Chapter 20
Trend Analysis of Groundwater Level Using Innovative Trend Analysis

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Contents

20.1 Introduction

Groundwater is the major source of freshwater as it contributes to about 30% of the total fresh water volume available on earth (Pande and Moharir 2018; Pande et al. 2019; Sharma et al. 2019). Groundwater is the lifeline for not only sustenance of human and animal life, but also the vegetal cover on the earth surface. Groundwater is the source of water supply for domestic, industrial and agricultural purposes (Birkinshaw et al. 2008; Li et al. 2013; Muzzammil et al. 2015; Pande et al. 2018). Groundwater is stored in pore spaces in various earth formations such as aquifer, aquitard, aquiclude and aquifuge. Earth formations are classified into aquifer, aquitard, aquiclude and aquifuge on the basis of permeability and porosity. However, these classifications are relative classifications depending on the availability of water in the region. Aquifers are further classified as confined aquifer and unconfined aquifer (Khadri and Moharir 2016; Khadri and Pande 2016a; Moharir et al. 2017, 2020). Water table or water level is the free water surface of unconfined aquifer and static level of well penetrating into the confined aquifer (Khadri and

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Pande 2016b; Pande et al. 2017). Water level continuously changes in response to recharge and withdrawal rate of water (Patle et al. 2015; Khadri and Pande 2016c; Patode et al. 2016; Zhou et al. 2017). Obviously if the recharge rate is higher than withdrawal rate water level will increase, otherwise, if the withdrawal rates are higher water level is bound to decline. Perpetual alteration in the water level is eminent if there is substantial withdrawal/ recharge. Ground water level fluctuates due to both natural and anthropogenic causes (Abiye et al. 2018; Alipour et al. 2018; Ndlovu and Demlie 2018; Zakwan 2019; Arshad and Umar 2020). Natural causes include alteration in the amount and pattern of rainfall and temperature while anthropogenic causes encompass changes in land-use pattern, type of irrigation, discharge of industrial effluents, ground water withdrawals and groundwater recharge, etc. (Patle et al. 2017; Ara and Zakwan 2018; Alexander et al. 2018; Marghade et al. 2020). Recently, it has been observed that both quality and quantity of groundwater are depleting in developing countries (Tsanis et al. 2008; Rodell et al. 2009; Jiao et al. 2015; Alexander et al. 2018; Salam et al. 2019; Sharma et al. 2019; Arshad and Umar 2020; Anand et al. 2020). Groundwater recharge can be natural or artificial. Natural recharge involves infiltration of water after rainfall (fraction that reaches the saturation zone), seepage from river beds, canal beds, irrigated lands, reservoirs and other water bodies. Recharge through infiltration resulting from rainfalls forms the major portion of natural recharge. Artificial recharge involves induced recharge from water bodies, recharge through rainwater harvesting techniques, check dams, subsurface dykes and reduction in saltwater intrusion. Growing population and their needs along with thrust for development and industrial growth has forced to substantial increase in the pumping rate of groundwater (Pande 2020a, d). At the same time these factors have also adversely affected hydrologic cycle leading to decline in rainfall in many regions of the world or decline in frequency of rainfall. Decline in rainfall further increases the dependency of agricultural sector on groundwater resources. Recently, a new term ground water drought has been introduced. Groundwater drought can be defined as a "lack of groundwater recharge or a lack of groundwater expressed in terms of storages or groundwater heads in a certain area and over a particular period of time" (Van Lanen and Peters 2000). The lack is usually determined in comparison to some "normal" or average amount or level derived from frequency analysis using historical data.

As an example, in most semiarid parts of India, agricultural sector faces serious water scarcity and liability of crop failure even with slight decrease or lag in the monsoon rainfalls. With advanced pumping technologies and their cheap accessibility, ground water utilization for irrigation across the country has witnessed enormous surge. However, rampant population increase and ground water utilization over the past few decades in majority of the regions of the country has resulted in the exploitation of groundwater at a rate far greater than the natural recharge, thereby, leading to decline in ground water level. This example also clearly demonstrates that alteration in ground water level is caused by both natural and anthropogenic reasons.

