. Cities, like Delhi and Haridwar is over populous and hence it may also affect the aquifer resources. Remote sensing, now a day, plays an important role in water resources management. In this paper, study for groundwater fluctuations, from 2003 to 2016, has been done for Haridwar and Delhi regions using GRACE satellite data, whose results have been discussed in this section. The temporal variations in groundwater fluctuations for Haridwar and Delhi region have been shown in Fig.2. This figure depicted that the fluctuations in the groundwater table are continuously increasing in the study period. Delhi has shown the maximum fluctuation of the groundwater table.

Table 3 and Table 4 depicts the statistical results of the water table fluctuation for Delhi and Haridwar. The statistical analysis has been done for four different seasons, namely, Pre-monsoon, Southwest monsoon, post-monsoon and winter. Table 3 depicted that among all the seasons, the pre-monsoon period showed maximum fluctuations in the groundwater table. This might be because there was little rainfall during pre-monsoon and at the same time extraction of groundwater was more. The negative fluctuation was used for representing a fall in the groundwater table, while positive fluctuations indicate a raise in the groundwater table.

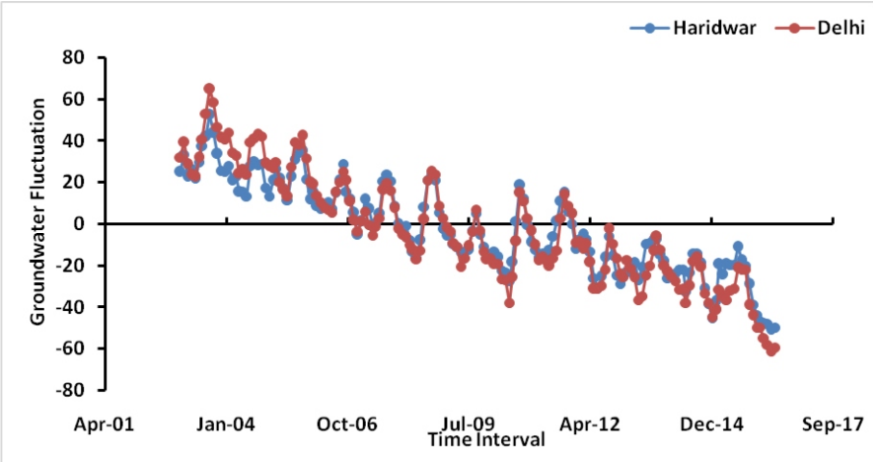

Fig. 2. Scatter plot of groundwater fluctuation in study area

Table 3. Groundwater Fluctuation statistics of Delhi

	Pre-Monsoon	Southwest Monsoon	Post-Monsoon	Winter
Mean	-10.96	1.47	-4.48	-0.46
Standard Deviation	25.33	25.16	25.65	27.44
Coefficient of Variation	-2.31	-55.20	17.47	-5.62
Skewness	0.16	0.54	0.37	0.24
Kurtosis	-0.42	-0.87	-0.65	-0.51
Standard Error	6.77	6.72	6.85	7.33

In the Haridwar region, fluctuation of groundwater was found less as compared to the Delhi region in the pre-monsoon period as shown in Table 4. The mean fluctuation in Haridwar was -7.80 cm, 2.06 cm, -1.33 cm and -6.77 cm for Pre-monsoon, southwest monsoon, post-monsoon and winter season respectively. The high fluctuation of groundwater in the winter season may be due to overexploitation of groundwater for irrigation purpose. In Haridwar region, farmers use groundwater for irrigating Rabi crops, for example, wheat, mustered etc, from October to February in this region. The standard deviation in groundwater fluctuation for this region is maximum for the winter season.

Table 4. Groundwater Fluctuation statistics of Haridwar

	Pre-Monsoon	Southwest Monsoon	Post-Monsoon	Winter
Mean	-7.80	2.06	-1.33	-6.77
Standard Deviation	20.88	19.96	20.92	22.94
Coefficient of Variation	-2.68	9.69	-15.70	-3.39
Skewness	0.04	0.37	0.14	-0.05
Kurtosis	-0.35	-0.93	-1.13	-0.63
Standard Error	5.58	5.33	5.59	6.13

To study the extent of variability in groundwater fluctuations, marginal disorder index (MDI) has been estimated for seasonal as well as monthly basis. The monthly marginal disorder index has been shown in Fig.3. Fig.3 suggested that MDI of Haridwar was more than Delhi from month January to August and also in December. For September to November, the MDI of Delhi was more than Haridwar. This might be due to the reason that in Delhi, before monsoon season, due to less precipitation and overexploitation, the groundwater table is very low and suddenly due to monsoon precipitation, it becomes remarkably high and thus showed high variability in fluctuations.

