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Trend Analysis of Groundwater Level Using Non-Parametric Tests in Alluvial Aquifers of Uttar Pradesh, India

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Abstract

In the present study, groundwater level trends have been evaluated using the non-parametric methods i.e., Modified Mann-Kendall (MMK) and Sen's slope estimator during the period 1998 to 2012 at 13 locations in 4 districts of Lucknow division namely Hardoi, Laxmipur, Lucknow and Sitapur of Uttar Pradesh, India. The entire trend analysis has been verified at a significance level of 5 percent. The groundwater level trend analysis has shown negative values for 7 locations covering 54 percent area and positive values for 6 locations covering 46 percent area in pre-monsoon season. However, in post monsoon season, 4 locations covering 31 percent area exhibitednegative and 9 locations covering 69 percent area revealedpositive trends. The difference in the water level trends in two different seasons may be attributed to the recharge by rainfall in post-monsoon season.

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Keywords

Groundwater levels,
Modified Mann-Kendall,
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Introduction

Agriculture is the most important sector of Indian economy contributing about 18 percent to the Gross Domestic Product (GDP). India has about 61% net irrigated agricultural area playing a vital role in food security of the country[12,46]. Groundwater is one of the most used water sources for irrigation. Introduction of contemporary drilling techniques, electrical controlled pumping systems, nominal cost of electricity and groundwater legislation rules are not fully promised in the agriculturally advanced regions of the country. The major cause of depletion of fresh groundwater resources and increase of grey and dark areas in Indiaare related to large scale population, exploitation in agricultural sector and changes in land use patterns for urbanization[13,34]. In India, most of the states i.e., Delhi, Punjab, Haryana, Rajasthan, Uttar Pradesh, Gujarat, Tamil Nadu, Karnataka and Andhra Pradesh are suffering with groundwater depletion problem due to over extraction and mismanagement of water resources. However, fresh groundwater resources are finite entity[13] but in

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recent past, it was experienced that the demand of water for agricultural, domestic and industrial sectors is increasing day by day due population explosion and rapid urbanization. Hence, the other natural weather conditions i.e., precipitation, temperature, relative humidity etc. are almost similar or adverse. Due to all these issues, the groundwater table is declining from past few decades. It was also noticed that the intensive agriculture and rapid development in the industrial sector have put more pressure onavailable groundwater resourcesin the Indo-Gangetic Plains (IGP)[9,27-29,34,41]. This has resulted in the reduction of aquifer yield, drying of wells and ponds. However, pronounced effect can be seen in rabi season as compared to kharif season. The IGP has experienced low productivity in rabi season due to mismanagement of water resources and depletion of groundwater levels[5]. Any kind of technical studies are usually based on historical database related to the cyclic behavior of weather parameters. In the study of sustainable development and utilization of groundwater resources, it is required to know the behavior of historical climatic parameters and their trends. Sustainable groundwater resources assessment and mitigation for future prospective can be estimated by time series analysis of historical datasets. Time series analysis and its inter-annual variability is dependent upon weather conditions and geographical features. The trend analysis can be utilized for detecting the trend in long-term observed historical time series of groundwater level and its seasonal inter-variability over the specific duration. Further, it can be utilized for planning and mitigation aspects[14,20]. One of the best techniques for trend analysis using non-parametric method is Mann-Kendall test, and further its modified version named as Modified Mann-Kendall test[26, 35]. In recent past studies, it was also experienced that Mann Kendall test extensively used for analyzing the trend of hydro-meteorological parameters[8,28,40,42,47]. Stochastic analysis of time series has also been performed by various researchers[1,22,31,45]. Temporal time series of groundwater level trend is estimated by Allen (2010), in coastalBritish Columbia of Canada using the nonparametric Spearman's rank correlation coefficient[2].Gehrels *et al.,* (1994)[18] analyzed the fluctuations in surface water and groundwater levels in the, and have reported that the groundwater levels have declined over the wide area due to the drainage, drought and excess overdraft by the farmers. A non-parametric time series decomposition technique to determine trends and seasonality in groundwater levels in the Ganges-Brahmaputra-Meghna delta in Bangladesh[45]. Both non-parametric Mann-Kendall trend test and Sen's slope estimator were applied for groundwater trend estimation of Holocene unconfined aquifer (HUA) in Hanoi[25]. Tabari *et al.,* (2012)[49] investigated the temporal trends in annual, seasonal and monthly groundwater level fluctuations during 1985–2007 for north Iran using the Mann-Kendall test and the Sen's slope estimator[49]. Various researchers have reported similar type of studies worldwide i.e., Canada[15], Netherlands[18], Kuwait[4], Taiwan[23],Korea[33], China[55], Bangladesh[44], Iran[47]. In India, Thakur and Thomas (2011)used the non-parametric Kendall rank correlation test and the parametric linear regression test for detecting trend in the seasonal groundwater levels of Sagar district[51]. Similar studies have been carried out in Gujrat[37] and Orissa[38]. The results of such studies generally indicated mixed combination of negative and positive trends in the groundwater level time-series. However, best management practices need to be implemented for groundwater conservation as well as protection. So far, no such study has been carried out in the fertile alluvial aquifers of Indo-Gangetic plains in India. Therefore the data of the groundwater levels of four districts *viz.* Hardoi, Lakhimpur, Lucknow and Sitapur are utilized in the present study for the estimation of groundwater level trends using the non-parametric methods.