Several researchers have seen fluctuation in ground water level in connection with the trends in rainfall and river discharge and several studies have been

conducted by hydrologists to analyse the trends in discharge, rainfall and ground water level (Zakwan 2018). Among the trend analysis tests nonparametric Mann-Kendall and Spearman's Rho test have been used by many researchers to detect the trends in hydrologic variables (Daniel 1978; Crawford et al. 1983; El-Shaarawi et al. 1983; Hirsch and Slack 1984; Hirsch et al. 1982; Pilon et al. 1985; Cailas et al. 1986; Hipel et al. 1988; Demaree and Nicolis 1989; Zetterqvist 1991; Hipel and Mcleod 1994; McLeod and Hipel 1994; Keim et al. 1995; Douglas et al. 2000; Meade and Moody 2010; Zhang et al. 2011; Muzzammil et al. 2018; Pandey et al. 2018; Zakwan and Ara 2019; Sharma et al. 2019; Yilmaz et al. 2020).

Walling and Fang (2003) analysed the pattern of sediment discharge of nearly 150 rivers and reported that nearly 50% of them demonstrate statistically significant upward or downward trend. Milliman et al. (2008) investigated the water yield of over 100 rivers and reported that more than one-third of the river possesses alteration of over 30%. Lu et al. (2003) analyzed the seasonal discharge data in several tributaries of Yangtze River, China, reporting remarkable alteration in the hydrological parameters thereby projecting reasonable concern about flooding and water scarcity in different regions of Yangtze River basin. However, rivers of central Japan did not exhibit any remarkable trend in discharges (Siakeu et al. 2004).

Zakwan and Ara (2019) and Zakwan et al. (2019) analysed monthly precipitation data of Bihar, India and reported significant decline in rainfall over the region. Tsanis et al. (2008) developed an ANN framework to estimate groundwater level fluctuations based on rainfall data. Patle et al. (2015) used Mann-Kendall test and Sen's slope method to identify the trends in groundwater and reported a significant decline in water level for Karnal district of Haryana, India, both during pre-monsoon and post-monsoon season. Singh et al. (2019) applied both parametric (linear regression trend line) as well as nonparametric test (Mann-Kendall test and Sen's slope) to understand the trends in groundwater of Haryana, India, confirming significant decline in groundwater level. Pathak and Dodamani (2019) forwarded the concept of regional groundwater drought asserting significant decline in ground water level in Ghataprabha basin, India. Based on the results of Mann-Kendall trend test they reported that the decline in water level for more than 60% of the wells in the region is above 0.21 m on an average. Gibrilla et al. (2018) revealed increase in groundwater level in most of the wells of Ghana based on trend tests and ARIMA model. Ndlovu and Demlie (2018) analysed the trend in ground water level along with rainfall of KwaZulu-Natal Province, South Africa and found that the decline in groundwater level is directly linked with decline in rainfall. Lasagna et al. (2020) analysed the impact of natural and anthropogenic factors on the groundwater resources of Italy and reported that rainfall and irrigation pattern mainly influence the available groundwater resources. Anand et al. (2020) employed GIS along with trend tests to detect groundwater level fluctuations in India.

Analysis of pattern of water level plays a vital role in assessing the future scenario of available ground water resources in the region. Trend analysis could also be used to detect the successfulness of various groundwater recharge techniques. In this regard, trend analysis of water level of five wells was performed using Mann Kendall, Spearman-Rho, Sens slope and innovative trend analysis.

20.2   Materials and Methods

In the present study water level data of five wells of Churu district, Rajasthan, India (28°17′32″ N, 74°57′59″ E) were utilized for the trend analysis. The region comes under arid and semiarid regions of India. The wells were randomly selected for study area; however, care was taken to select those wells where longest time series of groundwater level was available. Three wells were located in Sadarshahar, one each in Ratangarh and Sujangarh tehsil of Churu. Map of the study area is shown in Fig. 20.1. The region faces acute shortage of water during summer or pre-monsoon season. The data was obtained from the website of Central Ground Water Board (http://cgwb.gov.in/GW-data-access.html). Water level data for the period 1994–2017 was available on the website. The statistical properties of the data are given in Table 20.1. It could be observed that water level does not show significant variation.

