

Trend Analyses in Groundwater Levels of the Bikaner District, Rajasthan



Sanju R. Phulpagar, Ganesh D. Kale, Sagar Patel, and Sudhansu Mohanta

Abstract Groundwater (GW) is the essential part of the worldwide freshwater resources. Over-exploitation and insufficiency of GW resources are unfortunately widespread in several parts of the India. As per Central Groundwater Board (2016), groundwater level (GWL) fall of greater than 4 m was found in parts/patches of the Bikaner district, Rajasthan by comparison of depth to water level corresponding to year 2015 (2016 for January) with decennium average over the period 2005–2014 (for January, 2006–2015 is the decadal period) corresponding to January, August, November and May. Thus, in the current study, trend analyses of GWLs of six blocks of the Bikaner district, Rajasthan is carried out for monsoon, post-monsoon kharif, post-monsoon rabi and pre-monsoon temporal scales for the time period (1994–2018). For trend analyses, Mann Kendall (MK)/MK test with correction factor-2, Sen's slope test, innovative trend analysis plot and smoothing curve are used. The results showed presence of statistically significant decreasing trends in GWL time series of the Khajuwal and Dungargarh blocks corresponding to monsoon and pre-monsoon temporal scales, respectively. All statistically significant trends are decreasing, thus it shows improvement in GWLs in given blocks.

Keywords Six blocks · Bikaner · Groundwater · Trend analyses

S. R. Phulpagar (✉) · G. D. Kale · S. Patel · S. Mohanta
Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat
395007, Gujarat, India
e-mail: sanjup1213@gmail.com

G. D. Kale
e-mail: gdk@ced.svnit.ac.in

S. Patel
e-mail: sagarpatel2613@gmail.com

S. Mohanta
e-mail: sudhansusekhar94@gmail.com

Abbreviations

AC	Autocorrelation
ARIMA	Autoregressive integrated moving average
GW	Groundwater
GWL	Groundwater level
ITA	Innovative trend analysis
MK	Mann-Kendall
MK-CF ₂	Mann-Kendall test with correction factor 2
POMKH	Post-monsoon Kharif
POMRB	Post-monsoon Rabi
PREMON	Pre-monsoon
SS	Sen's slope
SGI	Standardized groundwater level index
TS	Time series

1 Introduction

Groundwater (GW) is the crucial part of the worldwide freshwater resources. It is the primary source of drinking, industrial and irrigation water requirements in many areas of the world (Panda et al. 2012). Due to the rapid population growth and the accelerated speed of industrialization, the demand for fresh water has risen exponentially in the last few decades. Rapid urbanization, particularly in developing countries such as India, has influenced GW availability and quality due to its over-exploitation and inappropriate disposal of waste, particularly in urban areas (Ramakrishnaiah et al. 2009). In India, more than 90% of rural population and almost 30% of urban population rely on GW to meet their domestic and drinking needs. Over-exploitation and scarcity of GW resources are unfortunately common in many parts of the India (Jha et al. 2010). Thus, study of groundwater levels (GWLs) in India is essential.

The stage of GW development in several blocks is greater than hundred percent in states like Rajasthan, Delhi, Haryana, Punjab, Gujarat, Uttar Pradesh, Tamil Nadu, Andhra Pradesh and Karnataka. In these states, this resulted in rapid decrease in water level (Patle et al. 2015). Maximum GWL fall was found in and around portions of the Rajasthan state by comparison of depth to water level for the year 2016 (2017 for January) with decadal average over the period 2006–2015 (for January decadal period is 2007–2016) corresponding to January, August, November and pre-monsoon (Central Ground Water Board, Year Not Mentioned). Thus, study of GWLs in the Rajasthan state is essential.

Analysis of depth to water level during May 2015 (i.e. pre-monsoon) showed that, water levels of greater than 40 m below ground level were found in 19.20% of stations, which fall mostly in the districts of Jaisalmer, Barmer, Jalore, Jodhpur,

Bikaner, Alwar, Bharatpur, Churu, Hanumangarh, Ganganer, Jaipur, Nagaur, Jhunjhunu presenting western and north-central part of the Rajasthan state (Central Ground Water Board 2016). According to Central Ground Water Board (2016) of the Rajasthan state, GWL fall of more than 4 m was found in patches/parts of the Bikaner district of the Rajasthan state by comparison of depth to water level for year 2015 (2016 for January) with decadal average over the period 2005–2014 (for January decadal period is 2006–2015) corresponding to January, August, November and May. Thus, study of GWLs in the Bikaner district of the Rajasthan state is very important.

