

Original Research Article

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Trend detection Analysis of Seasonal Groundwater Levels in Arpa River Basin, Bilaspur District, Chhattisgarh, India

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A B S T R A C T

Groundwater (GW) trend analysis provides an early warning system for changes in water table caused by climatic conditions or in response to human activities such as water withdrawal. This analysis investigates the pattern and trends of the seasonal groundwater level data of Arpa River Basin in Bilaspur district, Chhattisgarh for the period from 1984 to 2015. A study was undertaken for identifying the trends in pre- and post-monsoon groundwater levels using non parametric Mann-Kendall test and Sen's slope estimator for time series modelling and forecasting of pre- and post-monsoon groundwater. The test has been used to analyze the groundwater data collected from the open/bore wells in the Arpa basin. For analysis using pre monsoon (May- June) and post monsoon groundwater data for six blocks of Bilaspur district. The result of the analysis shows that there is a decreasing trend in Belha block, but increasing trend observed in Masturi and Takhatpur block during pre and post monsoon season for the period of (1984-2015).

Keywords

Ground water level,
Trend analysis,
Mann-Kendall
t-test, Arpa River
basin

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Introduction

Globally water resources of any region have become a major concern for planning and development of projects such as sustainable development of agricultural and food production projects, effective water resource management techniques and erosion and flood estimation and control methodologies etc. The

available groundwater in the watershed is key factor, source of fresh water and important element for determining the availability of water to fulfil the different demand and agriculture mainly depends upon time of occurrence and amount of rainfall on any area to meet others numerous needs and demands such as hydropower water supply, industrial, domestic water supply. Changes in the land

use and land cover scenario and rapid population growth are putting unavoidable stress over the water resources of the nation. The Indian aquifer system is facing an acute crisis due to the unscientific abstraction of groundwater for agricultural, industrial and domestic sector by the 1.3 billion growing population. Groundwater levels in several districts of agriculturally dominant states of Chhattisgarh have been declining at rapid rate. Bilaspur district in Chhattisgarh is famous for cultivation of export quality Dubraj rice. If declining trend of groundwater level continues in the district it will not only affect the sustainability of irrigated agriculture but also add to increase in energy consumption for groundwater pumping and CO₂ emission.

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 (M-K) test (Mann 1945, Kendall 1975) is widely used to evaluate statistically significant trends in hydrological and climatological time series. The test assumes that the studied time series are stable, independent and random, with equal probability distributions. No assumption of normality is required. The test is recommended by the World Meteorological Organization for non-parametric analysis of the significance of monotonic trends. Examples of the use of the M-K test for detecting trends in climatic and hydrological time series data include the works of Xu *et al.*, (2005) and Liu *et al.*, (2008) for precipitation; Xu *et al.*, (2006), Burn and Hesch (2007) and Bandyopadhyay *et al.*, (2009) for evaporation and evapotranspiration; Douglas *et al.*, (2000), Yue *et al.*, (2003), Burn *et al.*, (2004), Kahya and Kalayci (2004), Zhang *et al.*, (2006), Wu *et al.*, (2008) and Kumar *et al.*, (2009) for streamflow; and Sprague and Lorenz (2009) for surface water quality. The non-parametric Mann-Kendall statistical test was used in this study for a monotonic and piece wise trend analyses of the long term groundwater levels of pre-monsoon and post-monsoon season over long period from 1984 to 2015 of Bilaspur district Chhattisgarh.

Materials and Methods

Study area

The Arpa river sub-basin in the upper Mahanadi basin in Bilaspur district of Chhattisgarh is selected for study the significant trend in seasonal rainfall trend in long term (1984-2015). Arpa River is a main tributary of Mahanadi River which is known

as the perennial source of irrigation in the state of Chhattisgarh. Making the lands of the state fertile from a very long time, Mahanadi intersects the various districts of Chhattisgarh. The Mahanadi river gives rise to Shivnath river which in turn gives rise to the Arpa river.

Arpa river is originated in Pendra (tehsil) in Bilaspur district at Khondari-Khongsara place. The length of Arpa is about 147 km and average water flow is 400 m. River catchment area is 2022 sq.km. In 147 kms of the river length, before meeting to Shivnath river it contributes more than 90 kms to the forest area, including Bilaspur city and irrigated lands of this district. The water flows from north-west to south direction.