Generally, to analyse the temporal variation, parametric as well as nonparametric tests are used. Nonparametric tests have an advantage over parametric tests in way that they can be used for non-normal time series also. These nonparametric test does not require data series to follow normal distribution and yet are at par with other parametric trend tests (Yue et al. 2002; Ebadati et al. 2014; Tirkey et al. 2020). The preliminary assumption for conducting the test is that the data series is not serially correlated. Presence of auto correlation among data series might result in incorrect trend detection. Prewhittening of auto correlated series is one of the methods to avoid incorrect trend detection. But Bayazit and Onoz (2007), concluded that prewhitening should be avoided when coefficient of variation (C_v) of the data series is very low ($C_v = 0.1$) for all sample sizes or C_v is low ($C_v = 0.3$) and slope of linear trend (b) is high ($b > 0.006$) for moderate sample sizes, $n = 50$–75. The details of nonparametric used in present study are as follows.

20.2.1   Mann-Kendall Test

Mann-Kendall test (after Mann 1945; Kendall 1975) is a nonparametric statistical test used for the analysis of trend in climatologic and hydrologic time series (Hirsch et al. 1982; Yu et al. 1993; Gibbons and Chakraborti 2003; Sharma and Patel 2018). Mann-Kendall test is a rank based method used to analyse the trends in time series (Burn et al. 2004). This test has been found to be reliable even for non-normal time series (Lu 2005). Further, Mann-Kendall test statistics are not significantly affected by presence of outliers (Hirsch et al. 1982). In this test, the null hypothesis H_0 assumes that the realizations are independent that is no trend exists in data series which is tested against the alternative hypothesis H_1 that assumes that the monotonic trend exists in the time series (Pohlert 2017). Assuming X_i and X_j are two subsets of data series where $i = 1,2,3, \ldots n - 1$ and $j = i + 1, i + 2, i + 3, \ldots, n$.

Fig. 20.1 Study area

Table 20.1 Statistical properties of groundwater data

Serial number	Location	Mean	Maximum	Minimum
W1	Ratangarh	37.47	39.50	35.86
W2	Sadarshahar	60.29	65.9	58.41
W3	Sadarshahar	56.32	63.17	52.98
W4	Sadarshahar	60.56	69.4	58.8
W5	Sujangarh	30.12	31.53	28.52

The Mann-Kendall S_m Statistic may be represented as follows:

$$S_m = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(X_j - X_i) \tag{20.1}$$

$$\text{Sign}(T_j - T_i) = \begin{cases} 1 \text{ if } X_j - X_i > 0 \\ 0 \text{ if } X_j - X_i > 0 \\ -1 \text{ if } X_j - X_i > 0 \end{cases} \tag{20.2}$$

The variance (σ^2) for the S_m statistic is defined by:

$$\sigma^2 = \frac{[n(n-1)(2n+5)]}{18} \tag{20.3}$$

The standard test statistic Z_s is calculated as follows:

$$Z_S = \begin{cases} \dfrac{S_m - 1}{\sigma} & \text{for } S_m > 0 \\ 0 & \text{for } S_m = 0 \\ \dfrac{S_m + 1}{\sigma} & \text{for } S_m < 0 \end{cases} \tag{20.4}$$

If $|Zs|$ is greater than $Z_{100-\alpha}$, where α represents the chosen significance level (at 5% significance level or 95% confidence level with $Z_{95\%} = 1.96$) then the null hypothesis is invalid implying that the trend is significant (Zhang et al. 2011). Positive values of Z statistics indicate an increasing trend while negative values of Z statistics represent the negative trend (Timbadiya et al. 2013; Gebremicael et al. 2013).

20.2.2 Spearman's Rho Test

Spearman's Rho is a nonparametric test used to determine whether correlation exist between two classifications of the same series of observations (Esterby 1996). In

accordance with this test, the null hypothesis H_0 assumes that the population is independent and identically distributed which is tested against the alternative hypothesis H_1, which assumes that the trend exists. A time series of n data points X_i, where $i = 1$ to n, are ranked according to their value from highest to lowest as $R(X_i)$.