Trend detection is a necessary task in hydrological series assessment, as it is not only basis for understanding the long-run alterations of hydrological processes, but also for showing hydrological processes periodicities and other characteristics (Sang et al. 2014). Thus, trend analysis in GWLs of the Bikaner district in the Rajasthan state, India is necessary. Consequently, it is considered as study area in the present study.

The research publications are reviewed to obtain information on the previous research work carried out in the field of trend analysis in GWL time series (TS) outside the India and in India. Trend detection studies performed outside the India are reviewed in the literature review (Abdullahi et al. 2015; Bui et al. 2012; Brocque et al. 2018; Gibrilla et al. 2017; Goode et al. 2013; Hodgkins et al. 2017; Iliia et al. 2018; Kawamura et al. 2011; Lee et al. 2014; Ribeiro et al. 2015; Shamsudduha et al. 2009; Tabari et al. 2012; Vousoughi et al. 2013; Yilmaz et al. 2020; Zafar et al. 2017; Zhou et al. 2016).

Thakur and Thomas (2011) have analyzed GWL trends for the few blocks of the Sagar district, Madhya Pradesh, India. The analysis was performed for the periods of 15–17 years. To identify the trend in GWLs, they have applied the parametric linear regression test and the non-parametric Kendal rank correlation test. Results of the study shown that, at three blocks of the Sagar district (i.e. Bina, Khurai and Sagar) decreasing trends were found.

Panda et al. (2012) have analyzed trends in GWL, maximum temperature and rainfall, to study the response of GW systems to anthropogenic and climatic stresses in the Gujarat state for the period of 1995 to 2005. They have applied non-parametric Kendall slope test for analyzing the trends and variability. The results of the study showed that, GWLs in the majority parts of the study area were declined, while the maximum temperature and rainfall was increased. Noticeable changes were identified in the intensity and frequency of the rainfall and also in percentiles of the temperature for the data sets corresponding to station scale. Therefore, they have concluded that, combined effect of the human induced forcing mechanism of over-withdrawal and climatic extremes may be one amongst the main causes of the decline in observed water table in the study area.

Patle et al. (2015) have analyzed long-term GWLs of pre and post-monsoon seasons to identify trends and predict future GWLs in the Karnal district of the Haryana state, India. They used Sen's Slope (SS) estimator and Mann Kendall (MK) test to examine the trend over the period 1974 to 2010. The non-seasonal Autoregressive Integrated Moving Average (ARIMA) model was used for modelling and

forecasting of GWL TS. They found that, GWLs declined significantly during pre and post-monsoon seasons, with average rates of 0.228 m/year and 0.267 m/year, respectively. Results of the study showed that, in 2050, pre and post-monsoon GWLs will decline by 12.97 m and 12 m, respectively over the GWL observed in 2010.

Kumar et al. (2018) have analysed the trends in GWLs of four districts in Lucknow division (i.e. Lucknow, Sitapur, Hardoi, Laxmipur) of the Uttar Pradesh, India, corresponding to the period of 1998 to 2012. They have applied non-parametric tests such as SS estimator test and Modified MK test for analysis of trend in GWL TS. For preparation of spatial maps during post-monsoon and pre-monsoon seasons, they utilized inverse distance weighted interpolation technique and ArcMap 10.4 software. Positive trends were observed at 6 locations and negative trends were observed at 7 locations corresponding to pre-monsoon season. Nonetheless, 4 locations showed negative trend and 9 locations exhibited positive trends in post-monsoon season.

Pathak and Dodamani (2019) have studied GWL trends and estimated regional GW drought characteristics for the drought-prone Ghatprabha river basin in India. They used the MK test to evaluate the seasonal and annual GWL trends. To categorize the wells, in case of long-term monthly GWLs, cluster analysis was performed. For evaluation of GW drought, they utilized standardized GWL index (SGI). More than 61% of wells were found to have significantly decreasing trends with an average decrease of 0.21 m. The SGI indicated a significant number of GW droughts in the study area, nonetheless, the wells of clusters 1 and 2 were found to be suffered by frequent droughts.

The following research gaps are found from the reviewed literature: (a) in some studies linear regression was used to assess the trend magnitude. But the linear regression test is affected by outliers (Sen 1968), (b) majority of studies have not assessed data assumptions, which is required for the selection of appropriate statistical test, (c) previous studies have not used innovative trend analysis (ITA) plot and smoothing curve concurrently to support trend analysis results and (d) trend analysis in GWLs of six blocks in the Bikaner district, Rajasthan was not carried out for the period of more than one decade.