Materials and Methods

Study Area

The region of Indo-Gangetic plain is considered as most fertile land for agriculture purpose. Entire Uttar Pradesh state falls under the Indo-Gangetic Plain region. The Uttar Pradesh state is bound by Nepal on the North, Himachal Pradesh on the northwest, Haryana on the west, Rajasthan on the southwest, Madhya Pradesh on the south and south- west and Bihar on the east. The state spreads between 23°52' N and 31°28' N latitudes and 77°3' and 84°39' E longitudes. The land of the study area has the dominance of deep silty-loam soils, which are most suitable for agriculture production. The study area zone receives a e large amount of fresh water from the snow/glacier melting from the Himalayas. This water is responsible for groundwater recharge in the region. In the present study, thirteen locations were considered for groundwater level trend analysis under four districts namely as Hardoi, LakhimpurKheri, Lucknow and Sitapur. The location map of the study area is shown inFigure 1.

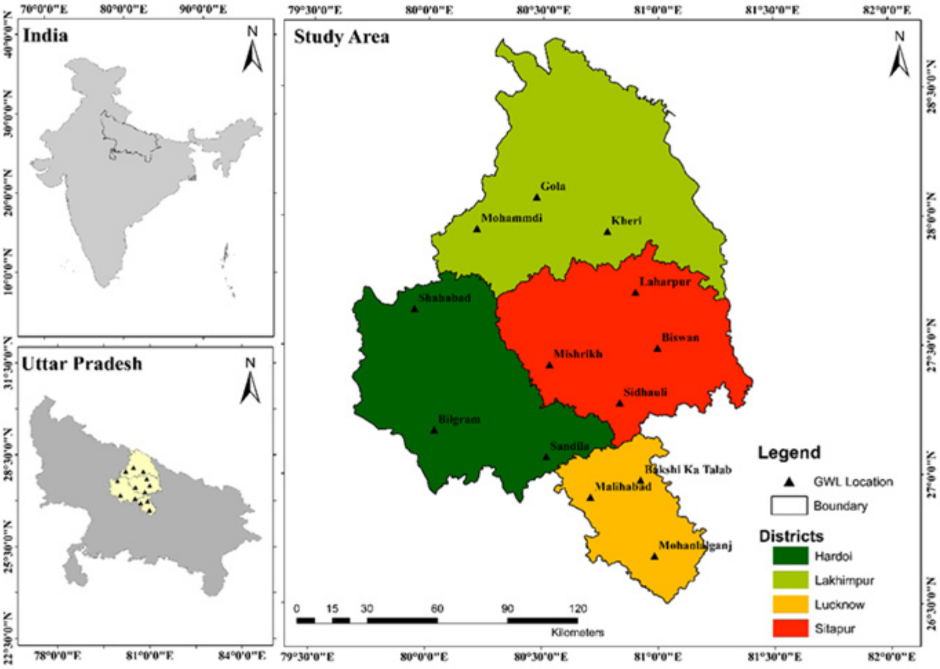


Fig. 1: Location map of study area

Data

Groundwater level data sets of pre-monsoon and post-monsoon seasons for the period 1998-2012 have been acquired from Central Ground Water Board (CGWB). Consistency of data has been checked by double mass curve technique before using the raw data. The entire data sets are segregated by two-part i.e., pre-monsoon and post-monsoon time step. The Location details of groundwater level stations are illustrated in Table 1.

Table 1: Location details of groundwater level station

District	Location of GWL Station	Latitude	Longitude
Hardoi	Bilgram	27.1735° N	80.0339° E
	Sandila	27.0729° N	80.5179° E
	Shahabad	27.6441° N	79.9447° E
Lakhimpur	Gola	28.0786° N	80.4716° E
	Kheri	27.9462° N	80.7787° E
	Mohammdi	27.9547° N	80.2135° E
Lucknow	BakshiKaTalab	26.9834° N	80.9235° E
	Malihabad	26.9168° N	80.7076° E
	Mohanlalganj	26.6895° N	80.9843° E
Sitapur	Biswan	27.4938° N	80.9965° E
	Laharpur	27.7101° N	80.9014° E
	Mishrikh	27.4293° N	80.5300° E
