SPATIO-TEMPORAL TREND ANALYSIS OF GROUNDWATER LEVEL IN UNNAO DISTRICT, UTTAR PRADESH, INDIA

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Abstract: Groundwater, a precious natural resource, is the main source of water in many parts of the world. India is the largest user of groundwater in the world, with an estimate use of 230 cubic kilometers of groundwater every year, which is more than a quarter of the global level. The trend of groundwater levels has been also analyzed in different blocks of the Unnao district, Uttar Pradesh. The analysis revealed a declining trend in groundwater levels in most of the wells. Mann Kendall's trend test was used to explore the trend in groundwater levels obtained from the Central Ground Water Board using long-term data (1985-2011) for a network of 45 observation wells. Results indicates that about 49%, 53% and 58% wells showed downward trends in the pre-monsoon season and about 11%, 13% and 16% wells showed upward trends at 1%, 5% and 10% significance level, respectively. In the post-monsoon season, about 49%, 56% and 58% wells showed downward trend and about 11%, 13% and 13% wells showed upward trend at 1%, 5% and 10% significance level, respectively. The rate of the trend has been also estimated using Sen Slope estimator. The results are further verified with the satellite images of 1986 and 2009, indicating that the salt-affected and waterlogged areas have decreased over time, which may be attributed to increased usage of groundwater. These results provide useful information to ensure sustainable groundwater development.

Keywords: Groundwater, Hydrogeological, Mann-Kendall's

I. INTRODUCTION

Groundwater is a natural and most widely distributed precious resource to meet the requirements for different purposes such as irrigation, domestic and industrial (Reghunath et al., 2005; Ahmadi and Sedghamiz, 2007). The increasing dependence on groundwater has resulted in its indiscriminate extraction in various parts of the country leading to the decline of groundwater level. On the other hand, several parts of the country are suffering from problems of water logging and soil salinity due to rise in groundwater levels. This is due to the lack of groundwater development and management. Therefore, monitoring the groundwater levels and interpretation of the trends over time are important for the proper management of groundwater resources. The trend analysis of hydrological series is important as excessive decline in water table has an adverse effect on environment and is associated with land subsidence and global climate change (Bihrat, 2003; Sarkar, 2009). However, lack of frequent and adequate data over a long-term often limits the investigation of the temporal trend of groundwater level as monitoring of groundwater level is expensive as well as time and labor consuming (Tabari *et al.*, 2011).

A number of parametric and non-parametric tests have been used for trend detection. Parametric trend test requires data to be independent and normally distributed. On the other hand, a non-parametric test does not require the data to follow any particular statistical distribution and can tolerate outliers in the data (Hamed and Rao, 1998; Kisi and Ay, 2014). Hence, non-parametric tests are more suitable for non-normally distributed data, such as groundwater levels (Yue *et al.*, 2002; Caloiero *et al.*, 2011). The best known non-parametric test is based on the Mann-Kendall's test and has been used by various researchers to understand long-term trends in groundwater levels (Tabari et al., 2011; Vousoughi et al., 2013; Machiwal and Jha, 2014; Ribeiro et al., 2014).

Helsel and Hirsch (1992) and Thakur and Thomas (2011) investigated the changes in the values of a random variable over some period of time using non-parametric test. Tabari (2011) determined the temporal trends in groundwater level using Mann Kendall's test and Sen's slope estimator. Machiwal (2013) identified the long-term trend of annual rainfall time series and pre-monsoon and post-monsoon groundwater levels. Ribeiro (2014) used Mann-Kendall's test to detect monthly trends of piezometric time series and their magnitude. The non-parametric Mann-Kendall statistical test was used in this study for a monotonic and piece wise trend analyses of the time-series data. The objective of this study is to examine the trend in the groundwater level of the Unnao district. The series of graphs of groundwater level trends at selected observation wells has been shown. The resulting trend derived from the Mann Kendall's test has been further analyzed and explained using the satellite image, geomorphology map and canal command area.

II. Study Area

The Unnao district in the central part of Uttar Pradesh, India forms the study area having a geographical area of 4558 km^2. It lies between latitudes 26º06′ and 27º03′ North and longitudes 80º03′ and 81º03′ East (Figure 1). The maximum and minimum temperature ranges between 45ºC and 3ºC, respectively, during summer and winter with a normal annual rainfall of 837.80 mm with rainy days experiences sub-tropical climate. The district is mainly drained by the Ganga River and its tributaries Kalyani,

