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ORIGINAL PAPER

Potential impact of rainfall variability on groundwater resources: a case study in Uttar Pradesh, India

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Abstract
Groundwater systems are largely influenced by rainfall variability which is considered the principal source of recharge. The present study explores the relation between the long-term rainfall (1992–2014) and the corresponding water table variation over the Varanasi district. The temporal trends of both the water table and long-term rainfall were analyzed using non-parametric Mann-Kendall time-series trend test. The district experienced an annual rainfall average of 876 mm during the study period. In the recent decade (2003–2014), the amount of annual rainfall and rainy days declined by 42 mm and 8 days, respectively, were compared with previous decade (1992–2002). The water table fluctuation had also shown decreasing trend in the recent decade and were compared with the previous decade. The frequent fluctuations in rainfall anomaly and water table fluctuation had been related to El Nino and La Nina events to study the impact of these events at regional scale. The intense cultivation of water intensive crops as well as rainfall variation was found to be one of the major causes behind the water table fluctuation in the study area. Therefore, artificial water recharge and change in cropping pattern through cultivating less water consuming crops with efficient irrigation technologies of water management may help to overcome the upcoming adverse situations.

Keywords Rainfall · Rainy days · Rainfall anomaly · Groundwater · Water table fluctuation · Mann-Kendall trend test

Introduction

The entire ecosystem face various severe, persistent threats generated by the changes in climate. These changes have been observed across the spectrum of various climate parameters, e.g., temperature, extreme temperature and rainfall events, and sea level rise. Intergovernmental Panel on Climate Change (IPCC) estimated the accelerating temperature trend of 2 to 4.8 °C over the twenty-first century (IPCC 2014). IPCC reports confirm the evident increase in intensity and frequency of hot extremes, heat waves, and heavy precipitation along with increase in amount of precipitation in high latitude and decrease of the same in subtropical regions (IPCC 2014).

In India, about 75% of the rainfall occurs during the period of four monsoon months of June to September (CGWB 2014). The year-to-year variability in monsoon rainfall leads to extreme hydrological events (large scale drought and floods) resulting in serious reduction in groundwater level and agricultural output as well as the populace and the national economy. Droughts, floods, and desertification are directly connected with monsoon rainfall patterns, atmospheric circulation, soil moisture, and water availability (Mall and Anandha Kumar 2010; CGWB 2014; Bhatt and Mall 2015). Long-term trends of Indian monsoon rainfall for the whole Indian continent have been studied by several researchers (Jhajharia et al. 2012; Bhatla et al. 2015). Existence of trends in monsoon rainfall in spatial scale has been observed, but the same is hardly discernable on a vast temporal scale (Narjary et al. 2014). Increase in extreme rainfall trend and decrease in monsoon rainfall and their frequent temporal variations escalate the famine conditions by the frequent floods and droughts. India's 68% area is drought-prone, and 12% area is flood-prone (Mall and Anandha Kumar 2010). In general, agricultural productivity is largely hampered by the extreme climatic

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conditions. Climate change may introduce the "climate refugee" (Wamelink et al. 2018), a new class of species with the potentiality to become invasive towards cultivation and indirectly affects gross domestic products (GDP).

The spatial and temporal variations in rainfall pattern basically affect the surface water storage. The inadequacy leads to the groundwater development activities for irrigation, domestic, and industrial sectors. The prolific aquifers have enormous groundwater storage, and above all, these are the replenishable natural resources (Chatterjee and Purohit 2009; NWM 2009). Replenishment occurs mainly by significant recharge through rainwater percolation, but canals seepage and irrigation return flows also have contribution in some extent. Recently, rampant use has augmented pressure (Tahershamsi et al. 2018) for replenishment into the aquifers. The Central Ground Water Board (CGWB) is carrying out groundwater resource assessment of the country (Fig. 1). The spatiotemporal decrease in groundwater level leads to a serious threat to sustainability and management of groundwater resources. Especially, in arid and semi-arid regions, sustainability of groundwater development depends on groundwater recharge which further controlled by regional groundwater flows across hydrogeologically open catchments (Pacheco 2015). However, groundwater recharge is also governed by the climatic parameters such as rainfall, and evapotranspiration, temperature. Rainfall is considered the prime source of groundwater resources, and rainfall variability has a discrete imprint on groundwater reservoirs of any region (Acworth et al. 2016). Minute change within the rainfall intensity can influence the groundwater recharge in those regions (Crosbie et al. 2012) though the recharge largely dependent on the geology, topography, land use, land pattern (Taylor et al. 2013). In general, higher rainfall is more prone to enough recharge whereas, lower rainfall into a poor recharge establishing the relation between the rainfall variability and water table fluctuation. The rainfall-runoff is also one of the most complex hydrologic relationship, and the rainfall variation has definite control over this physical process (Patel and Joshi 2017). In dry seasons, the streams get water to maintain their base-flows from the groundwater through the subsurface flow (Jan et al. 2007). The recharge event not only enriches the yield of the aquifer but also may adjust the groundwater networks. Such as sometimes, it may transfer a stream from effluent nature to influent nature and vice-versa (Dragoni and Sukhija 2008). Therefore, contribution of