Then the Spearman-Rho test statistics D_s is given by,

$$D_s = 1 - \frac{6 \times \sum_{i=1}^{n} \{R(X_i) - i\}^2}{n(n^2 - 1)} \tag{20.5}$$

The standard test statistic Z is calculated as follows:

$$Z = D_s \sqrt{\frac{(n-2)}{1 - D_s^2}} \tag{20.6}$$

If $|Z|$ is greater than $t_{(1-\alpha/2, n-2)}$, where α represents the chosen significance level, then the null hypothesis is invalid implying that the trend is remarkable.

20.2.3 Sen's Slope Estimator

Sen (1968) proposed the nonparametric Sen's slope statistics. Slope for each pair may be calculated as

$$Q_i = \frac{(X_j - X_k)}{j - k} \text{ where } (j > k) \text{ (for } i = 1, 2, 3 \ldots n) \tag{20.7}$$

where X_j and X_k are the data values at times j and k ($j > k$), respectively.

Sens slope estimator can then be calculated as

$$Q_{\text{med}} = \begin{cases} Q[(n+1)/2] \text{ if } n \text{ is odd} \\ \dfrac{Q_{n/2} + Q_{(n+2)/2}}{2} \text{ if } n \text{ is even} \end{cases} \tag{20.8}$$

The Q_{med} sign reflects data trend, while its value indicates the steepness of the trend.

20.2.4 Innovative Trend Analysis

Innovative trend analysis was proposed by Şen (2012). The procedure for innovative trend analysis is as follows:

Divide the entire time series into two equal halves
Calculate the average of both the time series as $\overline{Y_1}$ and $\overline{Y_2}$.
Arrange both the time series in ascending order.
Plot a graph with first half of time series on abscissa and second half series on ordinate. Also plot the 1:1 (45°) line on the same plot.

Relative position of scatter point with respect to 45° line demarcates the trend. If all the points lie above the 45° line it represents monotonically increasing trend, on the other hand if all the points lie below the 45° line it would represent monotonically decreasing trend, otherwise trend may not be monotonic (Caloiero et al. 2018; Güçlü et al. 2019).

The magnitude of trend may be calculated (after Şen 2017) as

$$s = \frac{2\left(\overline{Y_2} - \overline{Y_1}\right)}{n} \tag{20.9}$$

Confidence limit (CL) of trend may be calculated using the following relationship

$$\mathrm{CL}(1 - \alpha) = 0 \pm s_{\mathrm{cri}}\,\sigma_s \tag{20.10}$$

Where s_{cri} is critical slope; σ_s = Slope standard deviation.

$$\sigma_s^2 = \frac{8\sigma^2\left(1 - \rho_{Y_2 Y_1}\right)}{n^3} \tag{20.11}$$

where $\rho_{Y_2 Y_1}$ = Cross-Correlation coefficient of averages of two halves given by

$$\rho_{Y_2 Y_1} = \frac{E(Y_2 Y_1) - E(Y_2)E(Y_1)}{\sigma_{Y_2}\sigma_{Y_1}} \tag{20.12}$$

Explains the innovative trend analysis. Figure 20.2 shows 1:1 line with two parts of time series on either axis. It may be observed that this graph shows low magnitude, moderate magnitude and high magnitude event and from the plotted points trends for low magnitude, moderate magnitude and high magnitude event can be understood separately. In this way innovative trend analysis have an advantage over nonparametric trend tests, nonparametric trends can only reveal monotonic trend; however, it may be possible that hydrological events of different magnitude may have different trends. As can be observed from Fig. 20.2, low magnitude events are trendless, while moderate magnitude events show significant negative trend and high magnitude events show slight positive trend.
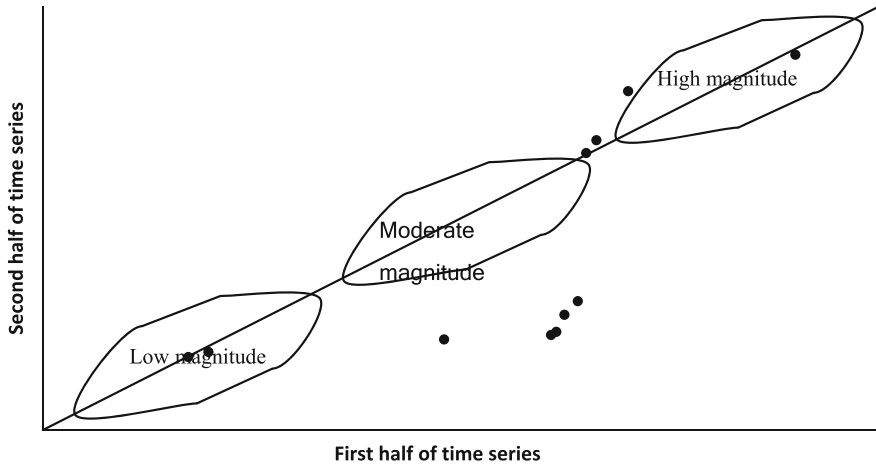
Fig. 20.2 Graphical representation of innovative trend analysis