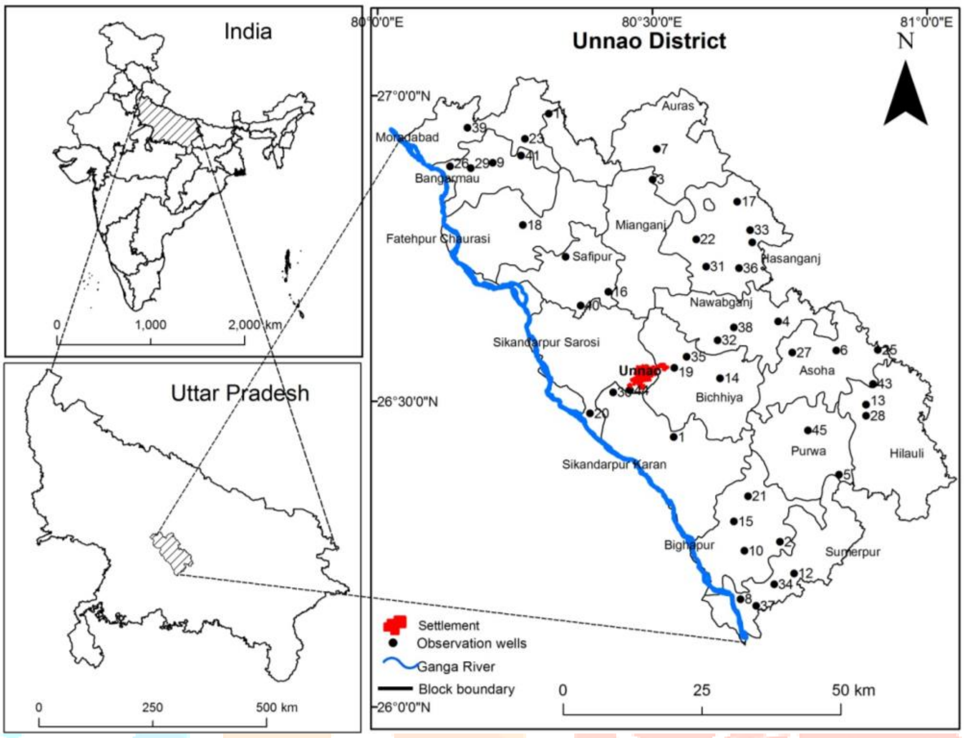


Figure 1. Location of Study area

Khar, Loni and Morahi in the western part and by the Sai River in the eastern part. The occurrence and movement of groundwater in the district is mainly governed by topography, geomorphology, lithology, landuse and their interrelationships. Geologically, the district forms a part of the vast Indo-Gangetic alluvial plain. The alluvium formation of the district comprises of sand, silt & clay with kankar and gravel. The older alluvium called bhangar, forms slightly elevated terraces usually above the flood levels. About 87% of the area of net shown area (3, 00,000 hectares) is irrigated by both surface water (Sharda Canal network system) and ground water through shallow and moderately deep tube wells. The share of surface water irrigation is 48% while that of ground water is 52%. The economy of the district mainly depends upon agriculture. The District is divided into 5 Tehsils: Unnao, Hasanganj, Safipur, Purwa & Bighapur and 16 development Blocks shown in Figure 1.

Geomorphological mapping was carried out by a visual interpretation of Landsat Enhanced Thematic Mapper plus (ETM+) image of 11 Oct 2006. Three broad geomorphic units have been identified in the district: an active flood plain, older flood plain and alluvial plain. In the older flood plain, the following landforms have been identified: older flood plain-Meander Scar (OFP-MS), older flood plain-Terrace T1 (OFP-T1), and older flood plain-Terrace T2 (OFP-T2). The alluvial plain consists of various landforms described as: alluvial plain- Marsh (AP-M), alluvial plain- Oxbow Lake (AP-OL), alluvial plain- Meander Scar (AP-MS), and alluvial plain- Paeleochannel (AP-P).

2.1 Groundwater Level

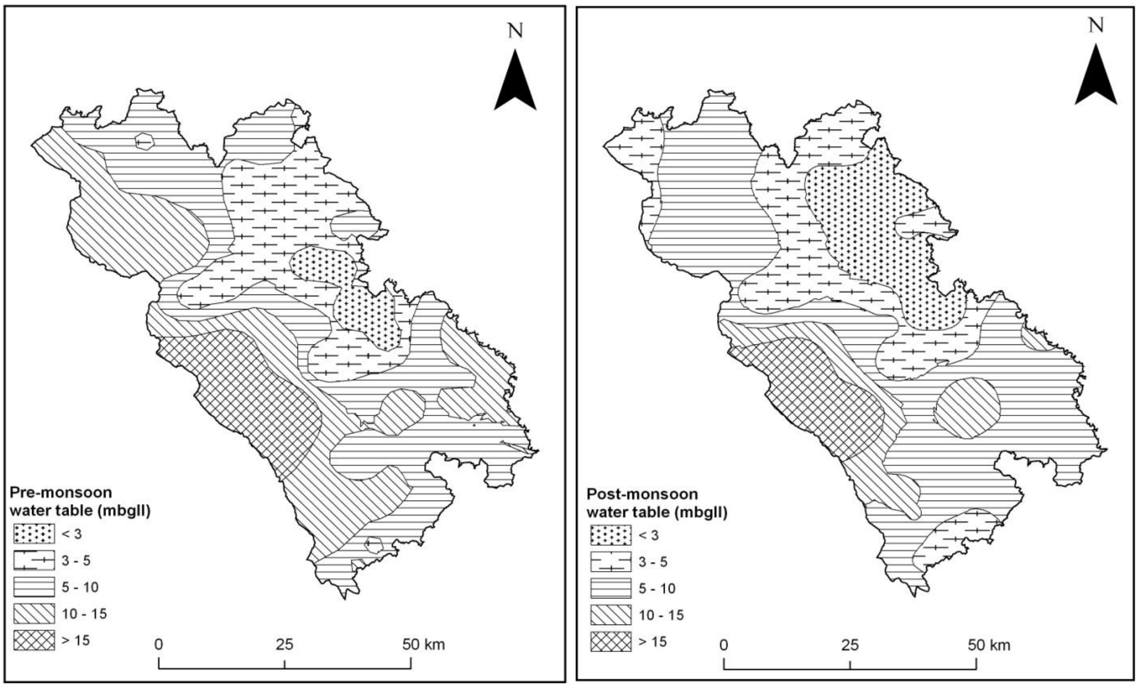
Groundwater is being replenishable and dynamic in nature; it becomes essential to assess the qualitative and quantitative changes in the groundwater regime in time and space. Groundwater occurs in the pore spaces of the unconsolidated alluvial material in the zone of saturation. Data collected from CGWB and SGWB have been utilized in the preparation of depth to water table map.

2.3.1 Depth to water table

Depth to water table map for pre-monsoon and post-monsoon has been prepared using IDW interpolation technique. Water table varies between 1.9 to 18 mbgl for pre-monsoon season and 1.8 to 17 mbgl for post-monsoon season. The deep water table conditions are found to occur in the central west part of the study area. The depth to water table is divided into five zones: < 3, 3 – 5, 5 – 10, 10 – 15 and > 15 mbgl. Figure 2 shows the depth to water table in pre-monsoon and post-monsoon season for the year 2011. The water table in most of the area lies between 5 – 10 mbgl in both the pre-monsoon and post-monsoon season. In post-monsoon season, the depth of water table is shallow in the eastern part of the study area, which shows combined effect of rainfall and seepage through canal beds.