Therefore, in the current study, trend analyses in GWLs of six blocks in the Bikaner district, Rajasthan is carried out by addressing the above research gaps by: (a) using SS test to determine the trend magnitude, as this test is not influenced by outliers as per Sen (1968), (b) assessing the assumption of data independence by using autocorrelation (AC) plot to select suitable statistical test (MK test and MK test with correction factor 2 (MK-CF₂) are utilized for the assessment of trend significance in serially uncorrelated and serially correlated data, respectively), (c) using ITA plot and smoothing curve simultaneously to support results of trend analyses and (d) performing trend analyses in GWLs of six blocks in the Bikaner district, Rajasthan for the period of more than one decade.

2 Study Area

Bikaner district is situated in the north-western part of the Rajasthan state and covers a geographical area of 30247.90 km². and have east longitudes 71° 52' to 74° 15' and north latitudes 27° 11' to 29° 03'. As the Bikaner district lies in the desert region, the desert is characterized by cold in winter and extremes of heat in summer. In the Bikaner district temperature varies from 1 °C in winter to 48 °C in summer. Temperatures rises gradually during both day and night time and reach their highest values in June, May and April months. Average annual rainfall (1991 to 2010) of the Bikaner district is 277.55 mm, while normal rainfall (1901 to 1971) of the district is below average rainfall and it is 257.8 mm. The soils of the Bikaner are mainly weak-structured, light textured, sand to sandy loam with the clay content. Soils of the district are usually of desertic type with very low water holding capacity and poor fertility status. In the Bikaner district, soils are usually have good porosity (40%) and good to very good permeability. In the Bikaner district one of the major GW problem is decline in water level (Central Ground Water Board 2013). Location of six blocks of the Bikaner district in the Rajasthan state, India is shown in Fig. 1.

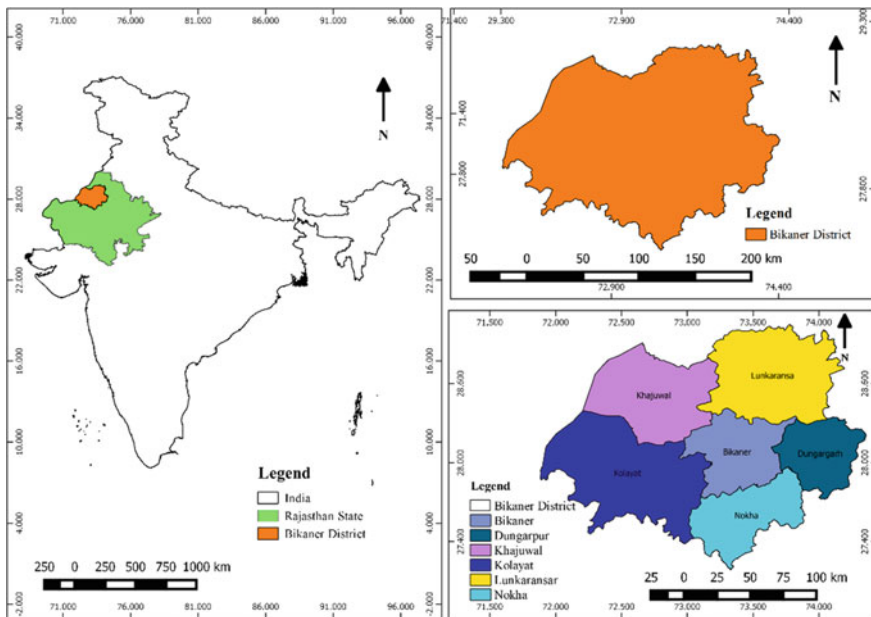


Fig. 1 Location of six blocks of the Bikaner district in Rajasthan state, India

3 Data Collection

In the current study, trend analyses in GWLs of six blocks in the Bikaner district, Rajasthan is carried out for the period of 1994 to 2018. The GWL data is available for four seasons viz. post-monsoon Rabi (POMRB) (January to March), pre-monsoon (PREMON) (April to June), Monsoon (July to September) and post-monsoon Kharif (POMKH) (October to December) (<http://59.179.19.250/GWL/GWL.html?UType=R2VuZXJhbA==?UName=> last accessed on 10th February 2020"). The GWL data of six blocks in the Bikaner district (1994 to 2018) is downloaded from website '<http://59.179.19.250/GWL/GWL.html?UType=R2VuZXJhbA==?UName=>' (last accessed on 10th February 2020). For the preparation of GWL data, average of GWLs of all sites in a block for a given season of the given year is taken as the value for the corresponding season of the given year and likewise GWL data of all seasons for each year of analysis period is prepared. If, there is single site in a block for a given season of the given year, then, it is taken as the value for the corresponding season of the given year. In the data, there were some missing values, which are filled by the average of all available seasonal data of the corresponding season.