	Sidhauli	27.2821° N	80.8344° E

Mann-Kendall Test (MK Test)

The Mann–Kendall test[26,35] is a non-parametric test, which does not require the data to be distributed normally. The second advantage of the test is its low sensitivity to abrupt breaks due to in homogeneous time series[48]. MK test has been widely used by various researchers for detecting the trends in rainfall[30,35,39]. The non-parametric Mann-Kendall (MK) statistical test has been popularly used to assess the significance of the trend in hydrological time series. The test requires sample data to be serially independent[53,54].

The MK statistic, S, is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad ...(1)$$

where, x_1, x_2, x_3....x_n represents γ data points where x_j represents the data point at the time j of data (time series); and x_j - x_i = θ

$$Sgn(\theta) = \begin{cases} 1 & if\ \theta > 0 \\ 0 & if\ \theta = 0 \\ -1 & if\ \theta < 0 \end{cases} \quad ...(2)$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. (2) are given by Kendall (1975)[26] as (Dinpashoh *et al.,* 2011)[16]: E = [S] = 0

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad ...(3)$$

where m is the number of groups of tied ranks, each with t_i tied observations. The original MK statistic, designated by Z and the corresponding P-value (p) of the one-tailed test was computed as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{If } S > 0 \\ 0 & \text{If } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{If } S < 0 \end{cases} \quad ...(4)$$

$$p = 0.5 - \phi(|Z|)$$

$$\phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-\frac{t^2}{2}} dt \quad ...(5)$$

If the p-value is small enough, the trend is quite unlikely to be caused by random sampling. The Z values are approximately normally distributed, and a positive Z value larger than 1.96 (based on normal probability tables) denotes a significant increasing trend at the significance level of 0.05, whereas a negative Z value lower than -1.96 shows a significant decreasing trend.