2.3.2 Groundwater movement

The elevation of the water table varies between 98 m to 132 m above mean sea level (amsl). Spatial distribution of groundwater level map in amsl is prepared by subtracting the elevation acquired from SRTM data with water table data. Then, these points were interpolated using IDW interpolation. The spatial distribution of reduced groundwater level and groundwater flow direction is shown in Figure 3. Groundwater flows along the ganga river in the west and Sai river in the east. Groundwater flow is from north towards south-west and south-east. The Ganga and Sai appear to be effluent in nature. The hydraulic gradient of the area ranges from 0.13 m/km in the central and northern part to about 0.16 m/km in the southern sector. This indicates that slope of the



water table is very gentle depicting the permeable nature of shallow aquifer.

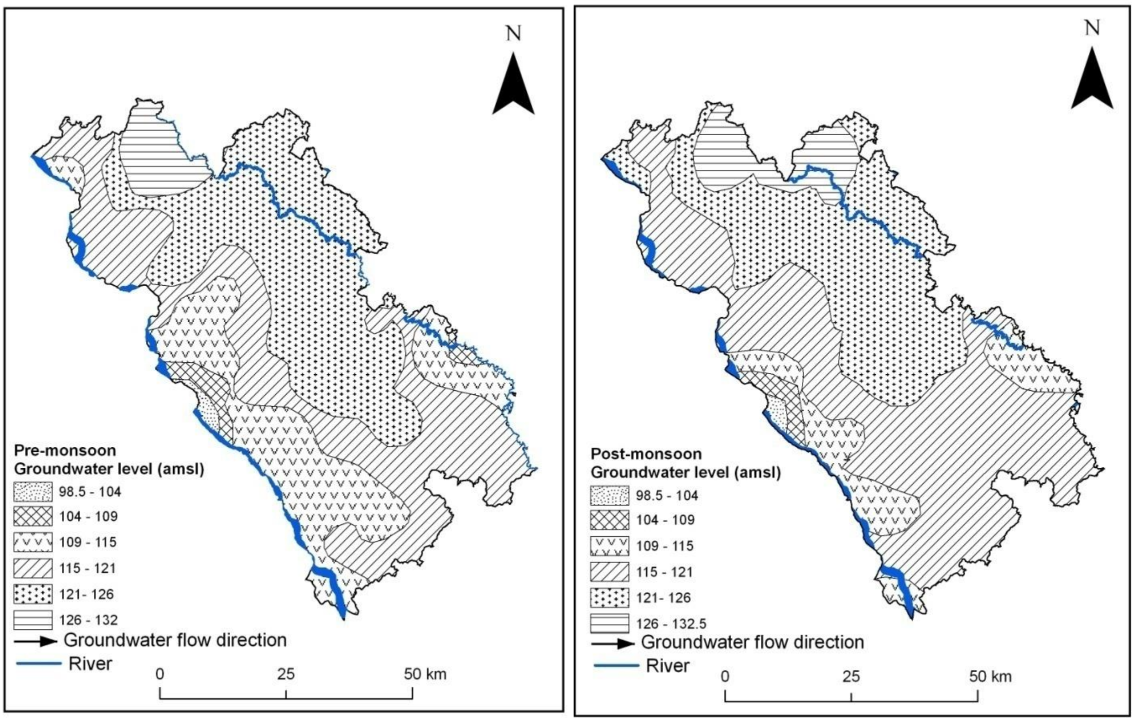


Figure 2. Spatial distribution of pre-monsoon (left) and post-monsoon (right) water table in mbgl

Figure 3. Spatial distribution of pre-monsoon (left) and post-monsoon (right) groundwater level

2.3.3 Piezometric head

There are no latest data available for piezometric head. The analysis has been done on the basis of data of year 1986. Piezometric surface ranges between 8.80 to 12.32 mbgl lying above the second aquifer. Auto-flowing condition has been recorded at Bharshar Naushara with a piezometric head of 2.3 m above ground level.

III. Research Methodology

3.1 Long-Term Groundwater Level Trend

The purpose of determining trend is to analyze the changes in the values of a random variable over a period of time by using relevant statistics (Helsel and Hirsch, 1992; Thakur and Thomas, 2011). Parametric and non-parametric tests have been applied for trend detection. The non-parametric Mann-Kendall statistical test is used in this study for monotonic and piecewise trend analyses of the time-series data. One of the objectives of this study is to examine the trend in the groundwater level of the study area. The Mann Kendall's trend test has been used to explore the trends in groundwater levels using long-term data (1985-2004) for a network of 45 observation wells available in the Unnao district during the pre-monsoon and post monsoon season.

For spatio-temporal analysis, it is important to properly prepare and understand the data used in the study. The box-plot and graphical representation of data show the distribution of data. The box contains the center 50th percentile of the data and a horizontal line within the box indicates the median. The top edge of the box is the 75th percentile and the bottom edge is the 25th percentile (boundaries of the box). Vertical lines called whiskers extend to the last observation within one step beyond either end of the box. One-step is defined as 1.5 times the Interquartile range (IQR) (difference between the 75th and 25th percentiles). Data points that fall outside one step are considered outliers, and values that fall outside of two steps are labeled extreme. Figure 4. shows the box plot of the groundwater level data describing the extreme values such as mean, median for 16 blocks. The horizontal lines of the rectangle correspond to the lower, middle and upper quartile. The mean is displayed as '+', and a horizontal black line corresponds to the median. Values lying between the upper and lower limit are represented as 'o' and outside the limits are shown as '•'. The blue rhombuses correspond to the minimum and maximum values. B1-B16 represents the 16 blocks of the Unnao district following the sequence Asoha, Auras, Bangarmau, Bichhiya, Bighapur, Fatehpur Chaurasi, Ganj Moradabad, Hasanganj, Hilauli, Miyanganj, Nawabganj, Purwa, Safipur, Sikandarpur Karan, Sikandarpur Sarosi, and Sumerpur, respectively. The box plot show that the mean of the groundwater level ranges from 3 to 11 mbgl for a period of 26 years (1985-2011). The higher value of IQR for Asoha, Bangarmau, Sikandarpur Karan and Sikandarpur Sarosi indicates a large variation of groundwater levels in these blocks.