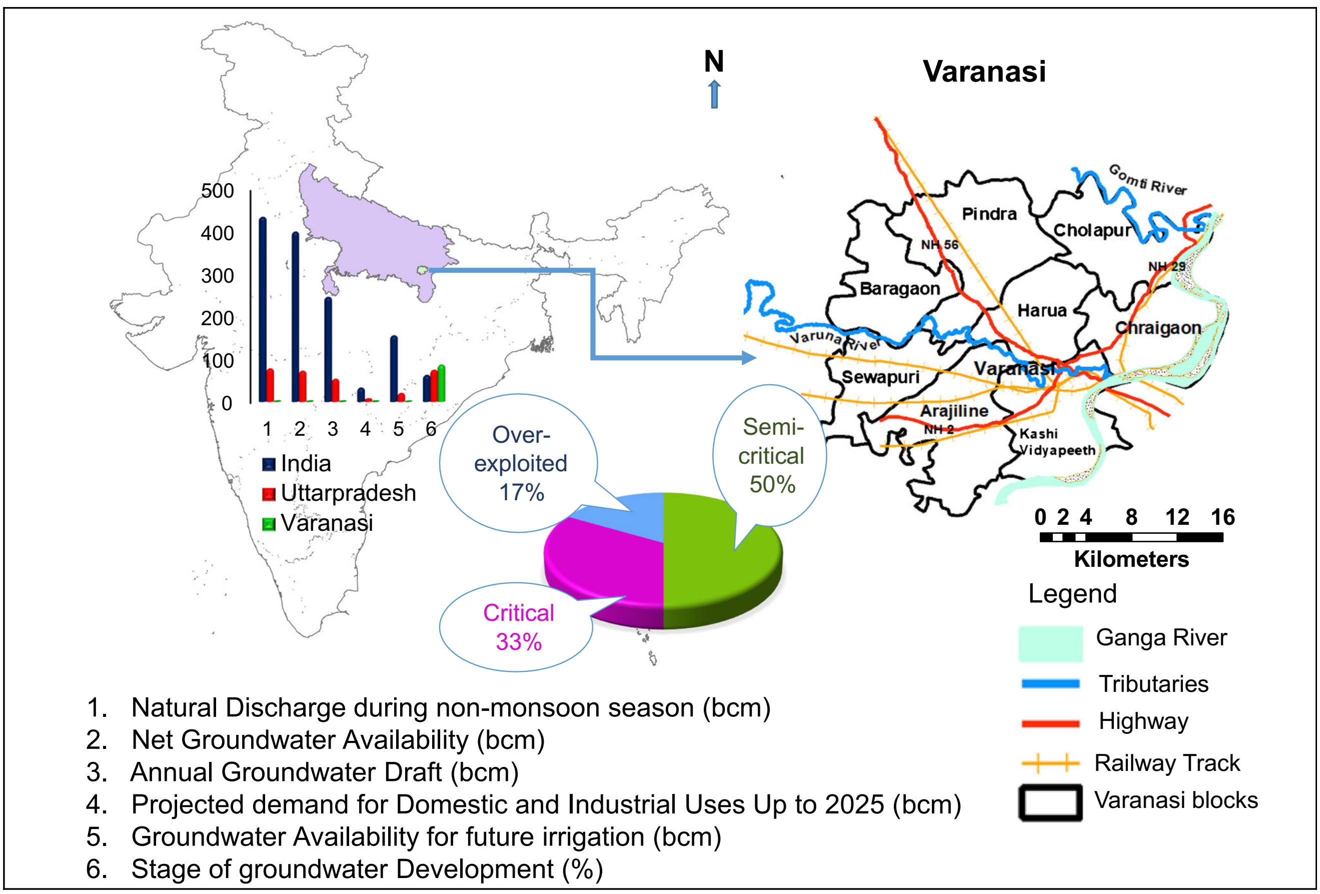


Fig. 1 Location map of the Varanasi district and overall groundwater scenario in country level (India), state level (Uttar Pradesh), and district level (Varanasi) (source: CGWB 2014)

rainfall and its changing behavior pattern is of great importance in present and future aquifer recharges conditions. Recharge can be enhanced through implementing the conjunctive use of surface water with groundwater by using high rainfall water to balance the existing water resources and extra feeds to the aquifer (Amiresmaeili and Jahantigh 2017; Soares et al. 2019; Salis et al. 2019) at regional level.

Recently, Varanasi region is going through rainfall deficiency which can create alarming condition for groundwater recharge. In this respect, the present study was constructed to correlate the changing pattern of the rainfall with the ground water recharge in Varanasi district of Uttar Pradesh and to evaluate the temporal trends as well as the influence of rainfall variability on the groundwater level fluctuations. To our best of knowledge, this is the first attempt to study the groundwater level fluctuations scenario under the rainfall variation in around Varanasi region. The study would guide and help validating the appropriate management of the prevailing water resources.

Materials and methods

Study area

The study area is situated along the western bank of the river Ganga. It is located between 25°15′ N–25°22′ N latitudes and 82° 57′ E–83° 01′ E longitudes coming under the toposheet no. 63 K/11, K/14, K/15, K/16, O/2, O/3, and O/4. The district occupies an area of 1535 km^2 and with a total population of 3,676,841 (Census Report 2011). The area experiences a humid subtropical climate with large variations between summer and winter temperature. The temperature ranges at the Varanasi region from 22 to 46 °C in summer and from 15 to 5° C in winter. Generally, southwest monsoon brings the rainy season with average annual rainfall of 1020 mm (Raju et al. 2011).

The landscape of Varanasi region is associated with the drainage system of the Varuna River and Assi Nala. At Varanasi, the Ganga River carries a mixed sediment load derived both from the Himalayas and Peninsular craton including the Vindhyan rocks (Shukla and Raju 2008). Varanasi is situated over the thick Quaternary Gangetic plains, which consist of alternating sand and clay layers. Shallow groundwater aquifers exhibit unconfined conditions, and the deep aquifers are in semi-confined to confined state. The aquifer lithology revealed through the borehole sediments and comprises of multiple sand layers. The sand layers are the most important aquifers with high potentiality and confined by thick zone of muddy sediments extending up to the surface (Shukla and Raju 2008). The water level fluctuations in the unconfined aquifers were observed from 9 to12 m below ground level from the shallow wells (hand pumps) and dug wells penetrating into unconfined aquifers. Generally, deep-bore wells range from 60 to 250 m below ground level yielding highly up to 750–3500 l/m (Raju et al. 2011).

Data collection and analysis

Seasonal and annual time series (1992 to 2014) of rainfall and rainy days were computed by using daily data which were collected from India Meteorological Department (IMD), New Delhi. Water table fluctuations of the corresponding years were also considered to explore the variations due to the changing pattern of rainfall (Table 1). The pre-monsoon, monsoon, and post-monsoon seasons groundwater level data of 8 blocks (Baragaon, Sewapuri, KashiVidyapeeth, Harhua, Pindra, Cholapur, Chiraigaon and Arajiline) of Varanasi district were collected from the CGWB, Lucknow (Fig. 1). Number of rainy days (rainfall > 2.5 mm) and two extreme rainfall events were considered when rainfall of more than 50 mm and 100 mm occurred in a single day. The analysis of the data was performed through estimation of the long period average (LPA) and coefficient of variation (CV) of rainfall. Further, the monsoon rainfall was classified into deficient, normal, and excess on the basis of LPA and CV. When actual rainfall was less than the difference between LPA and CV, i.e., (LPA−CV) was classified as deficient monsoon rainfall, when actual rainfall was more than LPA and CV, i.e., (LPA + CV) came under excess monsoon rainfall, and normal monsoon rainfall when actual rainfall was within (LPA ± CV) (Narjary et al. 2014). Rainfall anomaly was calculated and correlated with El Nino and La Nina events to evaluate the effect of these phenomenon in this regional level. An increase in precipitation trend leads towards flooding whereas decreasing trend causes drought with normal water table conditions. Hence, as the trend detection is important, analysis was carried out through well-known non-parametric Mann-Kendall time-series test. To specify the extent of control of rainfall variability over water table, regression analysis was carried out (Generalized Additive model in Software R 3.4.3 version) (Ekeleme and Agunwamba 2018) (Fig. 2).