20.3 Results and Discussions

In the present chapter time series of water level of five wells located in Churu, India, were analysed to recognize the temporal variation in water level. Trend analysis was performed using Mann-Kendall, Spearman-Rho, Sens slope estimator and innovative trend analysis. The results of trend of Mann-Kendall, Spearman-Rho and Sens slope are presented in Table 20.2 while the results of innovative trend analysis with statistical details can be found in Table 20.3. At four out of the five wells, water level was found to be declining significantly, only at one location water level showed positive trend. At Ratangarh and Sujangarh wells (W1 and W5 respectively), negative trend was observed which was insignificant at 5% significance level in accordance with the Mann-Kendall and Spearman-Rho test. However, as the magnitude of trend slope is higher than critical slope for innovative trend analysis as shown in Table 20.3, the trend is considered significant in accordance to innovative trend analysis. Out of the three wells (W2, W3 and W4) located in Sadarshahar, W2 and W4 presented significant negative trend but significant positive trend was observed at W3. Presence of positive trend at 5% significance level is confirmed from all the trend tests.

Perusal of Table 20.3 reveals that for all the location the magnitude of trend slope is higher than critical slope, thereby indicating presence of significant trend at all the locations. It may also be observed that the average of first half of time series is greater than average of second half of the time series for all the wells, except for the well W3, indicating presence of negative and positive trend respectively. Standard deviation at well W3 and W4 are higher as compared to other wells indicating greater fluctuations in water level these wells. On the other hand lowest deviation in water level is observed at well W5 signifying minimum fluctuation in water level.

Table 20.2 Results of trend analysis for water level

Serial number	Mann-Kendall	Spearman-rho	Sens slope
W1	−0.34	−0.17	−0.01
W2	−1.96[a]	−1.99[a]	−0.14
W3	3.47[a]	3.14[a]	0.20
W4	−2.34[a]	−2.54[a]	−0.10
W5	−1.76	−1.71	−0.04

[a]Significant trend at 5% significance level

Table 20.3 Statistical results of Innovative trend test

Serial number	Average of first half ($\overline{Y_1}$)	Average of second half ($\overline{Y_2}$)	Standard deviation (σ)	Cross-Correlation (ρ_{xy})	Trend slope (s)	Critical slope (Scr)
W1	37.84	37.10	1.26	0.65	−0.07[a]	0.04
W2	61.58	59.01	1.96	0.81	−0.23[a]	0.05
W3	55.11	57.53	2.93	0.72	0.22[a]	0.08
W4	61.13	59.99	2.36	0.35	−0.10[a]	0.09
W5	30.34	29.90	0.78	0.86	−0.04[a]	0.01

[a]Significant trend at 5% significance level

These observations are further supported by minimum and maximum water level observed at various wells as reported in Table 20.1.

Figure 20.3 shows the results of innovative trend analysis at various wells. At well W1 moderate water level show significantly downward trends while low and high water levels do not represent any significant trend. At well W2, all the points plot below the 1:1 line indicating that low, moderate and high water levels have declined during second half of the time series and therefore significant downward trend is observed at well W2. It may also be observed from Table 20.3 the trend slope for well W2 is −0.23 which is much smaller than critical slope 0.05.

At well W3, all the points plot above the 1:1 line indicating that low, moderate and high water levels have increased during second half of the time series and therefore significant upward trend is observed at well W3. Also, in Table 20.3 the trend slope for well W3 is reported as 0.22 which is much greater than critical slope 0.08. At wells W4 and W5 most of the points plot below 1:1 line indicating declining trend for these will which is further confirmed from trend and critical slopes as reported in Table 20.3.