Except rainy season, it faces scarcity of water. The level of water raises 2-3 m up during rainy season and in summer season it moves 5m down (Joshi *et al.*, 2004). The river bed is mostly sandy having thickness of about 1.5m and few rock exposures at some places.

Data collection and analysis

Pre-monsoon (May-June) and post-monsoon (October-November) groundwater data of Bilaspur district for the period of 1984 to 2015 were used for the analysis. The groundwater data collected from water resource department Madhya Pradesh.

Methods of analysis

Mann-Kendall test

The Mann Kendall (MK) commonly known as the Kendall's tau statistic, is a non-parametric test used for trend analysis. Mann (1945) first used this test and Kendall (1975) derived the test statistic distribution. The test has been suggested by the World Meteorological Organisation (WMO) to

assess trends in environmental data time series (WMO 2014) as the test is suitable for cases where the trend may be assumed monotonic and therefore no seasonal aspects are presented in the data. The method is simple, does not require assuming normality, robust against outliers and can handle missing values (Hess *et al.*, 2001). Accordingly, when compared to parametric test like t-test, the Mann-Kendall test has a higher power for nonnormally distributed data, which are normally presented in hydrological data (Yue and Pilon, 2004). It is worth to mention that some researchers (e.g. Sang *et al.*, 2014) highlighted the need for pre-whitening of the time series data before conducting any trend analysis test, however, if the sample size is more than 70 then serial correlation does not affect the MK test (Basistha *et al.*, 2009). The Mann-Kendall test calculates the slope of the line formed by plotting the variable of interest against time, but only considers the sign and not the magnitude of this slope. Hence, the MK test statistic is calculated from the sum of the signs of the slopes. The statistic S is:

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

Where, SisMann-Kendall statistic and sgn is the signum function. The application of trend test is done to a time series x_i that is ranked from $i = 1, 2 \dots n-1$ and x_j , which is ranked from $j=i+1, 2, \dots, n$. Where X_j and X_i are the consecutive series of data values, and n is the length of the dataset. Each of the data point x_i is taken as a reference point which is compared with the rest of the data point's x_j so that,

$$sgn(x_j - x_i) = \begin{cases} 1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases}$$

At certain probability level H_0 is rejected in favour of H_1 if the absolute value of Sequ also

r exceeds a specified value $S\alpha/2$, where $S\alpha/2$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive value of S indicates an upward trend and negative value indicates downward trend (Salmi *et al.*, 2002; Luo *et al.*, 2008). For $n=10$, the statistic S is approximately normally distributed with the mean $E(s) = 0$ and variance ($Var(s)$).

The Mann-Kendall test is based on the null hypothesis that a sample data is independent and identically distributed, which means there is no trend in the data points. Thus, if the null hypothesis the null hypothesis H_0 is accepted at the significant level α , then the mean and variance of the S statistics are given by Kendall (1975) as it is approximately normally distributed, mean (S) is zero.

$$\text{Mean (S)} = 0$$

In the case where there are no ties in either ranking, the distribution of S may be well approximated by a normal distribution with mean zero and variance as stated in Equation

$$\frac{n(n-1)(2n+5)}{18}$$

$$\text{Var}(S) = \frac{18}{n(n-1)(2n+5)}$$

In this method, the presence of a statistically significant trend is evaluated using the Z_c value.

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S>0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S<0 \end{cases}$$

A positive value of Z_c indicates an increasing trend and negative value indicates decreasing trend. The statistic Z_c is normally distributed. To test an increasing or decreasing monotone trend, a two-tailed test at α level of significance is used. Null hypothesis (H_0) is rejected if the absolute value of Z_c is greater than $Z_{1-\alpha/2}$ where, $Z_{1-\alpha/2}$ is obtained from

the standard normal cumulative distribution tables. In this the null hypothesis (H_0) was that “there is no trend in time series of ground water levels”. Where, α is the level of significance for the test and $\pm Z_{1-\alpha/2}$ are the standard normal deviates. In this study, α and $Z_{1-\alpha/2}$ were taken as 5% and ± 1.96 , respectively.