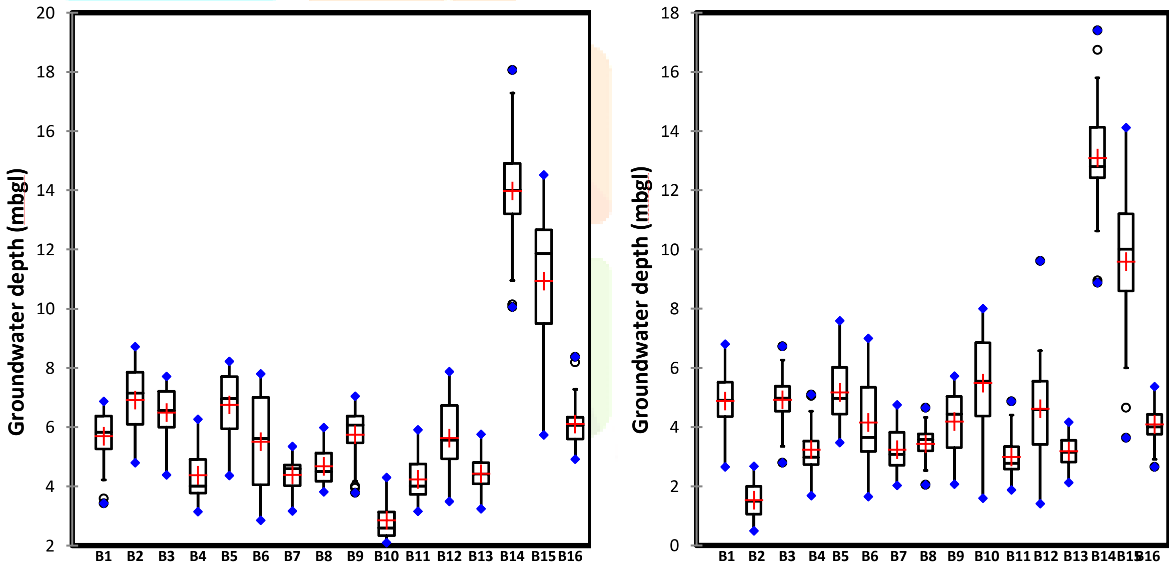


Figure 4. Box-plot of (a) Pre-monsoon groundwater depth (b) Post-monsoon groundwater depth for all blocks of the study area.

3.2 Mann-Kendall's Test

Mann (1945) proposed this test and Kendall (1975) subsequently derived the test statistic distribution. The Mann-Kendall test is a non-parametric trend test that does not require any particular distribution of data (Gilbert, 1987). The Mann-Kendall test has been widely used to test for randomness against trends in hydrology (Hirsch et al., 1982). The Mann-Kendall's test considers only the relative values of all terms in the series $X=\{x_1, x_2,\ldots,x_n\}$ to be analyzed. In this test, the null hypothesis H_0 states that the series X is a sample of n independent and identically distributed random variables having no trend (Yu et al., 1993). The alternative hypothesis H_1 of a two-sided test is that the distribution of x_i and x_j are not identical for all i; $j \le n$ with $i \ne j$ (Kahya and Kalayci, 2004).

The Mann Kendall's test statistic S is given by:

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

Where x_i and x_j are the sequential data values and n is the number of data points, and

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1 & if \quad (x_j - x_i) > 0 \\ 0 & if \quad (x_j - x_i) = 0 \\ -1 & if \quad (x_j - x_i) < 0 \end{cases} \quad \ldots (2)$$

under the null hypothesis of no trend and the assumption that the data are independent and identically distributed, the zero mean and variance of the S is computed as:

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} n_p(n_p-1)(2n_p+5)\right] \quad \text{... (3)}$$

Where *n* is the number of observations, q is the number of tying groups and n_p is the number of data in the pth tied group (Gilbert, 1987). For n>10, the standard normal variant Z is computed as follows (Douglas *et al*., 2000; Kahya and Kalayci, 2004):

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

Thus, in a two-tailed test for trend, the null hypothesis H0 is either rejected or accepted depending on whether the calculated Z is more than or less than the critical value of Z obtained from the normal distribution table at a significance level of α. Therefore, the values of Z are computed and if the values are within the limits of -1.96 and 1.96, the null hypothesis that the series has no trend cannot be rejected at the 5 % level of significance using a two-tailed test. GIS determined the spatial patterns of trends and the results were interpreted.

IV. Results And Discussion

The detailed hydrogeological investigation shows the presence of the three aquifers in the study area. The top aquifer extends upto 90 mbgl. The middle entity is disposed of in the depth range 100 m to 250 m, and the lower one is found to extend and appears to continue beyond 400 m depth within the maximum achieved a drilled depth of 400 mbgl. These three main aquifers are separated by impermeable clay beds. While the first aquifer is mainly unconfined, the second and third aquifers are confined in nature. The water levels in the shallow wells suggest that a subtle groundwater divide running NW-SE exists in the area dividing the groundwater flow system into two sub-flow systems, one draining towards Ganga River (i.e. towards west) and the other towards Sai River i.e. (towards east).

The results of the Mann Kendall's test for pre and post-monsoon groundwater levels at different significance levels are summarized in Table 1. A histogram of the percentage of wells for pre-monsoon and post-monsoon season at different significant levels is shown in Figure 5. The spatial variations of groundwater level trends for different observation wells during pre-monsoon and post-monsoon seasons are shown in Figure 6.