The non-parametric methods are widely used in detection of the trends in several hydrologic series, for example, rainfall, temperature, pan evaporation, and wind speed (Chattopadhyay 2007; Jhajharia et al. 2012). In this study, Mann-Kendall (MK) method (Mann 1945; Kendall 1975) was used for identifying the trends in rainfall and water table in Varanasi region. The Mann-Kendall test confirms the existence of the order of the trend, whether it is increasing or decreasing, by comparing the null hypothesis and alternate hypothesis. The null hypothesis, H_0, is assumed for that there is no trend, and alternative hypothesis, Ha, for that there is a trend (Onoz and Bayazit 2003). The null hypothesis was tested at 95% confidence level for both rainfall and water table data of Varanasi district. The statistic was obtained through

Table 1 Annual distribution of water table, water table deviation, rainfall, rainfall anomaly, and number of rainy days at Varanasi

Years	Water table (mbgl)			Water table deviation (m)	Total rainfall (mm)	Rainfall (mm)			Rainfall anomaly (%)	Total rainy days	Extreme rainfall	
	Pre	Mon	Post	Pre-post		Pre	Mon	Post			> 50 mm	> 100 mm
1992	9.6	8.74	8.21	1.36	826.2	31.5	737.7	36.5	− 6	56	4	0
1993	11.08	9.83	7.7	3.38	1130	63.6	1049.6	12.2	29	74	5	0
1994	9.66	9.34	6.81	2.85	653.2	4.7	627	0.9	− 25	84	2	0
1995	9.72	7.78	6.34	3.38	971.9	0.8	896.8	22.2	11	62	4	1
1996	8.73	5.82	6.19	2.54	1120	0	1008.7	20	28	62	6	0
1997	9.41	5.996	5.02	4.39	1066.2	0	908	147	22	70	3	1
1998	6.27	-	3.43	2.84	630.6	25.2	560.2	42	− 28	49	3	1
1999	7.73	-	2.63	5.1	1126	0	1076.5	29.8	28	83	4	1
2000	5.67	4.67	3.39	2.28	742.8	34.8	699.49	4.07	− 15	68	10	0
2001	7.28	3.45	2.8	4.48	895.7	0.54	753.24	141.9	2	77	14	1
2002	6.49	5.61	5.06	1.43	979.1	60	783.7	78.6	12	70	4	0
2003	8.57	3.49	4.51	4.06	1220.4	18.8	1069.5	29.8	39	92	4	1
2004	8	6.8	8.75	− 0.75	690.4	30.8	580.8	8.2	− 21	66	2	0
2005	10.53	6.7	8.82	1.71	772.8	65.9	549.7	78.6	− 12	50	3	0
2006	10.38	8.49	9.44	0.94	696.7	71.8	600.72	24.15	− 21	21	0	0
2007	11.31	8.7	9.77	1.54	901.1	79.8	702	48.7	3	30	1	1
2008	10.11	7.01	7.54	2.57	1025.6	33.6	963.6	0	17	30	2	0
2009	10.26	9.89	10.81	− 0.55	503	17.6	436.7	47.7	− 43	30	2	0
2010	11.95	12.13	11.31	0.64	655.5	58.2	391.9	57.9	− 25	29	2	0
2011	10.77	11.01	9.33	1.44	916.7	20.7	841.8	47	5	108	0	0
2012	12.96	11.12	10.43	2.53	737.7	18	685.1	6.4	− 16	44	0	0
2013	12.93	11.4	9.69	3.24	961.1	20	735.6	138.7	10	53	2	0
2014	12.46	9.96	10.48	1.98	826.2	35	688	84.8	6	64	4	1

Kendall's tau, p value, and Sen's slope. Kendall's tau (τ) is presented in (Eq. 1):

$$\tau = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \tag{1}$$

where n is the number of observations, and x_j is the j^{th} observation, and sign (θ) is defined as (Eq. 2):

$$\text{sign}(\theta) = \begin{matrix} 1 & if\,\theta > 0 \\ 0 & if\,\theta = 0 \\ -1 & if\,\theta < 0 \end{matrix} \tag{2}$$

Kendall's tau basically is the measure of correlation for describing the strength of the relationship between two variables. The test based on ranking of data values like other correlation analysis. The lowest value number as 1, and second lowest is 2 and so on. Kendall's tau takes values between − 1 and + 1. Positive correlation is indicated by observing the ranks of both variables while increasing together. Negative correlation indicates as the rank of one variable increase and the other decreases (Karmeshu 2012). In the case of time series analysis, two successive time intervals were considered for the correlation

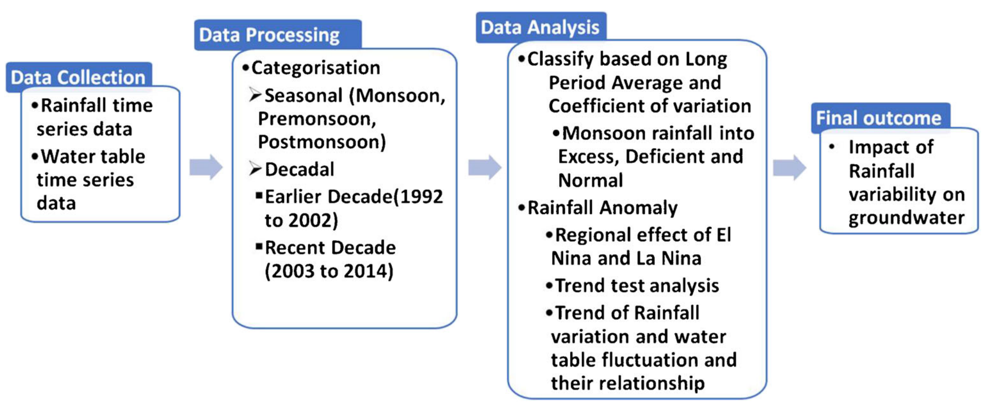


Fig. 2 Flow chart showing the overall methodology of the study

analysis. Initially, it assumes that there is no trend (i.e., the value of tau (τ) is assumed as 0). In comparison between two successive years, if the later time data value is higher than a data value of an earlier time, τ is elevated to 1. Similarly, if the later time data value is lower than a data value of earlier one, τ is decremented by 1. Therefore, τ with a high positive value is an indicator of an increasing trend, and a low negative value indicate a decreasing trend (Narjary et al. 2014).