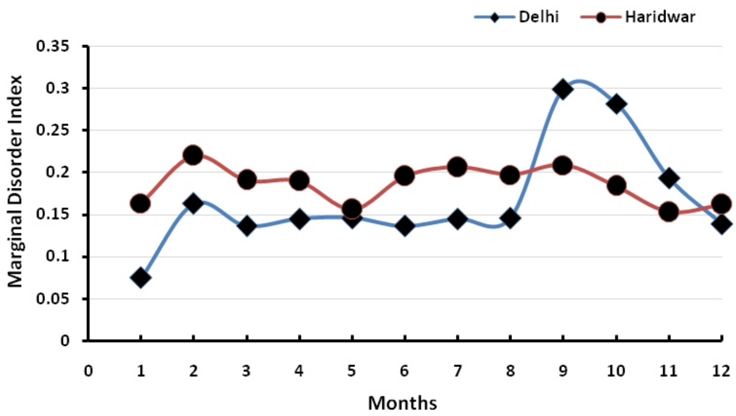

Fig. 3. Marginal disorder index on monthly basis

Similarly, seasonal MDI has been estimated and is shown in Fig.4. It depicts that the marginal disorder index (MDI) was greater for Haridwar region as compared to Delhi. The highest MDI of 0.221 has been observed for south-west monsoon season of Haridwar. In Delhi region, minimum MDI of 0.112 has been observed for Winter. Thus, for the winter season, fluctuations in groundwater is low as compared to other seasons. Similarly, for Haridwar region also, least variability in groundwater fluctuations has been observed in the month of Winter.

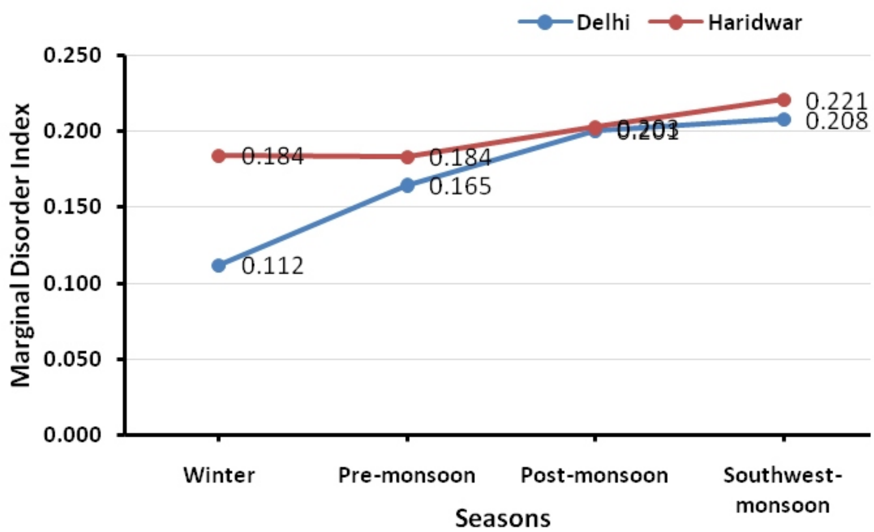

Fig. 4. Marginal disorder index variability on seasonal basis

CONCLUSIONS

This study was conducted based on entropy and statistical approaches for the region of Delhi and Haridwar to study variability in groundwater fluctuations. The fluctuations were continuously increasing for both Haridwar and Delhi regions from Winter season, pre-monsoon, post-monsoon and Southwest monsoon. It was investigated that fluctuation of groundwater was found high for the winter season, but in the post-monsoon season, the fluctuation in between Delhi and Hardwar has been detected just about same. The high fluctuation of groundwater in the winter season may be due to overexploitation of groundwater for irrigation purpose in agricultural fields which is under Rabi crop cultivation from October to February in this region. These fluctuations can be minimized by consumptive use of water in that region. To minimize the groundwater overexploitation, conjunctive use of water may be adopted by the local authority. The farmers of these regions have to be persuaded to use groundwater judiciary. If proper management of groundwater and water resources as a whole will not be adopted, then it may adversely affect life on Earth.

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