Table 1. Trends in groundwater levels at different well sites during pre-monsoon and post-monsoon periods.

S. No.	Well Location	Pre-monsoon			Post-monsoon		
		Slope (m/year)	τ	Trend	Slope (m/year)	τ	Trend
1	Achalganj	-0.231***	-0.587	⬇	-0.261***	-0.67	⬇
2	Ajaikhera	-0.095***	-0.593	⬇	-0.123***	-0.484	⬇
3	Arsena	–	–	➡	–	–	➡
4	Asakhera	0.059***	0.507	⬆	0.086***	0.465	⬆
5	Asgharganj	-0.126***	-0.613	⬇	-0.138***	-0.791	⬇
6	Asoha	-0.087***	-0.484	⬇	-0.086***	-0.484	⬇
7	Auras	0.098***	0.507	⬆	0.138***	0.47	⬆
8	Baksar	0.1**	0.333	⬆	–	–	➡
9	Bangarmau	–	–	➡	–	–	➡
10	Bara	-0.133***	-0.597	⬇	-0.157***	-0.527	⬇
11	Behta Mujawar	–	–	➡	–	–	➡
12	Bhagwantnagar	-0.051**	-0.345	⬇	-0.093**	-0.282	⬇
13	Bhawaniganj	-0.032*	-0.254	⬇	-0.1***	-0.45	⬇
14	Bichhia	0.05***	0.43	⬆	0.04***	0.362	⬆
15	Bisenmau	-0.211***	-0.684	⬇	-0.194***	-0.646	⬇
16	Chakhalwansi	–	–	➡	-0.009**	-0.305	⬇
17	Dhaura	–	–	➡	–	–	➡
18	Fatehpur Chaurasi	-0.179***	-0.775	⬇	-0.165***	-0.726	⬇
19	Gajauli	-0.113***	-0.399	⬇	-0.165***	-0.667	⬇

S. No.	Well Location	Pre-monsoon			Post-monsoon		
		Slope (m/year)	τ	Trend	Slope (m/year)	τ	Trend
20	Gangaghat	-0.35***	-0.792	⬇	-0.391***	-0.883	⬇
21	Gauri	–	–	➡	–	–	➡
22	Gazaffarnagar	-0.07***	-0.476	⬇	-0.056***	-0.504	⬇
23	Gosha Qutab	-0.066**	-0.339	⬇	-0.081***	-0.471	⬇
24	Hasinatganj	–	–	➡	–	–	➡
25	Jabraila	-0.113***	-0.59	⬇	-0.15***	-0.866	⬇
26	Jagatnagar	-0.23***	-0.877	⬇	0.111**	0.274	⬆
27	Kantha	–	–	➡	–	–	➡
28	Kudra	-0.119***	-0.628	⬇	-0.105***	-0.595	⬇
29	Madarnagar	-0.124***	-0.65	⬇	-0.169***	-0.643	⬇
30	Magarwara	-0.188***	-0.786	⬇	-0.191***	-0.761	⬇
31	Makdudpur	–	–	➡	–	–	➡
32	Malawan	–	–	➡	–	–	➡
33	Mohan	-0.043***	-0.419	⬇	-0.047***	-0.393	⬇
34	Mudiankhera	–	–	➡	–	–	➡
35	Murtazanagar	–	–	➡	–	–	➡
36	Nai Sarai	0.098*	0.248	⬆	–	–	➡
37	Naraindaskhera	0.16***	0.558	⬆	0.148***	0.484	⬆
38	Nawabganj	0.077***	0.369	⬆	0.064***	0.393	⬆
39	Pacha Purwa	-0.026*	-0.239	⬇	-0.034*	-0.268	⬇
40	Pawa	-0.087***	-0.633	⬇	-0.027**	-0.276	⬇
41	Rasulabad	-0.065***	-0.415	⬇	-0.104***	-0.44	⬇
42	Safipur	-0.1***	-0.618	⬇	-0.083***	-0.376	⬇
43	Sandauli	-0.091***	-0.658	⬇	-0.159***	-0.717	⬇
44	Singrosi	-0.275***	-0.712	⬇	-0.245***	-0.738	⬇
45	Shitalganj	-0.198***	-0.68	⬇	-0.2***	-0.675	⬇

****significance level (α) = 0.01;* ***significance level (α) = 0.05;* **significance level (α) = 0.1*
⬇ *decreasing trend;* ⬆ *increasing trend;* ➡ *no trend*

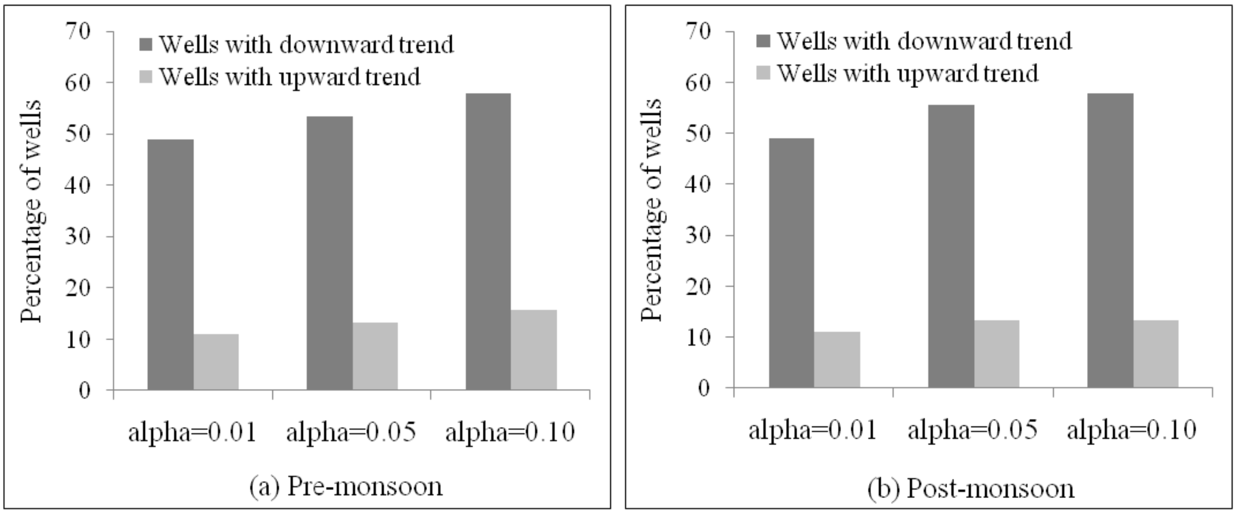


Figure 5. Histogram of the percentage of wells for pre-monsoon and post-monsoon season at different significant levels