The significance of the trends is determined by considering the p value. The significance level α (alpha) is allowed up to 0.05. If the p value is higher than the significance level α, H_0 is accepted ($p > 0.05$). Accepting H_0 ensures that there is no trend in the time series, while if the p value is less than the significance level α, H_0 is rejected. Rejecting H_0 confirms presence of trend in the time series. On rejecting the null hypothesis, the result is said to be statistically significant if the computed value of $p < p_\alpha$, in a two-sided test. The magnitude of the trend is estimated by Sen's slope estimation and is calculated using Eq. 3

$$T_i = \frac{x_j - x_k}{j - k} for i = 1, 2, 3, \ldots\ldots\ldots\ldots, N \quad (3)$$

where, x_j and x_k are data values at time j and k ($j > k$), respectively. The Sen's slope estimator is represented by β which is median of N values of Ti (Eq. 4):

$$\beta = T_{\left(\frac{N+1}{2}\right)} \; if N \; is \; odd$$
$$\beta = \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) \; if \; N \; is \; even \quad (4)$$

Positive and negative β indicates increasing and decreasing trend, respectively (Narjary et al. 2014).

Results and discussion

Significant changes had been observed in the frequencies and magnitudes of extreme monsoon rainfall events in the region. The analysis of rainfall showed that Varanasi received a mean annual rainfall of 876 mm (CV = 21.9%) during the period from 1992 to 2014. The total rainfall, monsoon rainfall, and rainy days showed decreasing trends while pre-monsoon and post-monsoon rainfall showed increasing trend (Table 2). The pre-monsoon and post-monsoon rainfalls contributed between 3 and 5%, respectively, with a slightly increasing trend (Fig. 3) to the total rainfall. The decreasing trend in total rainfall might be contributed by the annual rainfall (CV = 21.9%) and monsoon rainfall (CV = 27%) over the study period. Monsoon rainfall contributed 86% with CV of 27.4% to the annual rainfall. Monsoon rainfall classification indicated deficient rainfall during 10 years (5–42% lower than LPA), normal rainfall in

Table 2 Mann-Kendall test for rainfall, rainy days, and water table of different seasons

	Kendall's tau	Sen's slope	p value (two-tailed)	Alpha
January	− 0.060	− 0.039	0.710	0.05
February	0.060	0.05	0.710	0.05
March	0.188	0	0.250	0.05
April	0.148	0	0.362	0.05
May	− 0.017	0	0.935	0.05
June	0.067	1.13	0.677	0.05
July	0.174	4.458	0.256	0.05
August	− 0.356	− 10.1	0.019*	0.05
September	− 0.209	− 4.22	0.172	0.05
October	0.159	0.911	0.302	0.05
November	− 0.152	0	0.360	0.05
December	0.043	0	0.814	0.05
Total rainfall	− 0.115	− 5.9	0.465	0.05
Monsoon rainfall	− 0.162	− 8.54	0.295	0.05
Pre-monsoon rainfall	0.191	0.941	0.214	0.05
Post-monsoon rainfall	0.179	1.433	0.245	0.05
Rainy days	− 0.228	− 1	0.138	0.05
Monsoon water table	0.372	0.27	0.014*	0.05
Pre-monsoon water table	0.407	0.178	0.006*	0.05
Post-monsoon water table	0.423	0.228	0.004*	0.05
Water table deviation	− 0.217	− 0.075	0.156	0.05