Modified Mann Kendall Test (MMK Test)

In Modified Mann-Kendall test, the effect of all significant autocorrelation coefficients is removed from a data set[19]. For this purpose, a modified variance of S, designated as Var(S)*, was used as follows:

$$Var(S)^* = V(S)\frac{n}{n^*} \quad ...(6)$$

where, n*= effective sample size. The n/n* ratio was computed directly from the equation proposed by Hamed and Rao (1998)[19] as:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n=1} (n-1)(n-i-1)(n-i-2)ri \quad ...(7)$$

where, n= actual number of observations: and ri=lag-i significant autocorrelation coefficient of rank i of time series. Once Var(s)* was computed from Eq. (6), then it is substituted for Var(S) in Eq. (4). Finally, the Mann-Kendall Z was tested for significance of trend comparing it with threshold levels at 5% level of significance is about 1.96.

Sen's Slope Estimator

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated using a simple nonparametric procedure developed by Sen (1968)[43]. It has been widely used for determining the magnitude of the trend in hydro-meteorological time series[48,50]. In this method, the slope estimates of N pairs of data are first calculated using the following expression as:

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1,2,3,\ldots\ldots,n \qquad \ldots(8)$$

where, x_j and x_k are data values at time j and k(j>k) respectively. The median of these N values of Q_i is sen's estimator of slope which is calculated as:

$$\beta = \begin{cases} Q_{[(N+1[N/2])/2]} & N \text{ is odd} \\ \frac{1}{2}\left(Q + Q_{(N+2)/2}\right) & N \text{ is even} \end{cases} \qquad \ldots(9)$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series data.

Inverse Distance Weighted (IDW)

In the present study, the inverse distance weighted (IDW) interpolation technique has been used for the spatial maps usingpreparation of coefficient of variation in groundwater levels during pre-monsoon and post-monsoon season[32,48]. The inverse distance weighting tool is already available in ArcMap 10.4. In the IDW methodology, the weight of any known point is set to be inversely proportional to its distance from the estimated point. It is calculated as follows:

$$\hat{x} = \frac{\sum_{i=1}^{n} \frac{1}{d_i} x_i}{\sum_{i=1}^{n} \frac{1}{d_i}}$$

where: x = value to be estimated; x_i= known value; d_1, d_2, d_3, …, d_n= distance from the n data points to the point estimated n.

Results

Continuous records of pre-monsoon and post-monsoon groundwater levels are important parameters to study the water table fluctuation trends. The differences between pre-monsoon and post-monsoon water levels, represents the combined effect of groundwater recharge and draft in a region. The Z-statistics value of MMK test has been presented at 5 percent level of significance (Table 3). However, there are four major cases i.e., negative significant, negative, positive, and positive significant and values are less than -1.96, -1.96 to 0, 0 to 1.96 and more than 1.96, respectively. The Sen's slope estimator values are indicating the magnitude of GWL fluctuations for rising or declining trends.

Pre-processing

In any time series analysis, pre-processing of raw data is necessary step. However, in present study, various missing values were presented in raw data. Proper gap filling of missing data are required, so the double mass curve technique has been utilized for filling missing value and the data consistency was checked accordingly. Further, entire time series segregated into two parts e.g., pre-monsoon and post-monsoon during 1998 to 2012. Further, general statistical parameters i.e., mean, standard deviation and coefficient of variation have been for each station for both pre-monsoon and post-monsoon periods. Further, each time series has been treated as separate set for the analysis of MMK test and for estimating Sen's slope.