In trend analysis, it is also important to determine the rate from which the trend is either decreasing or increasing. For calculating rate, Sen slope has been estimated for various wells. The slopes of the different well sites are interpolated using an IDW interpolation. Spatial variations of slope are shown in Figure 7. The negative values with large magnitude show that the water table is declining at higher rate. Here, in the central western of the study area, rate of lowering of water table is higher whereas the eastern part having positive values shows the upward trend. This area falls near Sai River and contains dense canal network. This upward water table can be due to surface water irrigation and seepage from canals.

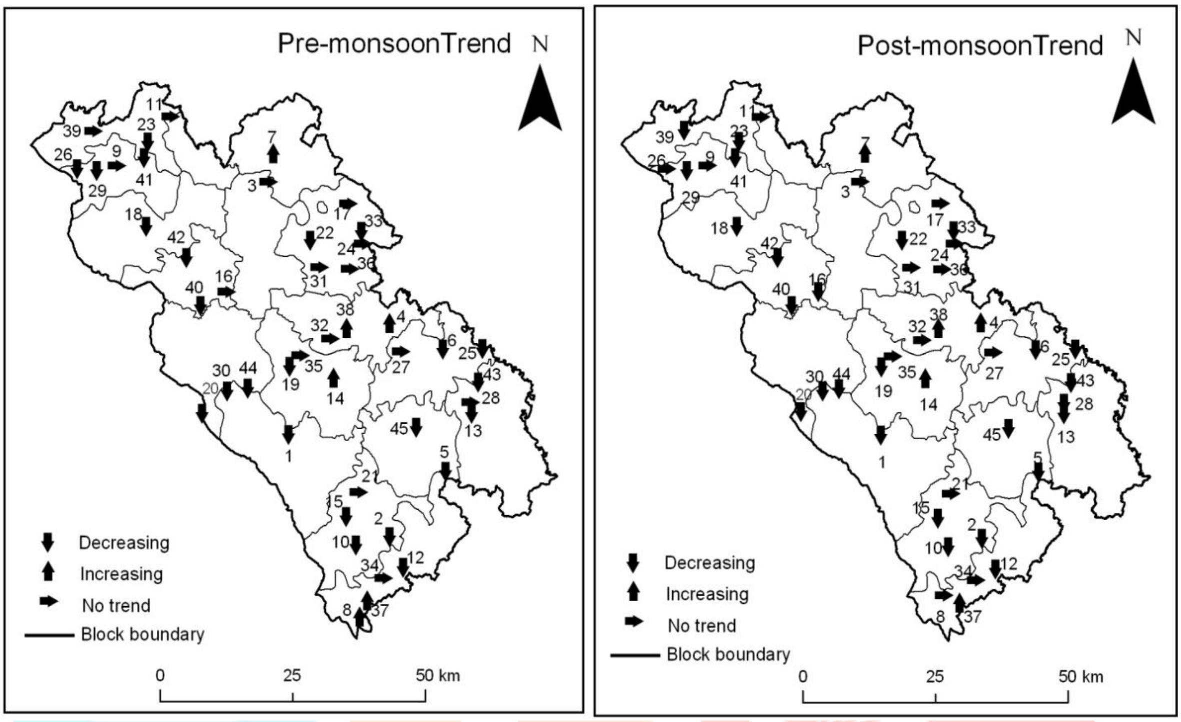


Figure 6. Spatial variation of groundwater level trend in pre-monsoon and post-monsoon season