4 Methodology

For analyses of trends in GWLs of the Bikaner district (six blocks) corresponding to POMRB, PREMON, monsoon and POMKH seasons over the period of 1994 to 2018, following methodology is applied. For the selection of suitable statistical test, the graphical method (i.e. AC plot) is utilized. AC plot (Kundzewicz and Robson 2000) is utilized in the current study for the evaluation of dependency of data. MK test (Bui et al. 2012; Tabari et al. 2012) or MK-CF₂ test (Sonali and Nagesh Kumar 2013; Yue and Wang 2004) is applied for the assessment of trend significance for serially uncorrelated or serially correlated data, respectively. The SS test (Sen 1968; Sonali and Nagesh Kumar 2013) is applied for the assessment of trend magnitude. ITA (Sen 2012; Sonali and Nagesh Kumar 2013) plot is used to identify monotonic or non-monotonic trend in the TS and to support trend analyses results. When plotting of smoothing curve is performed for the seasonal data, objective is generally to identify changes in long-term (Kundzewicz and Robson 2000). Smoothing curve (Kundzewicz and Robson 2000) is used to support the trend analyses results. The flowchart of methodology adopted in the present study is shown in Fig. 2. Details of statistical tests and graphical method used are given in Sects. 4.1–4.4.

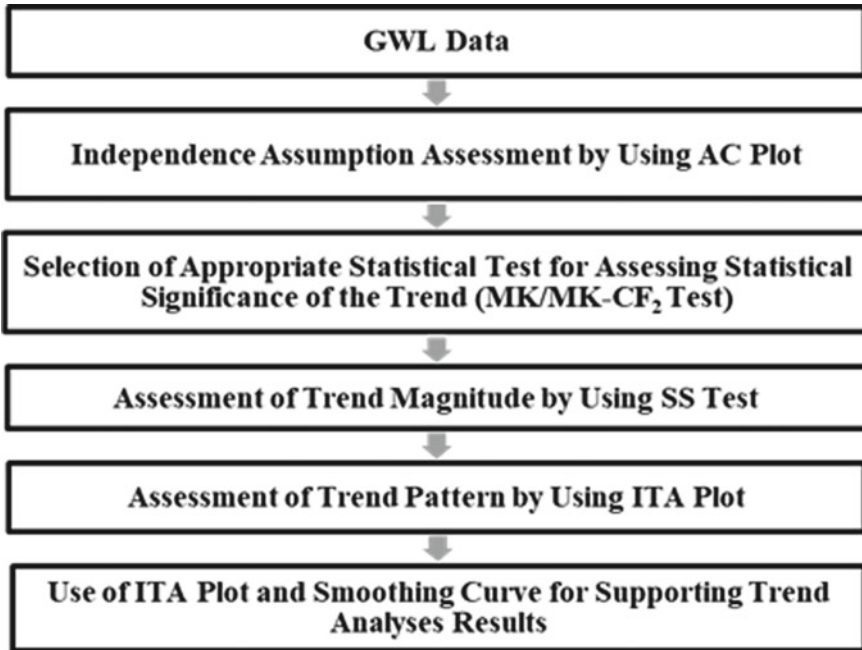


Fig. 2 Flowchart of trend analyses methodology

4.1 Mann Kendall Test

Majority of the studies on trend detection have analyzed trend by applying usually applied technique like MK test (non-parametric test having assumption of independent observations). MK test is rank-based test, which is a non-parametric test. The test statistics ‘S’ is determined by using Eq. 1 given below.

$$S = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(y_i - y_j) \tag{1}$$

where, data series length is ‘n’, y_i and y_j are the consecutive data in the series, and

$$\text{sign}(y_i - y_j) = \begin{cases} -1 \text{ for } (y_i - y_j) < 0 \\ 0 \text{ for } (y_i - y_j) = 0 \\ 1 \text{ for } (y_i - y_j) > 0 \end{cases} \tag{2}$$

$$E(S) = 0 \tag{3}$$

$$\text{Var}(S) = \frac{n(n - 1)(2n + 5) - \sum_{p=1}^q t_p(t_p - 1)(2t_p + 5)}{18} \tag{4}$$

where, ‘ t_p ’ is the tally of ties corresponding to p th value and ‘ q ’ is the tally of tied values. In the variance formula (Eq. 4), second term is for tied censored data. The standardized test statistic i.e. ‘ Z ’ is determined by Eq. 5.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{5}$$

To test for monotonous trend at the significance level of α , if absolute value of the standardized test statistic ‘ Z ’ is greater than ‘ $Z_{1-\alpha/2}$ ’ derived from the standard normal cumulative distribution tables, the null hypothesis of absence of trend is rejected (Sonali and Nagesh Kumar 2013).