Sen's slope estimator test

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:

$$Q_i = \frac{X_j - X_k}{j - k} \quad \text{for } i=1,2,3,\dots,n$$

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:

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

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

XLSTATE software

The XLSTAT statistical analysis add-in offers a wide variety of functions to enhance the analytical capabilities of Excel, making it the

ideal tool for your everyday data analysis and statistics requirements. Because it is quick, reliable, easy to install. XLSTAT has grown to be one of the most commonly used statistical software packages in the market. It relies on Excel for the input of data and the display of results, but the computations are done using autonomous software components. The use of Excel as an interface makes XLSTAT a user-friendly and highly efficient statistical and multivariate data analysis package. The quality of the computations is identical to that offered by classic scientific statistical analysis software.

Kendall's Tau

It is a coefficient that represents the degree of concordance between two columns of ranked data.

0 is no relationship.

1 is a perfect relationship.

From the value of Kendall's Tau, value of Z statistics is calculated by using formula:

$$Z = \frac{3 \times \text{tau} \sqrt{n(n - 1)}}{\sqrt{2(2n + 5)}}$$

Where n = number of samples

Variance

It measures how far a set of random numbers are spread out from their average from its mean Variance is given by:

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18}$$

Where n = number of samples

P-value

A *p*-value helps you determine the significance of your results. All hypothesis tests ultimately use a *p*-value to weigh the

strength of the evidence (what the data are telling you about the population).

The *p*-value is a number between 0 and 1 and interpreted in the following way:

A small *p*-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so you reject the null hypothesis.

Results and Discussion

Continuous records of pre and post-monsoon water levels are important to study the water table fluctuation trends and access the ground water potential. The differences between pre and post-monsoon water levels, represents the combined effect of groundwater recharge and draft in a region. The results obtained from the Mann-Kendall test was used to establish the trends in time series of pre-monsoon and post-monsoon ground water levels. Results obtained from analysis of time series data using XLSTAT Software were used for forecasting. The observed Groundwater levels in 20 observation wells of Six blocks in Arpa river basin as shown in Fig. 2

Water table fluctuations trends

To determine the trend in time series data on pre and post-monsoon groundwater levels in different blocks of Bilaspur district, Mann-Kendall statistics (Z_c statistics) were determined. Values of Z_c for different blocks for pre-monsoon and post-monsoon water levels varied from -7.25mm to 5.40 mm/year and -7.38mm to 6.23mm/year respectively which shown in Table 2 & 3

The results of Mann-Kendall t test carried out for six blocks included in this analysis shows that, there is negative increasing trend in most of blocks at 5% significant level.

Table.1 Block wise well location of Arpa basin Bilaspur district

S.No.	Well No.	Well type	District	Tehsil	Block	Village
1.	BSP-005-OW	Dug well	Bilaspur	Gaurela	Gaurela	Keonchi
2.	BSP-006-OW	Dug well	Bilaspur	Gaurela	Gaurela	Khodri
3.	BSP-012-OW	Dug well	Bilaspur	Takhatpur	Takhatpur	Ganiyari
4.	BSP-013-OW	Dug well	Bilaspur	Takhatpur	Takhatpur	Ghutkoo
5.	BSP-023-OW{A}	Dug well	Bilaspur	Takhatpur	Takhatpur	Sakri
6.	BSP-015-OW	Dug well	Bilaspur	Kota	Kota	Kata
7.	BSP-018-OW	Dug well	Bilaspur	Kota	Kota	Ratanpur
8.	BSP-019-OW	Dug well	Bilaspur	Kota	Kota	Belgahna
9.	BSP-020-OW	Dug well	Bilaspur	Kota	Kota	Khonsara
10.	BSP-021-OW	Dug well	Bilaspur	Belha	Belha	Bartori
11.	BSP-022-OW	Dug well	Bilaspur	Belha	Belha	Belha
12.	BSP-023-OW	Dug well	Bilaspur	Belha	Belha	Bilaspur
13.	BSP-023-OW	Dug well	Bilaspur	Belha	Belha	Semarta
14.	BSP-024-OW	Dug well	Bilaspur	Belha	Belha	Semarta
15.	BSP-025-OW	Dug well	Bilaspur	Belha	Belha	Chakrabhata
16.	BSP-025-OW{A}	Dug well	Bilaspur	Belha	Belha	Chakrabhata
17.	BSP-026	Dug well	Bilaspur	Belha	Belha	Beltara
18.	BSP-031	Dug well	Bilaspur	Masturi	Masturi	Seepat
19.	BSP-031{A}	Dug well	Bilaspur	Masturi	Masturi	Seepat
20.	KOB-001	Dug well	Korba	Pali	Pali	Pali