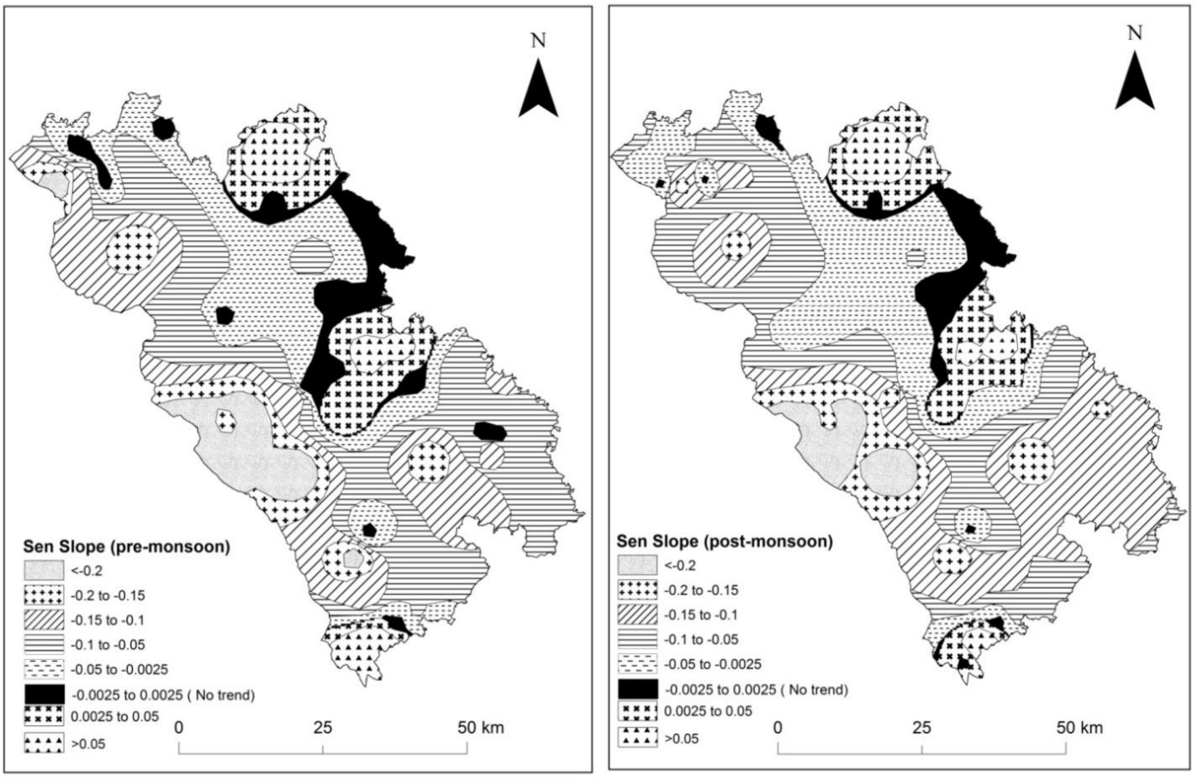


Figure 7. Spatial variation of Sen slope in pre-monsoon and post-monsoon season

The plots of the trends in the pre-monsoon and post-monsoon season for selected wells are shown in Figure 8. As for the results, in the pre-monsoon season, about 49%, 53% and 58% wells showed downward trends and about 11%, 13% and 16% wells showed upward trends at 1%, 5% and 10% significant level, respectively (Table 2). Magnitude of upward or downward trends in groundwater levels during pre-monsoon and post-monsoon periods is shown in Table 3. This downward trend can be due to the high pumpage of water and less recharge, while most of the well sites showing upward trend are located near a river or a canal.

However, 51% of the wells showed a downward trend and 11% showed an upward trend in both the pre-monsoon and post-monsoon season. These results provide useful information for groundwater analyses required to ensure sustainable groundwater development.

Table 2. Percentage and number (shown in parenthesis) of wells showing downward or upward trends in groundwater levels at different significance levels.

	Downward Trend			**Upward Trend**		
	α = 0.01	α = 0.05	α = 0.1	α = 0.01	α = 0.05	α = 0.1
Pre-monsoon	48.9 (22)	53.3 (24)	57.8 (26)	11.1 (5)	13.3 (6)	15.6 (7)
Post-monsoon	48.9 (22)	55.6 (25)	57.8 (26)	11.1 (5)	13.3 (6)	13.3 (6)

Table 3. Magnitude of upward or downward trends in groundwater levels (α = 0.1) during pre-monsoon and post-monsoon periods.

	Downward Trend			**Upward Trend**		
	Minimum (m/year)	Maximum (m/year)	% of wells	Minimum (m/year)	Maximum (m/year)	% of wells
Pre-monsoon	0.03	0.35	57.8	0.01	0.39	15.6
Post-monsoon	0.05	0.16	57.8	0.04	0.15	13.3