4.2 Sen’s Slope Test

The magnitude of the slope b_{sen} can be derived by using Eq. 6 given below.

$$b_{sen} = \text{Median} \left(\frac{X_j - X_i}{j - i} \right) \text{ for all } j > i \tag{6}$$

where, X_j = data at time point j and X_i = data at time point i . In the series, if ‘ n ’ is the total number of data points, then, there will be $n(n-1)/2$ slope values and the b_{sen} (i.e. test statistic) is the median of all slope values. If the sign of test statistic is positive (negative) then it indicate that the trend is increasing (decreasing) trend (Sonali and Nagesh Kumar 2013).

4.3 Mann Kendall Test with Correction Factor-2

Existence of negative (positive) serial correlation results in decrease (increase) in the variance of the MK test statistic. Due to this drawback, approach of variance correction was suggested. MK test statistic’s modified variance is calculated by using Eq. 7 given below.

$$\text{Var}(S)* = CF*\text{Var}(S) \tag{7}$$

where, CF = correction factor. Yue and Wang (2004) given correction factor 2 (CF_2), which is calculated by using Eq. 8.

$$CF_2 = 1 + 2 \sum_{k=1}^{n-1} \left(1 - \frac{k}{n}\right) r_k \quad (8)$$

where, r_k is the serial correlation coefficient of the data corresponding to lag- k and 'n' indicate length of the complete series. MK test with CF_2 is known as MK- CF_2 test (Sonali and Nagesh Kumar 2013).

4.4 Innovative Trend Analysis Plot

This technique is based on the notion that, if two TS are same, their plot against each other shows a straight line of 45° (i.e. 1:1 line) on the Cartesian coordinates regardless of not holding good corresponding to all the suppositions about distribution, serial correlation and sample length. In the ITA plot, if the data points are on the 45° line (i.e. 1:1 line), it indicate that, trend is not present in the series. If the scatter points are above or below the 45° line (1:1 line), it indicates monotonically increasing trend or monotonically decreasing trend, respectively. If the scatter points lie on both the sides of 45° line, it indicates non-monotonic decreasing or increasing trend hidden at the diverse time scales in the same TS (Sonali and Nagesh Kumar 2013). A monotonic downward (upward) trend means that the variable consistently decreases (increases) throughout the time, however the trend might be or might not be linear (https://vsp.pnnl.gov/help/vsample/Design_Trend_Mann_Kendall.htm).

5 Results and Discussions

In the present study, analyses of trends in GWLs of the Bikaner district (six blocks), Rajasthan is carried out for POMRB, PREMON, monsoon and POMKH seasons corresponding to the period of 1994 to 2018. The results of aforesaid trend analyses are given in Sects. 5.1–5.4. AC plot, ITA plot and smoothing curve are shown only for the statistically significant trend (if present) in a given seasonal TS.

5.1 Trend Analyses in Monsoon Groundwater Level Time Series (1994–2018) of Six Blocks in the Bikaner District of the Rajasthan

Statistically significant trend is detected in monsoon GWL TS of one block i.e. Khajuwal block, out of six blocks, by application of MK test as given in Table 1. The magnitude of significant trend found at the Khajuwal block is -0.267 m/year, while

Table 1 Trend analyses results for monsoon GWL TS (1994–2018) of six blocks in the Bikaner District of the Rajasthan

Block name	^a SS value (m/year)	Pattern of trend	Statistical test	Significant trend
Khajuwal	−0.267	Non-monotonic	MK	Yes
Nokha	0.248	Non-monotonic	MK-CF ₂	No
Bikaner	−0.367	Monotonic	MK-CF ₂	No
Kolayat	−0.424	Monotonic	MK-CF ₂	No
Dungargarh	0.001	Non-monotonic	MK-CF ₂	No
Lunkaransa	−0.610	Monotonic	MK-CF ₂	No

^aNegative trend denotes improvement in GWL and positive trend denotes decline in GWL

the pattern of trend found at the Khajuwal block is non-monotonous. Also, statistically significant trends are not detected in monsoon GWL TS of five blocks, namely as Nokha, Bikaner, Kolayat, Dungargarh and Lunkaransa. The negative magnitude of insignificant trends in monsoon GWLs of three blocks, namely as Bikaner, Kolayat and Lunkaransa, indicates an improvement in monsoon GWLs at the given blocks. While magnitude of insignificant trends in monsoon GWLs at the Nokha and Dungargarh blocks is positive, which shows decline in monsoon GWLs at corresponding blocks.