Table.2 Pre-monsoon groundwater levels observed from various block well

Sr. No.	Block name	Mann Kendall Statistic(S)	Kendall's tau(τ)	Variance	Z Statistics	P value	Sen's slope magnitude	Inference drawn
1.	Gaurela	49.00	0.106	3455.0	0.9137	0.414	0.016	↑
2.	Gaurela	176.0	0.356	3800.0	2.6649	0.005	0.133	↑
3.	Takhatpur	-82.00	-0.190	3131.3	-1.6822	0.148	-0.034	↓
4.	Takhatpur	-76.00	-0.175	3140.6	6.7287	0.181	-0.038	↑
5.	Takhatpur	27.00	0.257	408.3	6.2271	0.198	0.177	↑
6.	Kota	-206.0	-0.448	3456.0	-3.6998	0.000	-0.063	↓
7.	Kota	-102.0	-0.235	3138.6	-2.0474	0.071	-0.024	↓
8.	Kota	-302.0	-0.016	3800.6	-4.7887	<0.0001	-0.17	↓
9.	Kota	63.00	0.127	3799.6	1.0247	0.315	0.016	↑
10.	Belha	-5.00	-0.012	3139.6	0.6655	0.943	-0.002	↑
11.	Belha	-174.0	-0.375	3458.6	-2.5349	0.003	-0.032	↓
12.	Belha	6.00	0.050	491.3	4.6264	0.822	0.018	↑
13.	Belha	17.00	0.162	408.3	2.5298	0.428	0.113	↑
14.	Belha	-76.00	-0.633	493.0	-7.3753	0.001	-0.074	↓
15.	Belha	10.00	0.128	268.0	-3.1299	0.583	0.063	↓
16.	Belha	-73.00	-0.611	492.0	-3.3921	0.001	0.189	↓
17.	Belha	-68.00	-0.147	3458.0	-1.7731	0.255	-0.035	↓
18.	Masturi	-10.00	-0.074	589.00	-5.5470	0.711	-0.125	↓
19.	Masturi	-80.00	-0.776	407.34	-6.8944	<0.0001	-0.1	↓
20.	Pali	-244.0	-0.647	2560.0	-5.4922	<0.0001	-0.089	↓

Table.3 Post-monsoon ground water level observed from various block wells

Sr. No.	Block name	Mann Kendall Statistic(S)	Kendall's tau(τ)	Variance	Z Statistics	P value	Sen's slope magnitude	Inference drawn
1.	Gaurela	49.00	0.106	3455.0	0.9137	0.414	0.016	↑
2.	Gaurela	176.0	0.356	3800.0	2.6649	0.005	0.133	↑
3.	Takhatpur	-82.00	-0.190	3131.3	-1.6822	0.148	-0.034	↓
4.	Takhatpur	-76.00	-0.175	3140.6	6.7287	0.181	-0.038	↑
5.	Takhatpur	27.00	0.257	408.3	6.2271	0.198	0.177	↑
6.	Kota	-206.0	-0.448	3456.0	-3.6998	0.000	-0.063	↓
7.	Kota	-102.0	-0.235	3138.6	-2.0474	0.071	-0.024	↓
8.	Kota	-302.0	-0.016	3800.6	-4.7887	<0.0001	-0.17	↓
9.	Kota	63.00	0.127	3799.6	1.0247	0.315	0.016	↑
10.	Belha	-5.00	-0.012	3139.6	0.6655	0.943	-0.002	↑
11.	Belha	-174.0	-0.375	3458.6	-2.5349	0.003	-0.032	↓
12.	Belha	6.00	0.050	491.3	4.6264	0.822	0.018	↑
13.	Belha	17.00	0.162	408.3	2.5298	0.428	0.113	↑
14.	Belha	-76.00	-0.633	493.0	-7.3753	0.001	-0.074	↓
15.	Belha	10.00	0.128	268.0	-3.1299	0.583	0.063	↓
16.	Belha	-73.00	-0.611	492.0	-3.3921	0.001	0.189	↓
17.	Belha	-68.00	-0.147	3458.0	-1.7731	0.255	-0.035	↓
18.	Masturi	-10.00	-0.074	589.00	-5.5470	0.711	-0.125	↓
19.	Masturi	-80.00	-0.776	407.34	-6.8944	<0.0001	-0.1	↓
20.	Pali	-244.0	-0.647	2560.0	-5.4922	<0.0001	-0.089	↓