*Significant trend observed

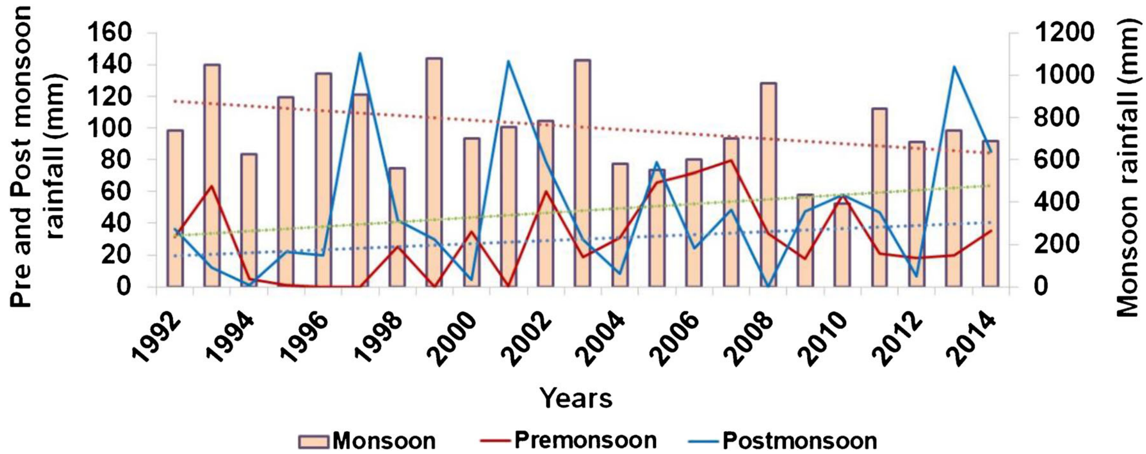


Fig. 3 Rainfall trend of different seasons at Varanasi region

1 year (2.2%), and excess rainfall in 12 years (2–39% higher than LPA) (Fig. 4). The comparison of last two decades' (i.e., 1992–2002 and 2003–2014) averages for the total rainfall of monsoon months (June to September) each showed that total average rainfall of June and July had increased by 1 mm and 20 mm, respectively, and decreased by 112 mm and 49 mm in August and September, respectively, from the previous decade to last decade. Last decade (2003–2014) witnessed less annual rainfall by 42 mm from the long-term normal rainfall, and the number of rainy days decreased by 8 days compared with normal rainfall, respectively. The means of monsoon, pre-monsoon, post-monsoon, total rainfall, and rainy days also showed negative trend in the last decade (Fig. 5). The frequency of 1-day extreme was maximum in August (50% of the total extreme rainfall) followed by that September and July (Fig. 6). The month of June received only two such extremes, which signified the shift of extreme rainfall events from June–July to August–September. Various parts of India underscore the fact that the pattern of extreme rainfall is changing (Pattanaik and Rajeevan 2010; Jain and Kumar 2012; Narjary et al. 2014). The shift in rainfall pattern is capable of potentially affecting the food productions, especially, the kharif production in this region as the food grain production in India largely depends on Indian Summer Monsoon Rainfall (Kumar et al. 2004; Mall et al. 2006). Therefore, though the extreme rainfall showed shifting trend in Varanasi region, the total rainfall complied with its usual distribution from June to September (Table 2).

The period from 1997 to 2000 was characterized by alternating positive and negative rainfall anomalies along with the occurrences of rainy days ranging from 49 to 83. Such fluctuations in rainfall may be logically linked to the El-Nino/ La Nina cycles. Generally, droughts are associated with the El Nino events and floods with La Nina events. Over the Gangetic Plain, a strong linear relationship has been found to exist between the El Nino events and droughts (Bhatla et al. 2015). The Gangetic Plain had witnessed four drought years, i.e., 1992, 2009, 2010, and 2012 (Bhatla et al. 2015).

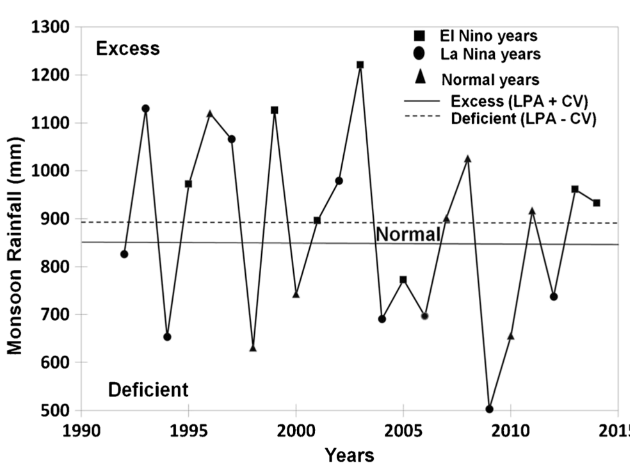


Fig. 4 Monsoon rainfall categorization as deficient, normal, and excess at Varanasi region

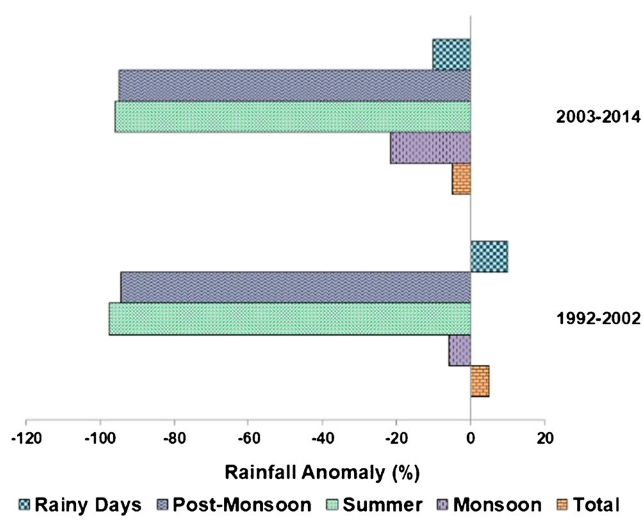


Fig. 5 Decadal variations of rainy days, total rainfall, and rainfall in different seasons

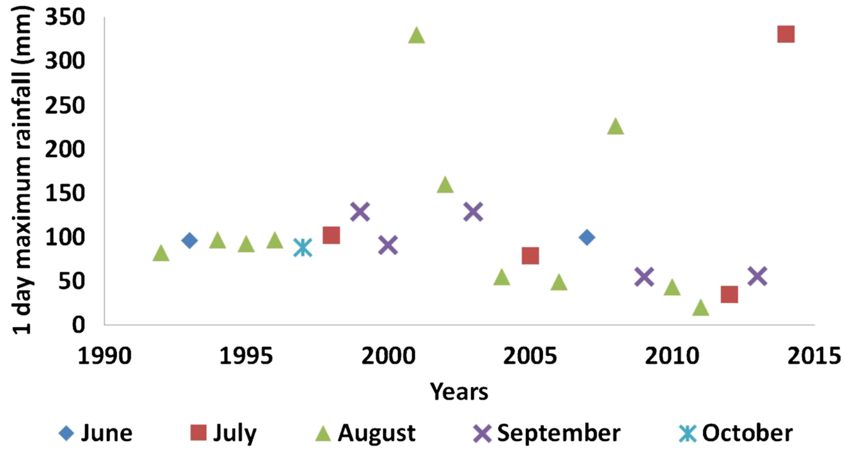


Fig. 6 Frequency of 1-day maximum rainfall in monsoon months at Varanasi district

However, Varanasi region experienced moderate scale droughts during 1994, 1998, 2009, and 2010 years. The largest negative expanse in rainfall anomalies were observed during the drought years. In Varanasi, negative anomalies were recorded during 1992, 1994, 1998, 2000, 2004, 2005, 2006, 2009, 2010, and 2012 years (see Table 1). Maximum rainfall negative anomaly in this area was noticed in 2009 which was an El Nino year, and the minimum water table fluctuation was also observed at that time probably caused by the less infiltration due to less rainfall activity.