AC plot of monsoon GWL TS at the Khajuwal block for the time period 1994–2018 is shown in the Fig. 3a. The AC plot is utilized for evaluation of independence of data, which is needed for the selection of suitable trend detection test. AC plot displayed in Fig. 3a shows that, the corresponding data is independent and thus, MK test is employed for the given TS. For analysing pattern of the trend in monsoon GWL TS (1994–2018) at the Khajuwal block, ITA plot is used and it is shown in Fig. 3b. Smoothing curve (with window 10) of monsoon GWL TS (1994–2018) at the Khajuwal block is shown in Fig. 3c. The monsoon GWL TS (1994–2018) at the Khajuwal block has shown significant decreasing trend, which is supported by decreasing pattern of data observed in corresponding ITA plot (Fig. 3b) and smoothing curve (Fig. 3c), respectively.

5.2 Trend Analyses in Post-monsoon Kharif Groundwater Level Time Series (1994–2018) of Six Blocks in the Bikaner District of the Rajasthan

Statistically significant trends are not detected in POMKH GWL TS (1994–2018) at all blocks, namely as Khajuwal, Nokha, Bikaner, Kolayat, Dungargarh and Lunkaransa as given in Table 2. Magnitude of trend in POMKH GWL TS at all blocks is negative, which shows an improvement in POMKH GWLs at corresponding blocks.

Fig. 3 **a** AC plot of monsoon GWL TS (1994–2018) at the Khajuwal block. **b** ITA plot of monsoon GWL TS (1994–2018) at the Khajuwal block. **c** Smoothing curve of monsoon GWL TS (1994–2018) at the Khajuwal block

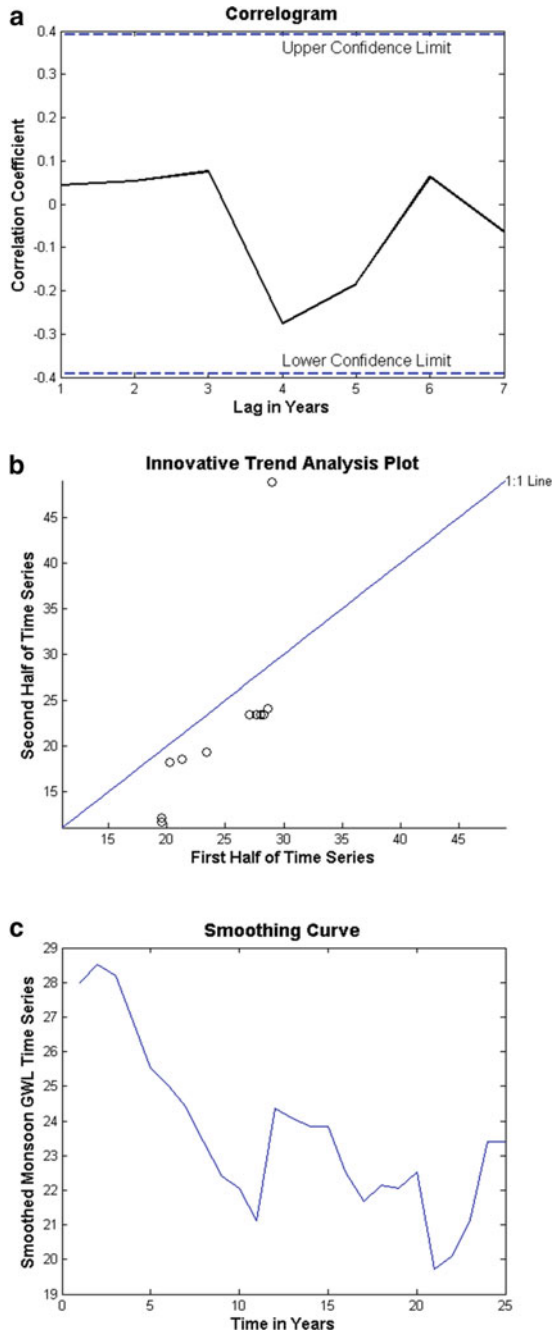


Table 2 Trend analyses results for POMKH GWL TS (1994–2018) of six blocks in the Bikaner District of the Rajasthan