Fig.1 Index map of Arpa River basin

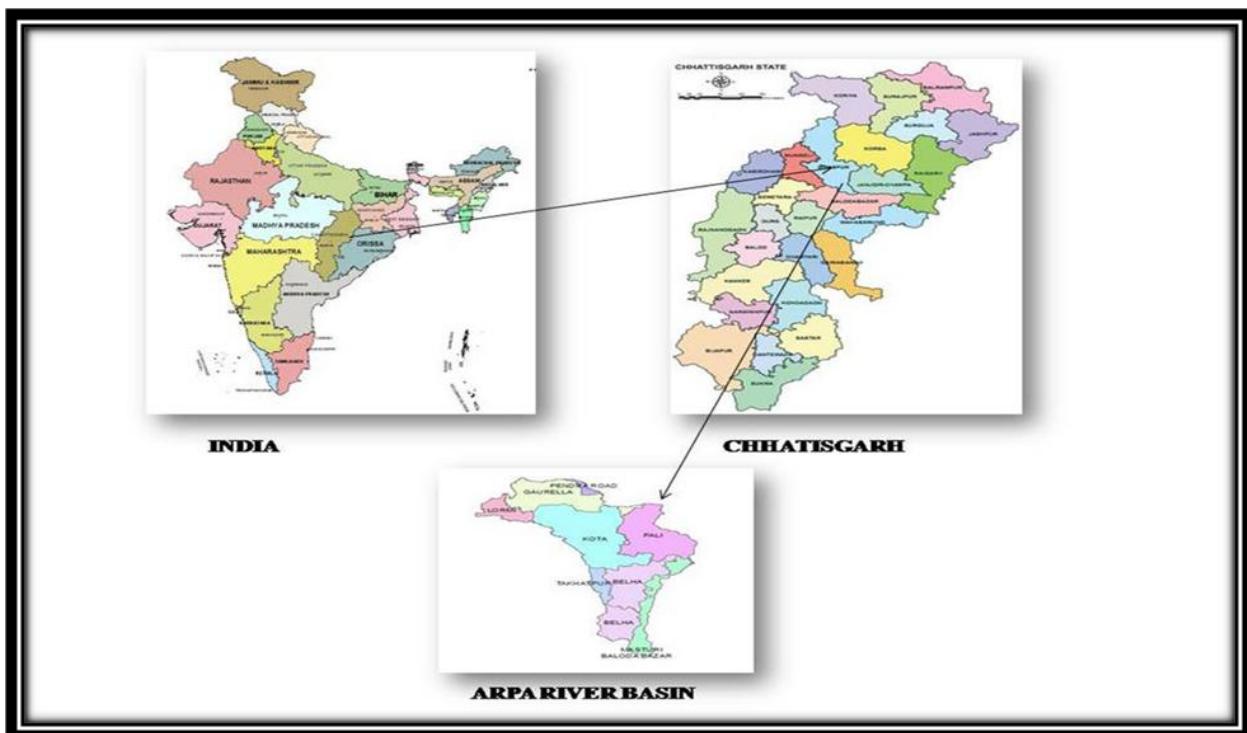


Fig.2 Pre monsoon and post monsoon groundwater levels of six blocks of Arpa River Basin