On the other hand, 1998, 2000, and 2010 being La Nina years, Varanasi showed a negative rainfall anomaly and water table decrease in these years. Water table fluctuation was significantly high in 1997, 1999, 2001, and 2003. Among these years, a remarkable water table increase (4.39 m) was observed in 1997 which was an El Nino year. The rainfalls in these years are also higher than the LPA that might have allowed good infiltration to augment water table fluctuations. In spite of very low positive rainfall anomaly (2%) in the year 2001, water table fluctuation was found remarkably high (4.06 m) wherein, the year 2001 had received 14 days of extreme rainfall in 77 rainy days might have supported the raise of the water table. Hence, it has been observed that El Nino and La Nina conditions have failed to bear any adverse impacts on the variability in rainfall pattern in the Varanasi region and is clearly dependent on the amount of infiltration of the rainwater. Generally, higher occurrences of extremes are related with higher surface runoff, and in the study area, surface runoff may probably have risen with moderate infiltration. This spatiotemporal variability in rainfall pattern is likely to bring changes in crop production (Mall et al. 2006). Decrease in rainfall reduces soil moisture and excess rainfall increases storm runoffs. Excessive water due to the heavy rainfall causes more accumulated water runoff. It can be hazardous and may cause serious yield loss due to stagnation of excess water into the depressed zones from adjoining fields of high elevation (Narjary et al. 2014).

The water table ranged from 5.67 to 12.96 m in pre-monsoon, 3.45 to 12.13 m during monsoon, and 2.63 to 11.31 m in post-monsoon seasons (see Table 1). Water table fluctuation had a decreasing trend over the study period (see Table 2) which signifies the reduction in water storage (Fig. 7). Post-

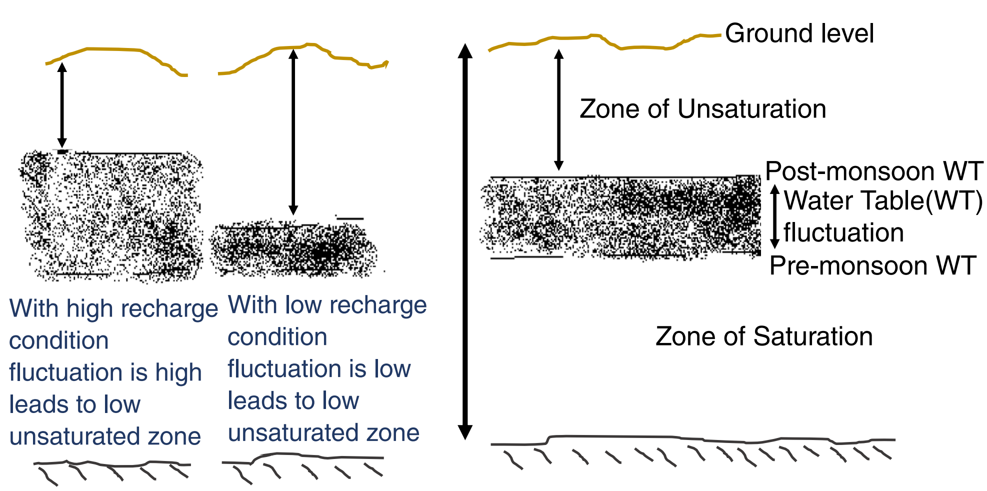


Fig. 7 Water table situation in the study area

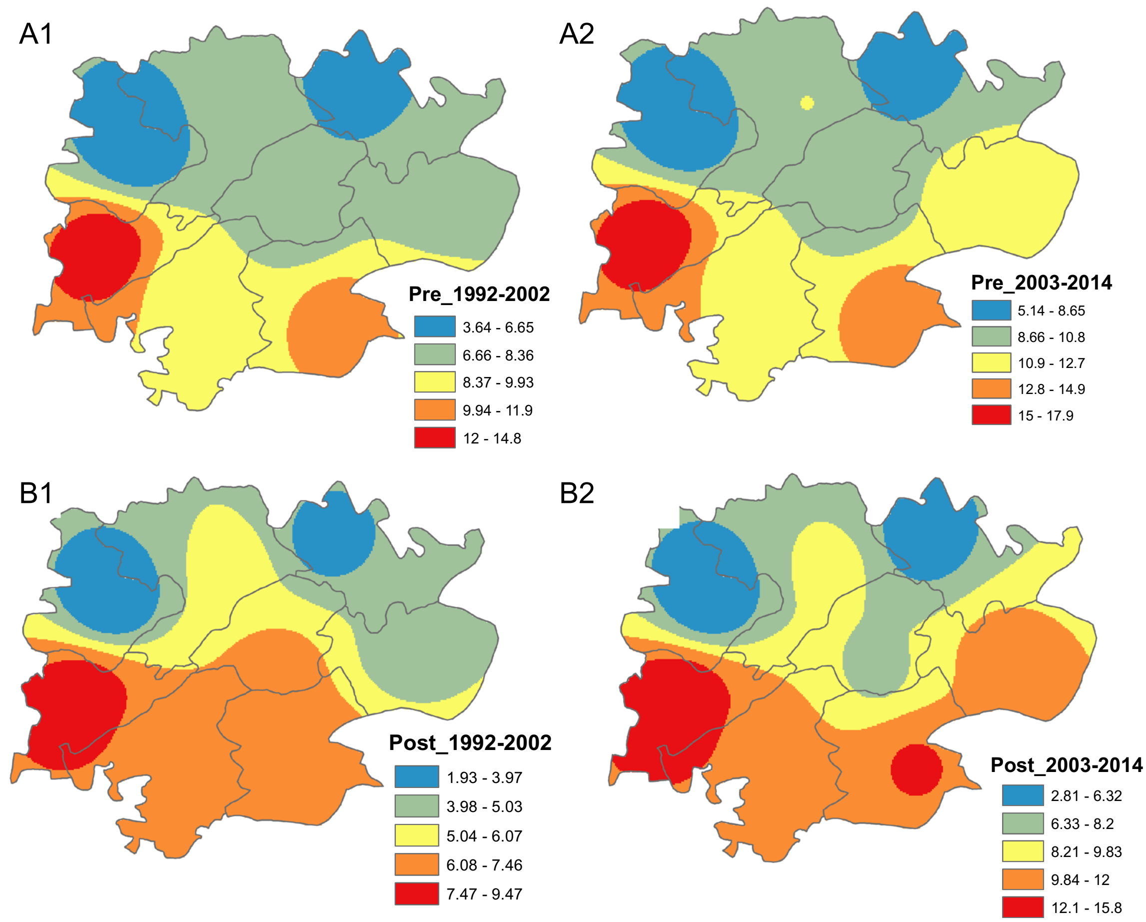
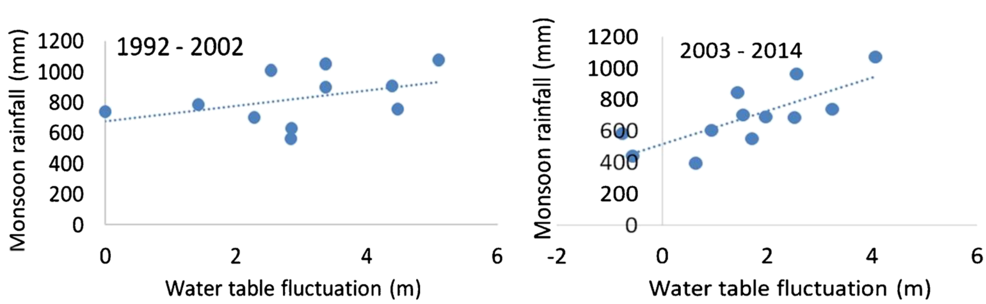