Block name	^a SS value (m/year)	Pattern of trend	Statistical test	Significant trend
Khajuwal	−0.422	Monotonic	MK-CF ₂	No
Nokha	−0.093	Non-monotonic	MK-CF ₂	No
Bikaner	−0.305	Non-monotonic	MK-CF ₂	No
Kolayat	−0.497	Monotonic	MK-CF ₂	No
Dungargarh	−0.196	Non-monotonic	MK	No
Lunkaransa	−0.524	Monotonic	MK-CF ₂	No

^aNegative trend denotes improvement in GWL

5.3 Trend Analyses in Post-monsoon Rabi Groundwater Level Time Series (1994–2018) of Six Blocks in the Bikaner District of the Rajasthan

Statistically significant trends are not detected in the POMRB GWL TS (1994–2018) at all blocks, namely as Khajuwal, Nokha, Bikaner, Kolayat, Dungargarh and Lunkaransa as shown in Table 3. The negative magnitude of trends in POMRB GWL TS at five blocks, namely as Khajuwal, Bikaner, Kolayat, Dungargarh and Lunkaransa, indicates an improvement in POMRB GWLs at corresponding blocks. Magnitude of trend in POMRB GWL TS at the Nokha block is positive, which shows decline in POMRB GWL at the given block.

Table 3 Trend analyses results for POMRB GWL TS (1994–2018) of six blocks in the Bikaner District of the Rajasthan

Block name	^a SS value (m/year)	Pattern of trend	Statistical test	Significant trend
Khajuwal	−0.395	Monotonic	MK-CF ₂	No
Nokha	0.333	monotonic	MK-CF ₂	No
Bikaner	−0.367	Non-monotonic	MK-CF ₂	No
Kolayat	−0.447	Non-monotonic	MK-CF ₂	No
Dungargarh	−0.122	Non-monotonic	MK	No
Lunkaransa	−0.641	Monotonic	MK-CF ₂	No

^aNegative trend denotes improvement in GWL and positive trend denotes decline in GWL

5.4 Trend Analyses in Pre-monsoon Groundwater Level Time Series (1994–2018) of Six Blocks in the Bikaner District of the Rajasthan

Statistically significant trend is detected in pre-monsoon GWL TS (1994–2018) of one block i.e. the Dungargarh block, out of six blocks, by application of MK-CF₂ test, as given in Table 4. The magnitude of significant trend found at the Dungargarh block is -0.185 m/year, while pattern of significant trend found at the Dungargarh block is monotonous. Also, statistically significant trends are not detected in pre-monsoon GWL TS at five blocks, namely as Khajuwal, Nokha, Bikaner, Kolayat and Lunkaransa. The negative magnitude of insignificant trends in pre-monsoon GWL TS at four blocks, namely as Khajuwal, Bikaner, Kolayat and Lunkaransa indicates an improvement in pre-monsoon GWLs at corresponding blocks. While magnitude of the trend in pre-monsoon GWL TS at the Nokha block is positive, which shows decline in pre-monsoon GWL at the given block.