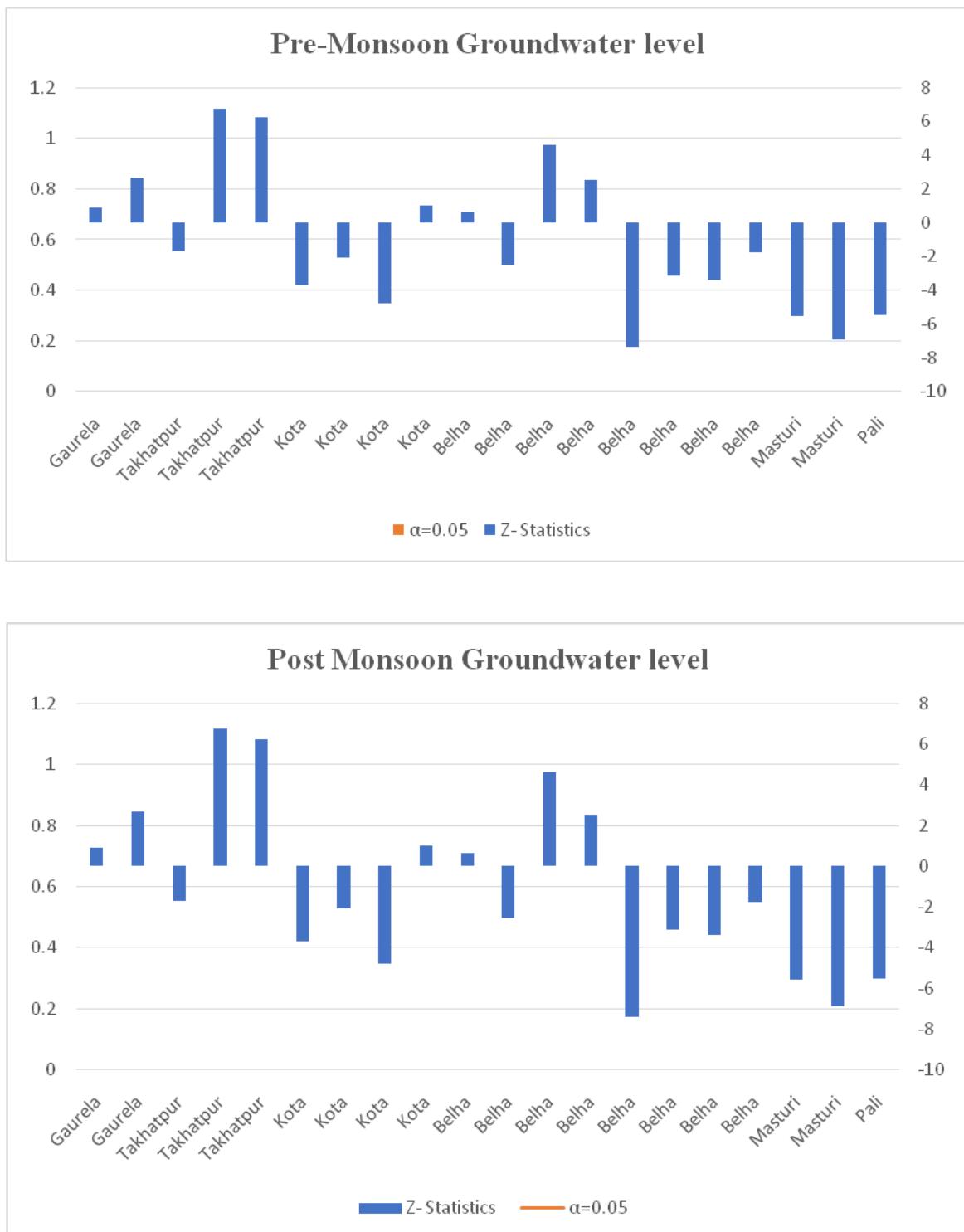


Fig.3 Zmk statistics and Sen's Slope magnitude for pre monsoon ground water level