Although no conflict was observed in the trend obtained from Mann-Kendall, Spearman-Rho, Sens slope estimator and innovative trend analysis, but, the innovative trend analysis provides the most exhaustive visualization of the changes taking place. In recent times, it has been a common observation that the number of rainy days is decreasing, overall rainfall is decreasing but the frequency of extreme rainfall is increasing (Rainfall is directly or indirectly related to most of the hydrologic observations such as streamflow, groundwater level and evaporation rate, etc.). In
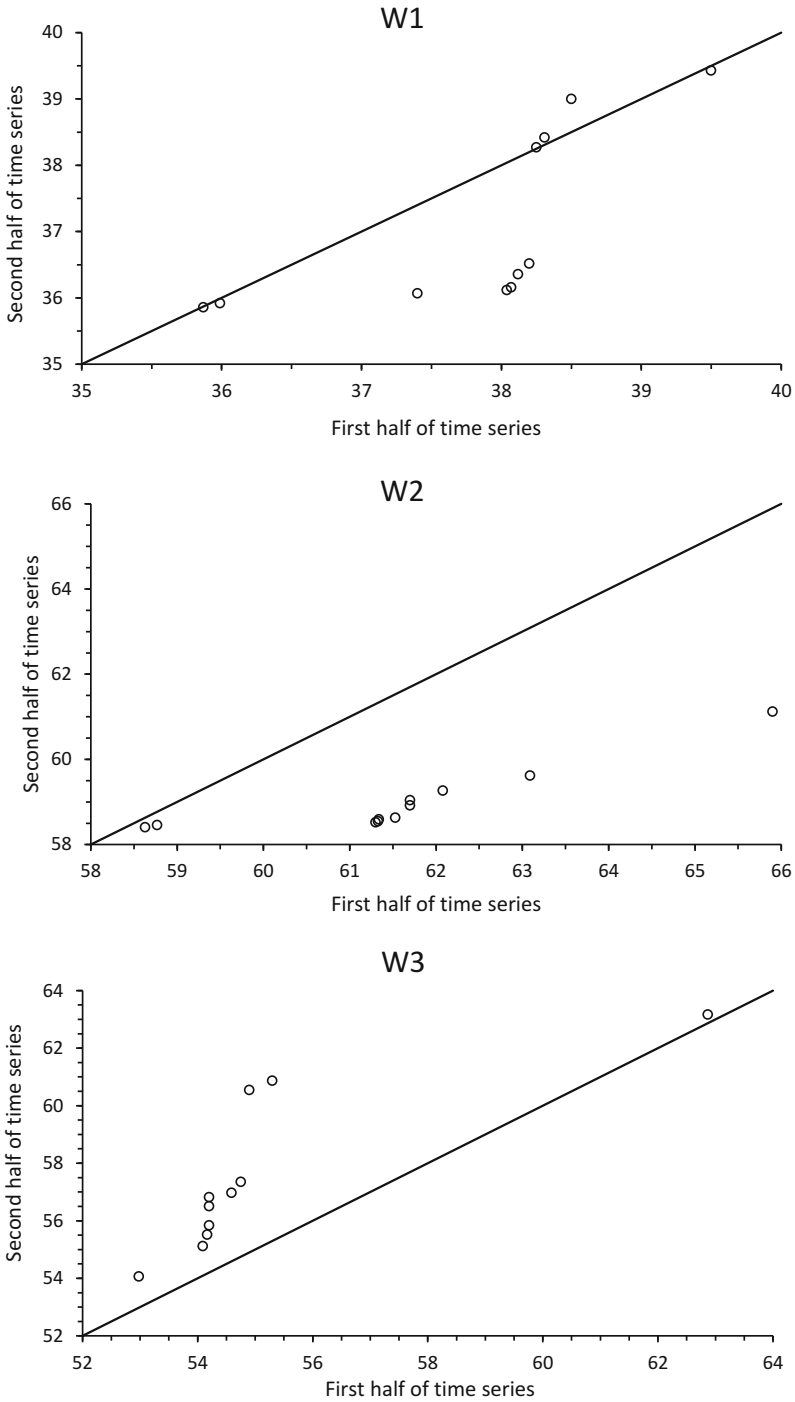
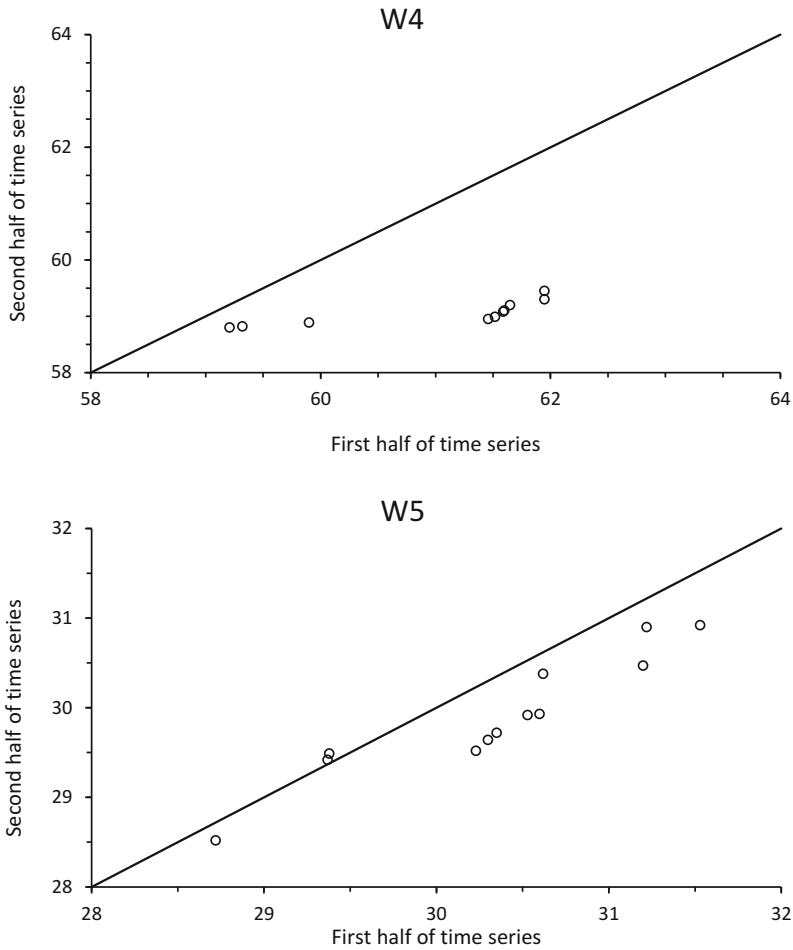**Fig. 20.3** Innovative trend graphs at various locations