Statistical Analysis

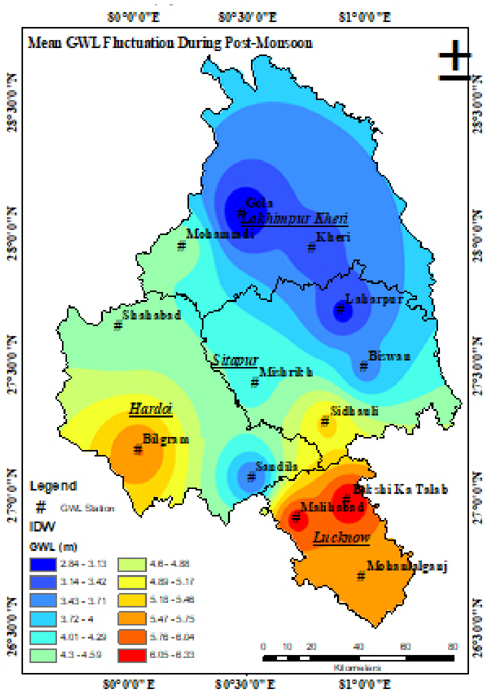
In the present study, mean, standard deviation (SD) and coefficient of variation (CV) have been calculated for all thesites during pre-monsoon and post-monsoon seasons. In pre-monsoon season, the values of mean, SD and CV are varying from 4.29 m (Gola) to 8.48 m (Malihabad), 0.45 (Shahabad) to 2.46 (Malihabad) and 7.79 % (Shahabad) to 28.98 % (Malihabad) respectively. Whereas, in post monsoon season it falls 2.84 m (Gola) to 6.33 m (BakshiKaTalab), 0.52 (Gola) to 1.69 (Malihabad) and 14.42 % (Shahabad) to 27.43 % (Malihabad) respectively. The detailed station-wise GWL fluctuations and its statistics are presented in Table 2.

Table 2: General statistics of Groundwater levels during 1998 to 2012

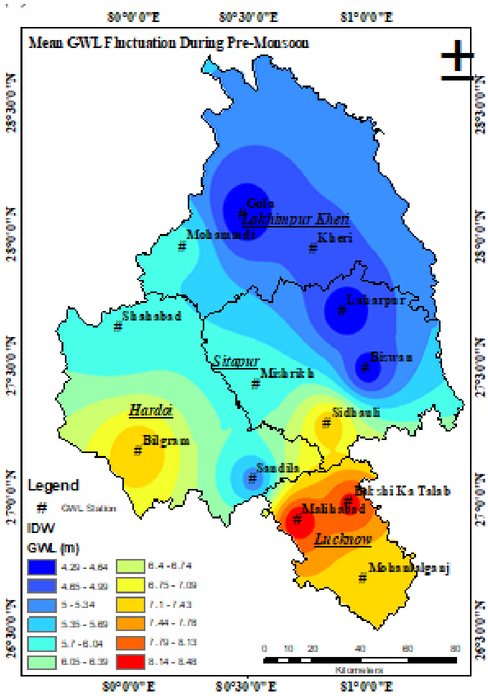
District	Block	Station	Pre-Monsoon			Post-Monsoon		
			Mean	SD	CV	Mean	SD	CV
Hardoi	Bilgram	Bilgram	7.41	1.33	17.91	5.76	1.22	21.20
	Sandila	Sandila	5.16	0.61	11.87	3.41	0.82	24.07
	Shahabad	Shahabad	5.71	0.45	7.79	4.46	0.64	14.42
Lakhimpur	Gola	Gola	4.29	0.75	17.43	2.84	0.52	18.33
	Kheri	Kheri	4.85	0.79	16.19	3.28	0.58	17.51
	Mohammdi	Mohammdi	5.80	0.56	9.71	4.44	0.76	17.08
Lucknow	BakshiKaTalab	BakshiKaTalab	8.25	0.78	9.41	6.33	1.35	21.31
	Malihabad	Malihabad	8.48	2.46	28.98	6.16	1.69	27.44
	Mohanlalganj	Mohanlalganj	7.22	0.95	13.14	5.72	1.16	20.27
Sitapur	Biswan	Biswan	4.44	0.78	17.49	3.61	0.68	18.92
	Laharpur	Laharpur	4.33	0.81	18.77	3.06	0.81	26.39
	Mishrikh	Mishrikh	5.81	0.62	10.64	4.24	0.73	17.25
	Sidhauli	Sidhauli	7.31	0.64	8.71	5.24	0.89	16.94