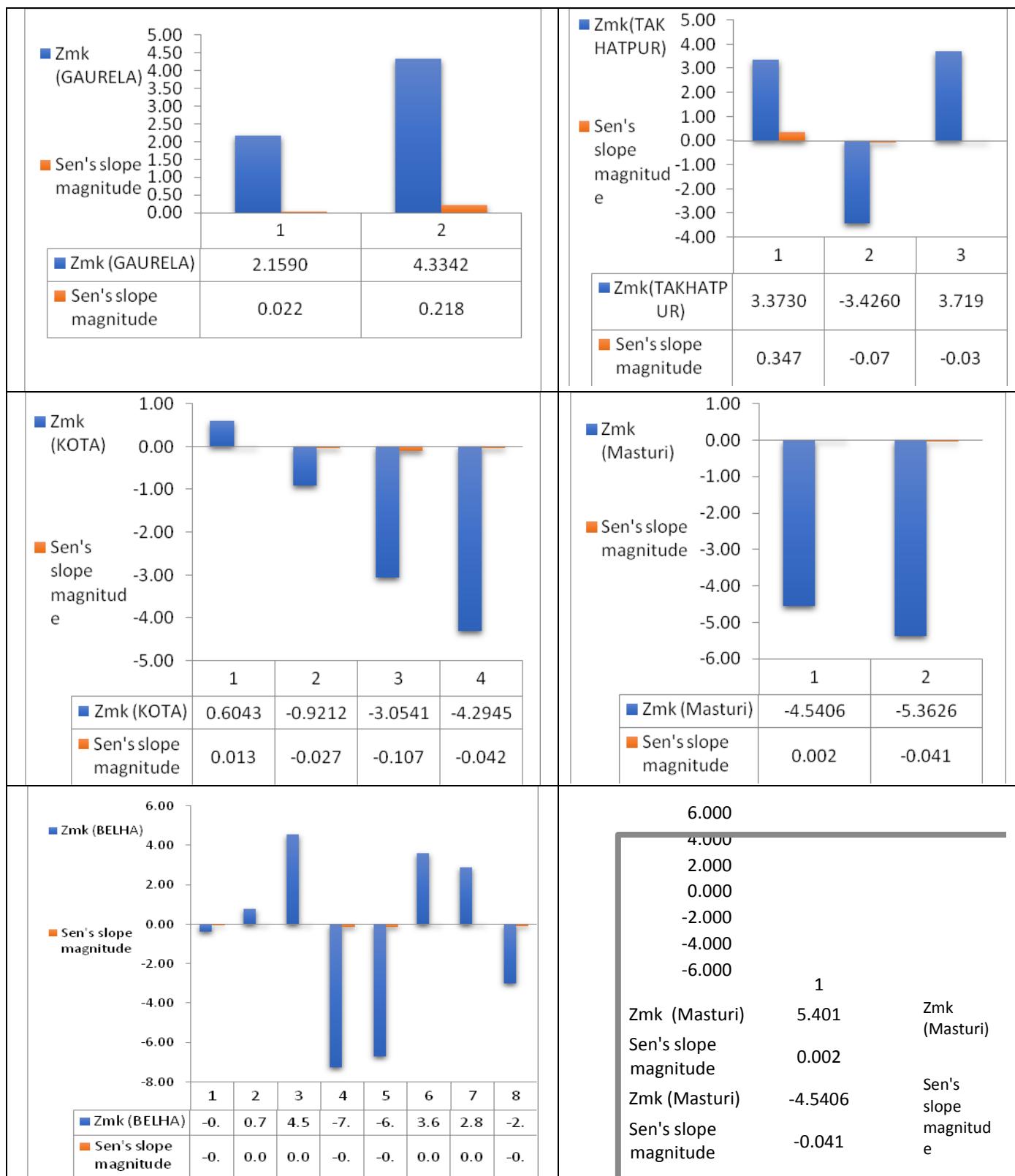
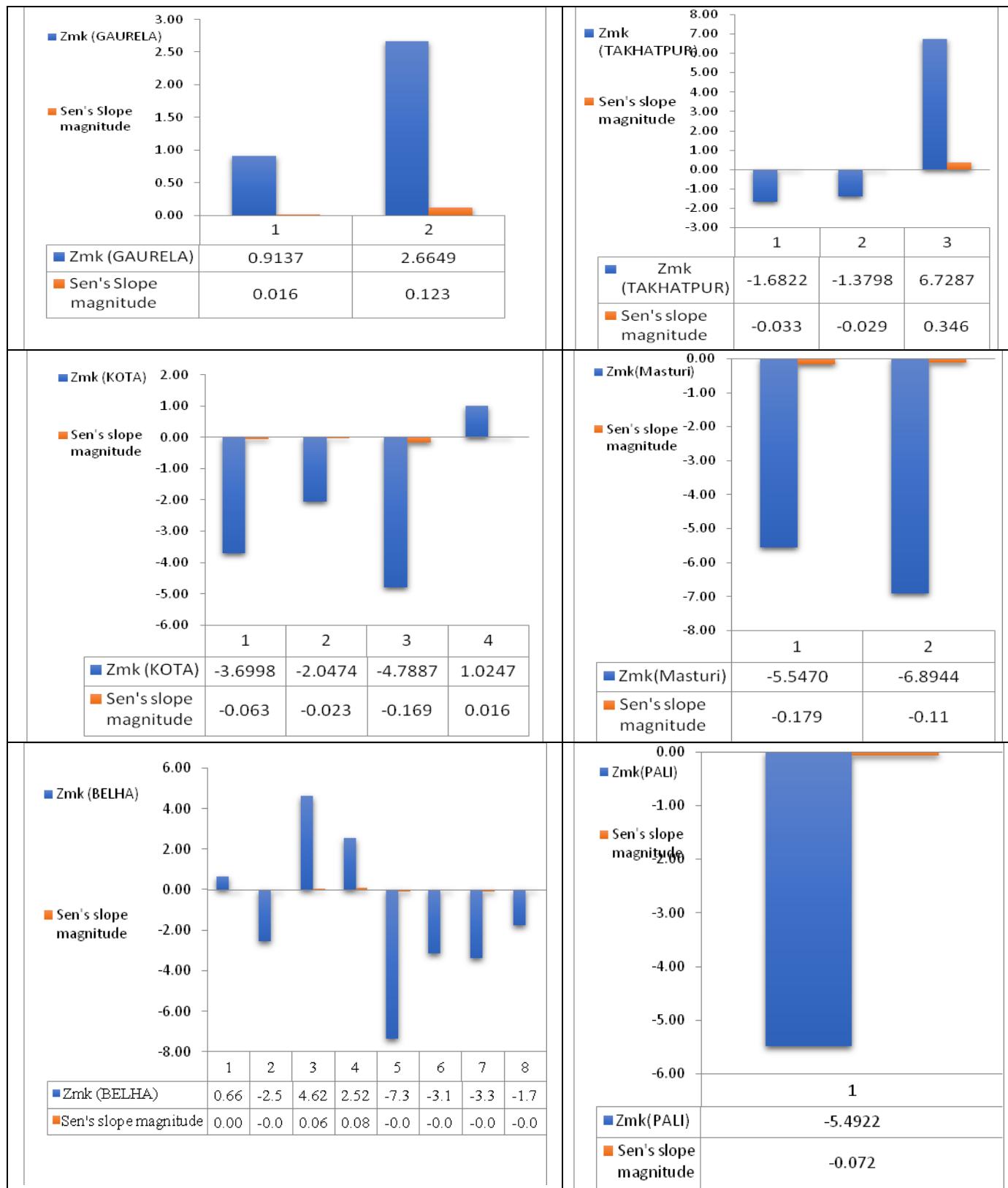