Fig. 8 Decadal distribution of pre-monsoon (**a**, **b**) and post-monsoon (**c**, **d**) water table (unit is in mbgl)

monsoon water table showed higher slope than pre-monsoon water table implying towards an insufficient recharge along with the high extraction in the consecutive years. The decreasing trend of rainfall in the study area also facilitates the low recharge conditions, which may drag the water table downward.

Decadal water table distribution showed that the area experienced less recharge during very recent decade compared with the earlier decade (Fig. 8). The area secured good recharge after monsoon rainfall in previous decade, and recent decade monsoon rainfall had less contribution in ground surface recharge (Fig. 9). Widespread agricultural activities in the district hold stronger connections for water table fluctuation when compared with the other anthropogenic activities. The district's more than 90% area issued for rice cultivation and depends on irrigation by groundwater (ACP 2012; CGWB 2014). All the blocks of the district are entirely dependent on groundwater for rice cultivation, and the irrigation is conducted mainly through tube wells (Fig. 10). Majority of the blocks were found to have witnessed considerable rise in area under irrigated rice during recent decade (Fig. 11). Maximum increase of 3.4% irrigation area under rice cultivation during recent decade was reported in Baragaon block, but contrastingly, water table fluctuation showed 2.5 m rise. The area is situated along the river Varuna and gained favorable conditions in terms of lithology and water availability rather than

Fig. 9 Relation between monsoon rainfall and water table deviation for two decades of study period



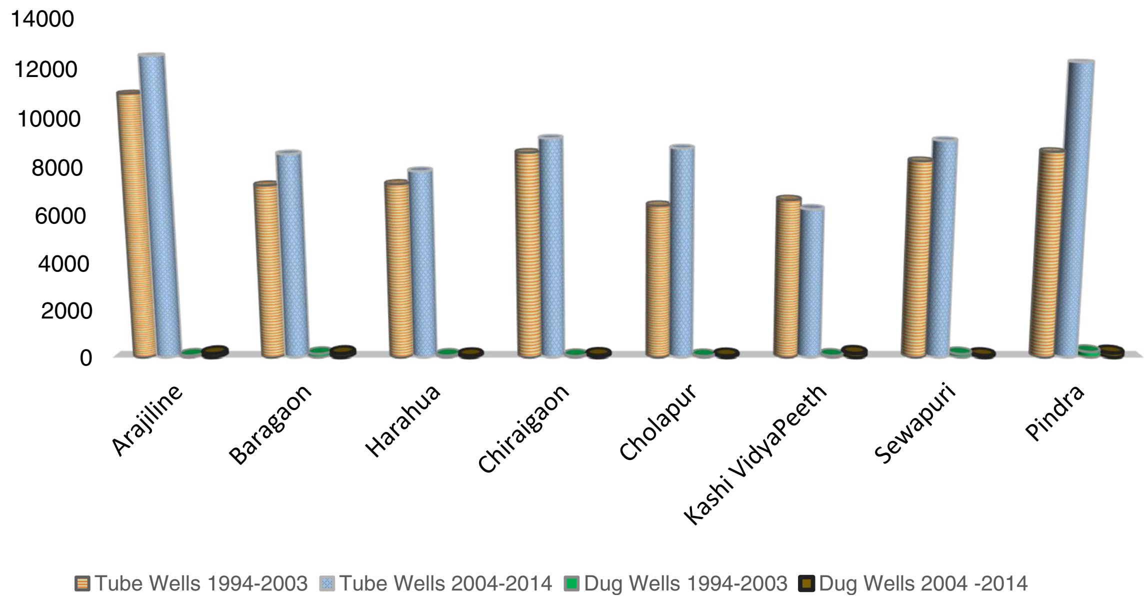
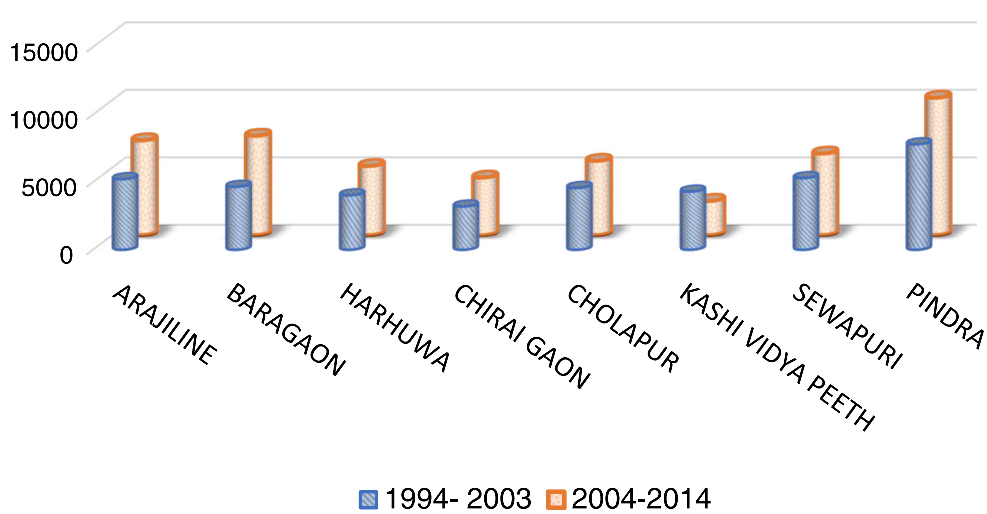