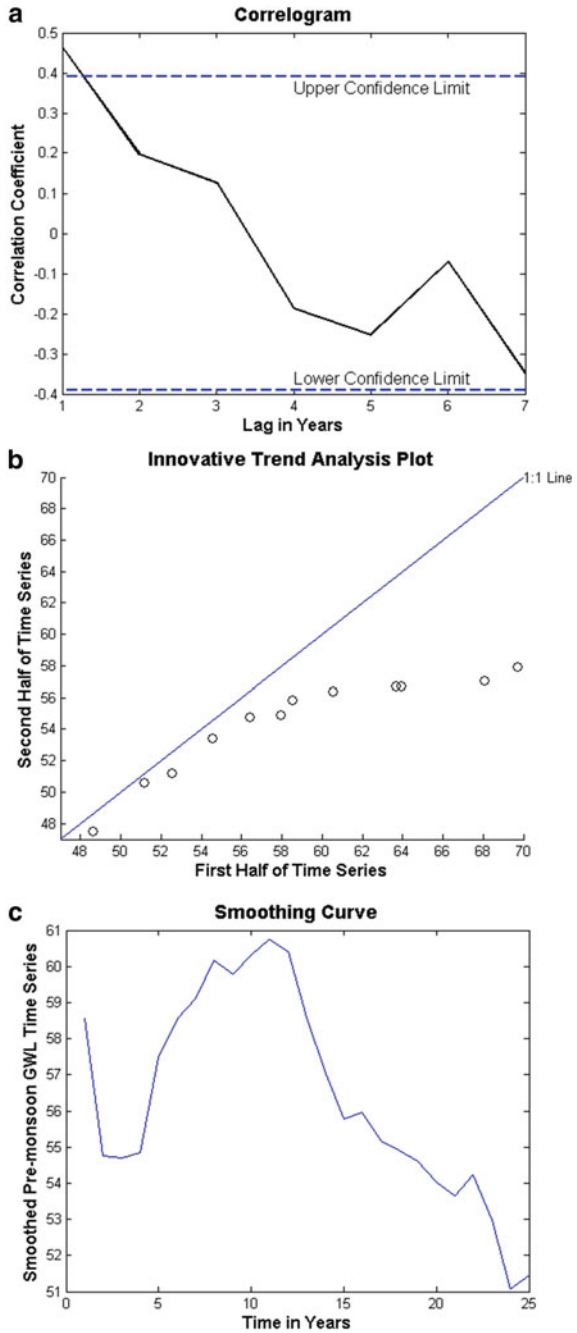
AC plot of pre-monsoon GWL TS at the Dungargarh block for the time period 1994–2018 is shown in the Fig. 4a. The AC plot shown in Fig. 4a corresponding to pre-monsoon GWL TS (1994–2018) at the Dungargarh block shows that, the corresponding data is dependent and thus, the MK-CF₂ test is employed for the given TS. For analyzing pattern of the trend in pre-monsoon GWL TS (1994–2018) at the Dungargarh block, ITA plot is used and it is shown in the Fig. 4b. Smoothing curve (with window 10) of the pre-monsoon GWL TS (1994–2018) at the Dungargarh block is shown in the Fig. 4c. The pre-monsoon GWL TS (1994–2018) at the Dungargarh block has showed a significant decreasing trend, which is supported by decreasing pattern of data observed in corresponding ITA plot (Fig. 4b) and smoothing curve (Fig. 4c).

Table 4 Trend analysis results for pre-monsoon GWL TS (1994–2018) of six blocks in the Bikaner District of the Rajasthan

Block name	^a SS value (m/year)	Pattern of trend	Statistical test	Significant trend
Khajuwal	-0.448	Monotonic	MK-CF ₂	No
Nokha	0.131	Non-monotonic	MK	No
Bikaner	-0.440	Monotonic	MK-CF ₂	No
Kolayat	-0.163	Non-monotonic	MK-CF ₂	No
Dungargarh	-0.185	Monotonic	MK-CF ₂	Yes
Lunkaransa	-0.795	Monotonic	MK-CF ₂	No

^aNegative trend denotes improvement in GWL and positive trend denotes decline in GWL

Fig. 4 **a** AC plot of pre-monsoon GWL TS (1994–2018) at the Dungargarh block. **b** ITA plot of pre-monsoon GWL TS (1994–2018) at the Dungargarh block. **c** Smoothing curve of pre-monsoon GWL TS (1994–2018) at the Dungargarh block



6 Conclusions

Statistically significant decreasing trend is found in GWL TS (1994–2018) at the Khajuwal block corresponding to monsoon temporal scale. Statistically significant decreasing trend is also found in pre-monsoon GWL TS (1994–2018) at the Dungargarh block. As given above, all statistically significant trends are decreasing, thus showing an improvement in GWLs at given blocks in corresponding seasons.

Increasing insignificant trends are found in GWL TS (1994–2018) at the Nokha block corresponding to temporal scales of monsoon, POMRB and pre-monsoon. Also increasing insignificant trend is found in GWL TS (1994–2018) at the Dungargarh block corresponding to monsoon temporal scale. These aforesaid increasing insignificant trends indicate decline in GWLs at given blocks in corresponding seasons. Insignificant decreasing trends found in GWL TS (1994–2018) at various blocks corresponding to temporal scales of monsoon, POMKH, POMRB and pre-monsoon, shows an improvement in GWLs at the given blocks in corresponding seasons. Attribution of statistically significant decreasing trends found in GWL TS at the Khajuwal and the Dungargarh blocks corresponding to monsoon and pre-monsoon temporal scales, respectively, can be performed in future.

In the present study, the effect of climate change on GWLs of six blocks in the Bikaner district of the Rajasthan is studied through trend analyses. Thus, this book chapter is related to this book titled “Water and Energy Management in India Artificial Neural Networks and Multi-Criteria Decision Making Approaches.”

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