Fig. 4 Zmk statistics and Sen's Slope magnitude for post monsoon ground water level



The result of the analysis shows that there is a negative increase in trends for the groundwater level of 1996 to 1998 which is -7.2454mm in Belha and positive increase in trends 5.401mm in Masturi during 2000-2002 in Pre monsoon season.

In Post monsoon there is negative increase in trends between 1996-1998 which is -7.3753 mm in Belha but slight increase during 1998-2000 but there are also positively increasing trends during 1987 to 1988 which is 6.7287 mm in Takhatpur block.

This indicated that there was a significant trend in time series data of pre and post-monsoon groundwater levels. The positive sign suggests that groundwater levels are declining with respect to the ground surface. After identifying the trend, Sen's slope estimator was used to find out the slope of trend line (i.e. rate of water level decline, mm/yr).

Positive value of slope indicated the declining trend (i.e. depth of water level with respect to ground surface is increasing) of groundwater level during the period of 1984-2015.

In conclusion, water resource has become a prime concern for existence and improvement of life, it depends on river basin. In the present study groundwater level trend in the Arpa river basin was assessed with Mann-Kendall test for various blocks of Bilaspur district. Mann Kendall's trend test was used to explore the trend in groundwater levels for a network of 20 observation wells obtained from Water Resource Department for both pre-monsoon and post-monsoon seasons. Results from the test indicate that Belha block having extremely decreasing trend during Pre and Post monsoon session but there is increasing in ground water level in Masturi block and Takhatpur block during Pre and Post monsoon 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.

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