Spatial Analysis of CV values of GWL

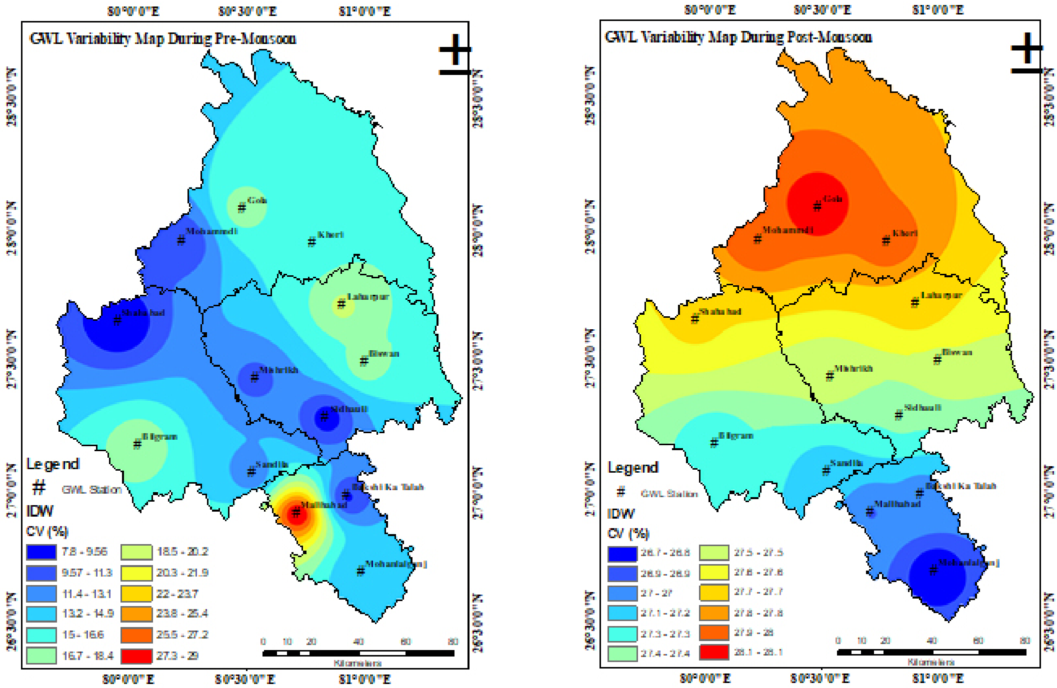
In this section spatial maps have been prepared on the basis of mean GWL and CV (%) values of all station during 1998 to 2012. Initially, spatial maps have been prepared for pre-monsoon and post monsoon periods using Inverse Distance Weightage (IDW) technique and ArcMap 10.4 software shown in Figure 2 (a) & (b). Furthermore, spatial map of GWL fluctuation on the basis of CV (%) values during pre-monsoon and post-monsoon seasons have been illustrated in Figure 2 (c) & (d).



(a) Pre-monsoon



(b) Post-monsoon



(c) Pre-monsoon **(d) Post-monsoon**

Fig. 2: Mean groundwater level fluctuation in (m) during pre-monsoon (a & c) and (b) post-monsoon (b & d) period 1998-2012

Groundwater Level Trend Analysis during 1998-2012

Results of Modified Mann Kendall

In present study, results are estimated by two parts - pre-monsoon and post-monsoon. In pre-monsoon season out of 13 stations, 7 locations are showing negative and remaining 6 are positive. However, the magnitude of GWL varies from -0.108 m/yr (Bilgram station of Hardoi) to 0.295 m/yr (Malihabad station of Lucknow). Whereas, in post-monsoon season out of 13 stations, 4 locations are showing negative and remaining 9 are positive trend. However, the magnitude of GWL varies from -0.228 m/yr (BakshiKaTalab station of Lucknow) to 0.234 m/yr (Malihabad station of Lucknow).

Z-statistics of entire 13 locations during pre-monsoon season varies from -3.107 to 2.926. In pre-monsoon season, 7 locations are showing declining trend and remaining 6 are showing rising trend. However, out of them Gola and Mohammdi stations are showing significant declining trend and Malihabad and Laharpur station are showing significant rising trends at 5% level of significance, respectively. In post-monsoon season, 4 locations are showing declining and remaining 9 are showing rising trend. However, out of them BakshiKaTalab station is showing significant negative trend and, Malihabad, Laharpur and Mishrikh stations are showing significant positive trends at 5% level of significance, respectively. The overall result of MMK test and Sen's slope is summarized in Table 3.