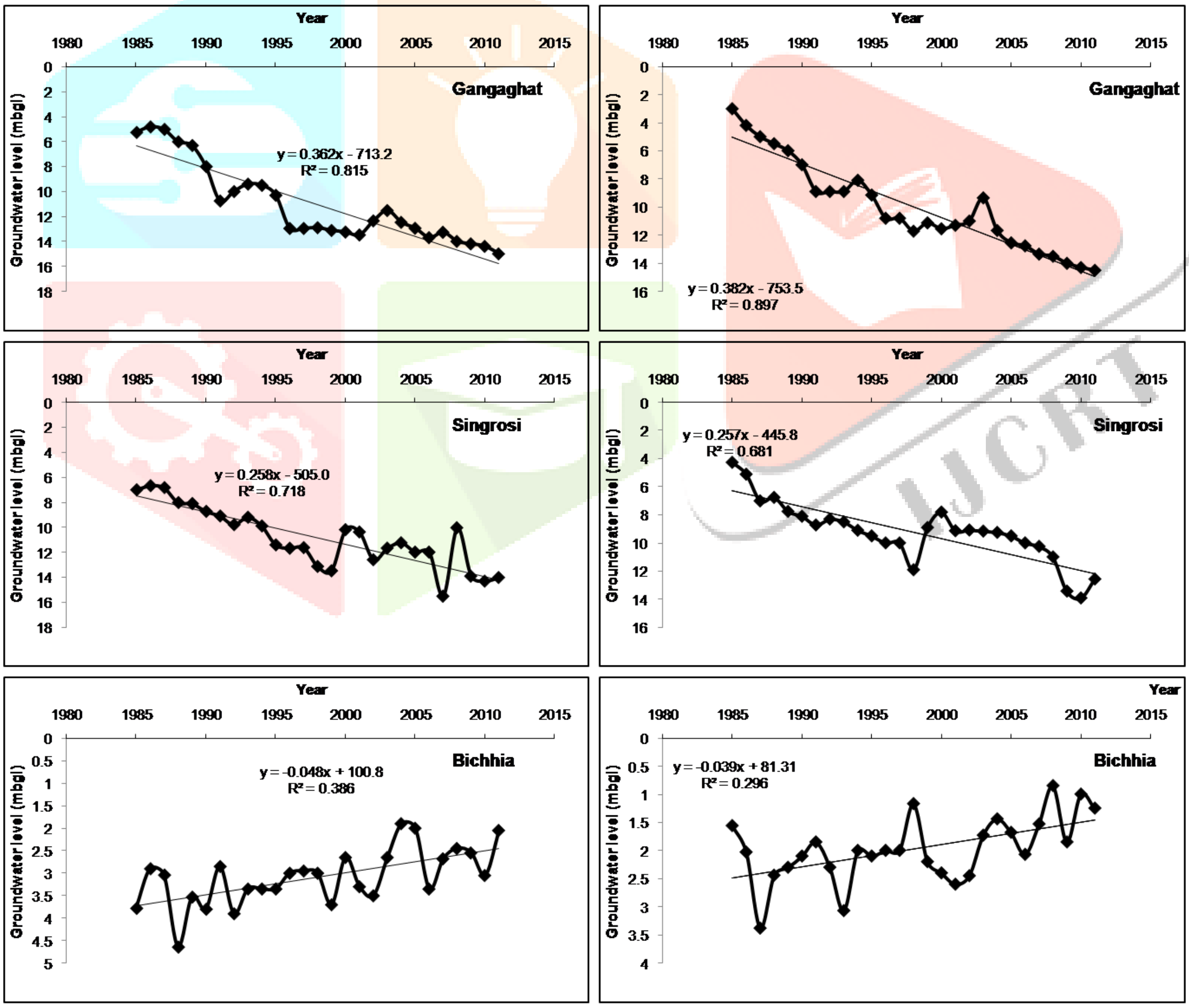


Figure 8. Long-term trend with fitted linear equation of groundwater depth for selected wells in pre-monsoon and post-monsoon season.

It is a known fact that rise in water table induces the water logging and the salts and minerals of the sub-surface soil come to the surface. It makes the area salt-affected, which is not good for most of the crops. The salt-affected region in the eastern part of the study area is clearly visible on the satellite image of year 1986 as shown in Figure 9. It is due to the upward rise of water table in this region due to intense canal network and other reasons. Government of UP has started U.P. Sodic Lands Reclamation Project in

1990s, which has resulted in reduction of salt-affected land by various measures (mixing of gypsum with the soil, flooding the fields and adopting particular crop cycle etc.). This has caused the decrease in salt-affected land as visible in satellite image of year 2009, while the upward rising trend of water table still exists.

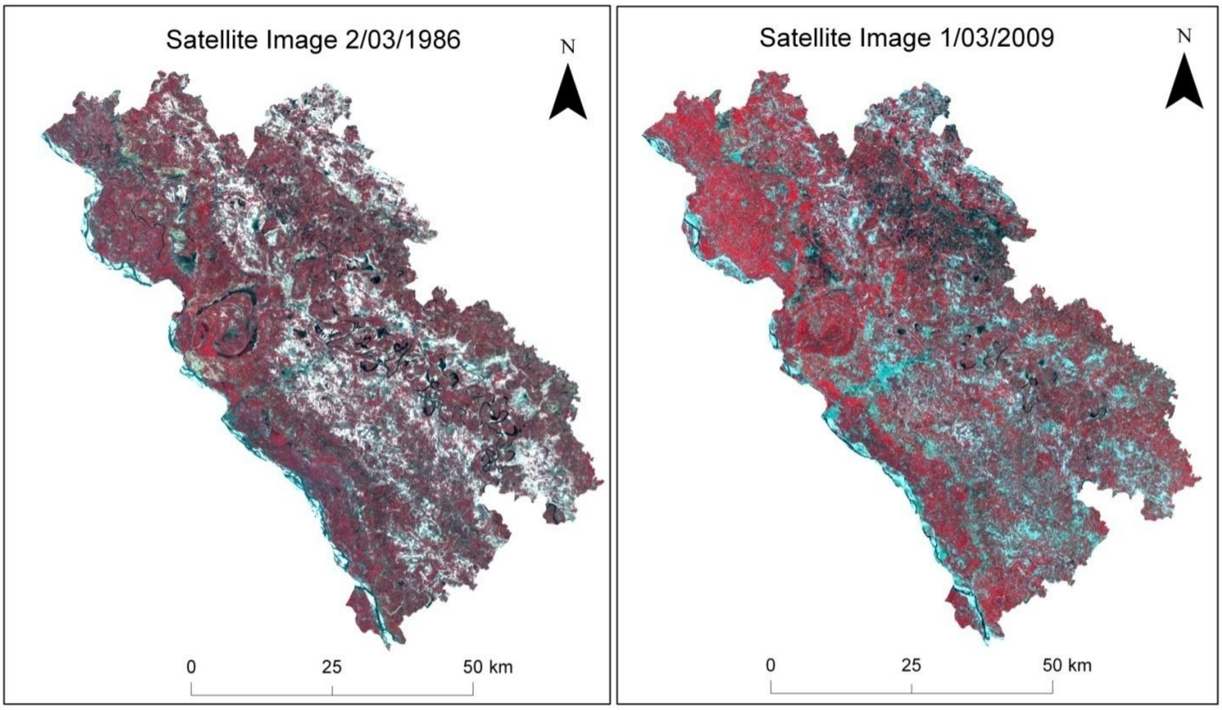


Figure 9. Satellite images for 1986 and 2009

V. Conclusion

Mann Kendall's trend test was used to explore the trend in groundwater levels for a network of 45 observation wells obtained from Central Ground Water Board for both pre-monsoon and post-monsoon seasons. Results from the test indicate that approximately 49%, 53% and 58% of the wells showed downward trends and about 11%, 13% and 16% of the wells showed upward trends at 1%, 5% and 10% significant level, respectively. In the post-monsoon season, 49%, 56% and 58% of the wells showed downward trends and about 11%, 13% and 13% of the wells showed upward trends at 1%, 5% and 10% significant level, respectively. In order to avoid groundwater depletion, groundwater development needs to be implemented in a planned manner to prevent adverse impacts on groundwater. An artificial recharge can be implemented to avoid the declining trend in groundwater levels. Water-logging and soil salinity problems, resulting from the gradual rise of ground water levels, are observed in many canal command areas due to surface water irrigation without environmental considerations. Therefore, a conjunctive water use strategy in areas experiencing water-logging problems needs to be adopted.

VI. Acknowledgment

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