Fig. 20.3 (continued)

such cases Innovative trend analysis can help us to avoid extracting misleading knowledge from the trend results.

Further, with ever increasing population and fast tracked industrialisation declining trend in water level are very common all over the world. Recently, Arshad and Umar (2020) presented a comprehensive review of ground water resources in India. They emphasized that due to population surge and industrial expansion along with climate change has contributed to the decline in quantity as well as quality of groundwater in India. In past few years many parts of Rajasthan, India has experienced acute shortage of water. In this regard, planned and judicious use of available ground resource with every possible attempt for enhancing groundwater recharge could help to maintain sufficient groundwater resources for future.

20.4 Conclusion

Knowledge of available groundwater resource and its future potential provide an important input for the design and management of water supply system. Over the years reliability over groundwater resources has increased due to industrial expansion and dwindling rainfall patterns. In the present chapter, trend analysis of water level of five wells, located in Churu, Rajasthan, India, was performed using Mann-Kendall, Spearman-Rho, Sens slope estimator and innovative trend analysis. At four of the wells water level was found to be declining significantly, only at one location water level showed positive trend. The results of all the trend test were in good agreement with each other. However, unlike monotonic trends detected from other trend tests, innovative trend analysis revealed different trends for low, medium and high water levels. In this regard, it may be concluded that application of innovative trend analysis provides the comprehensive view of the ongoing hydrologic changes in the region. Over the years, many developing countries have experienced steady decline in groundwater resources. Planned and judicious use of available ground resource with every possible attempt for enhancing groundwater recharge could help to maintain sufficient groundwater resources for future.

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