Fig. 10 Comparative overview of the area under rice irrigation through tube wells (source: Agriculture contingency plan for Varanasi district, Govt. of Uttar Pradesh, 2012)

other blocks, supported the increase in cultivation. Irrigation return flow due to intense irrigation activity in this region may also support the recharge and showed local rise in water table in recent years. On the other hand, Kashi Vidhyapeeth showed decrease (5.7%) in irrigation area of rice cultivation (Fig. 11) and irrigation through tube well (Fig. 10). Demographic study reveals that the particular block faces a remarkable rise in population (from 318,349 million to 456,326 million) (Fig. 12) in recent decade (Census Report 2011). The area alone contributes 26% of the total population growth of the district. Therefore, though Kashi Vidyapeeth is situated at the confluence of Ganga and its tributary Varuna, sufficient recharge still might not have been achieved for the heavily crowded city area endured by overexploitation. Hence, the intense cultivation of rice for most of the blocks and in the Kashi Vidyapeeth block excess domestic and industrial use may be the reason behind the decline in the respective water tables.

The maximum water table fluctuation had been noticed in the year 1999 (5.1 m) with 5-day extreme rainfall and 28% more rainfall along with 83 rainy days, which is higher than average number of rainy days (Table 1). A maximum rainfall anomaly was recorded in 2003 (+ 39%) which received 92 rainy days and was reflected in 4.06 m water table increment. During 2009, water table declined maximum (− 0.55 m) due to 43% decrease in rainfall, and only 30 rainy days were observed with 2 days (> 50 mm) of extreme rainfall. On the contrary, 2011 was marked by 108 rainy days along

Fig. 11 Decadal comparisons of rice cultivated areas in the blocks of Varanasi (source: Agriculture contingency plan for Varanasi district, Govt. of Uttar Pradesh, 2012)



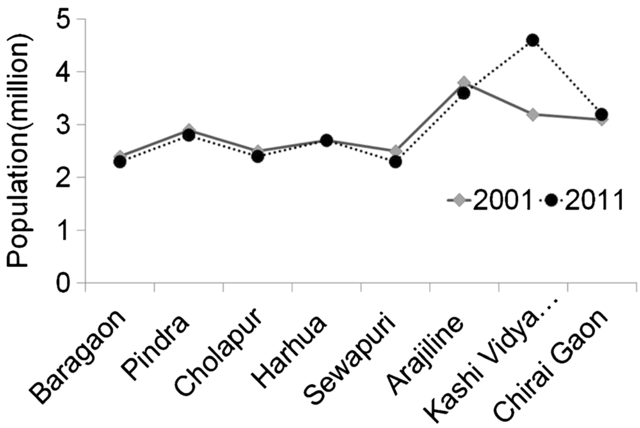


Fig. 12 Decadal variation of total population of the blocks of Varanasi

with normal rainfall witnessing only 1.44 m water table rise. The above fact showed the water table fluctuation of the region is mainly controlled by the rainfall variability.

A correlation between water table fluctuation and rainfall revealed the significant positive influence of monsoon rainfall (0.695) in water table (Table 3). Rainfall is not the sole controlling factor (evapotranspiration, land distribution pattern, etc.) for the recharge, and finally, groundwater table variation is a cumulative impact. In regression analysis, the coefficient of determination ($R^2 = 0.458$) represents that 45.8% variation of groundwater table is explained by monsoon rainfall. It has been also obtained from the Eq. 5 that 1 mm increase in rainfall leads to 0.005 m rise of ground water table.

$$\text{Groundwater table (m)} = -1.677352 + 0.005303\ \text{mm (Monsoon rain)}. \tag{5}$$

However, this study indicated that there are other factors apart from rainfall which have also significant influence on groundwater table fluctuation, but the groundwater has strong relationship with rainfall in the study area and is able to contribute significant role in water table fluctuation.

Conclusion

This study reveals that the water table fluctuation is strongly influenced by the rainfall variation in the study area. Overall observations showed that the area experienced both decreasing trend in rainfall and that in groundwater table. The assessment of rainfall variability and groundwater table fluctuations showed a significant linear relationship. Analysis of seasonal, annual rainfall, and rainy days showed statistically non-significant decreasing trends. The shift in the extreme rainfall had been noticed, but the total rainfall pattern has not changed in the recent years. Significant decreasing trend in August and non-significant decreasing trend in September specified the fact that monsoon rainfall dominated in June–July and became weak in August–September. Decreasing trend in water table was noticed in different seasons. Productivity of kharif would be hampered in the future due to the insufficient water availability as the increasing trend of extreme rainfall leads to run-off and less number of rainy days which create stress for irrigation in dry seasons. In most cases, major demand of water gets to be fulfilled with groundwater irrigation, which creates stress on aquifers. Apart from irrigation, a possibility of decrease in groundwater table may be due to the rise in population, which led to fast urbanization, mounting the use of groundwater. Global El Nino and La Nina conditions have meager impact on the changes of rainfall of this region, but water table is clearly dependent on the amount of infiltration of the rain water. These results indicate toward the necessity to formulate some adaptation strategies to mitigate the adverse impacts of the recent changes in rainfall pattern on groundwater as rainfall infiltration has great effect on groundwater recharge in this area and should consider to conserves every drop of rainwater so that the aquifers become productive during the lean period. Concurrently, considerations implemented toward the growing of less water-consuming crops, advancement of storage capacity of water resources by recharging, and augmenting different artificial methods for sustainable groundwater management is utmost necessary for the region.

Table 3 Correlation between the water table fluctuation and rainfall

	Water table fluctuation	Pre- monsoon rainfall	Monsoon rainfall
Pre- monsoon rainfall	− 0.493*		
	(0.017)		
Monsoon rainfall	0.695**	− 0.339	
	(0.000)	(0.114)	
Post-monsoon rainfall	0.259	− 0.108	− 0.092
	(0.233)	(0.624)	(0.676)

*Significant level at 0.05 level (2-tailed)

**Significant level at 0.01 level (2- tailed)

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