Table 3: Results of Modified Mann Kendall test statistic (Z) and Sen Slope estimator (β) test for pre-monsoon and post-monsoon during 1998-2012

District	Hardoi			Lakhimpur			Lucknow			Sitapur			
Block	Bilgram	Sandila	Shahabad	Gola	Kheri	Mohammdi	BakshiKa Talab	Malihabad	Mohan lalganj	Biswan	Laharpur	Mishrikh	Sidhauli
β (PRM)	-0.108	-0.020	0.035	-0.103	-0.082	-0.058	-0.051	0.295	0.053	-0.071	0.130	0.073	0.057
β (PTM)	-0.096	0.020	0.064	-0.038	-0.002	-0.046	-0.228	0.234	0.139	0.027	0.108	0.057	0.055
Z (PRM)	-0.765	-0.495	1.441	-3.107a	-1.711	-2.251a	-1.126	2.701b	1.216	-1.801	2.926b	1.756	1.126
Z (PTM)	-1.336	0.099	1.584	-0.990	0.000	-0.990	-2.573a	2.029b	1.683	0.643	2.227b	2.489b	0.581

where, a and b values show significant increase & decrease at 5% significant level. Negative (−) & positive (+) values indicate the declining&rising trends.

Discussion

Pre-monsoon and post-monsoon mean groundwater level fluctuations varied from 4.29 to 8.48 and 2.84 to 6.33, respectively. Malihabad and Bakshi KaTalab location of Lucknow district had maximum groundwater extraction in both pre and post monsoon periods. Hence, it varies from 7.79 to 8.48 and 5.76 to 6.33 in pre and post monsoon seasons, respectively. As compared to all the stations, south and south-western zone were identified as groundwater depletion zones. The overall water demand of Lucknow and Hardoi is greater due to the slightly higher populations of 45,88,455 and 40,91,380, respectively (Census, 2011) as compared to Sitapur and LakhimpurKheri district having populations 44,74,446 lakhs and 40,21,243 lakhs, respectively (Census, 2011)[11]. The rising trends indicate an increasing depth of water level from ground surface and declining trend indicates the decreasing depth of water level from the ground surface. Hence, most of the location of Lucknow and Sitapur are showing the significant rising trend(s) that means the groundwater table is declining in these locations due to over extraction of groundwater.

Conclusions

Long term groundwater fluctuation trends indicate the effect of groundwater withdrawal and recharge on changes in water stored in aquifer, which is required for assessing the groundwater potential available for utilization. Modified Mann-Kendall test performed on time series data of pre-monsoon groundwater levels in various district of Uttar Pradesh showed significantly increasing trend (increasing depth of water level from ground surface) in pre -monsoon groundwater levels during 1998-2013 and post-monsoon ground water levels showed significantly increasing trend (increasing depth of water level from ground surface) in post- monsoon during 1998-2012. The magnitude of GWL varies from -0.108 m/yr (Bilgram station of Hardoi) to 0.295 m/yr (Malihabad station of Lucknow) during pre-monsoon and magnitude of GWL varies from -0.228 m/yr (BakshiKaTalab station of Lucknow) to 0.234 m/yr (Malihabad station of Lucknow)during post-monsoon. Most of the locations of Locknow and Sitapur showedthe significant rising trend(s) that means the groundwater table is getting down at these locations due to over extraction of ground water. Hence, the best management strategies are needed to conserve the groundwater storage at particular places. The study revealed that the MMK test is an appropriate tool to identify the historical trends of groundwater level changes. The results from the study can be useful for planning and managing the water resources, agriculture and sustainable development of the state. Also, such findings are important for any strategic planning for future.

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