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ORIGINAL PAPER

Zoning of groundwater level using innovative trend analysis: Case study at Rechna Doab, Pakistan

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Abstract: Groundwater plays a pivotal role in the economy from several country due to the scarcity of surface freshwater. In Pakistan it is the second largest water source which is used for irrigation, drinking and domestic uses. To monitor the groundwater availability and variation in country, the trend needs to be observed over time period; therefore, a study was conducted at Rechna Doab (Punjab province, Pakistan) to analyze the groundwater level trends over (period 2006-2019) using innovative trend analysis (ITA). 134 tube wells data was collected from Punjab Irrigation Department in pre-monsoon (June) and post-monsoon seasons (October), which were subsequently segregated at tehsils. In ITA, the data was divided in two equal parts and arranged in ascending order, first half (2006-2012) placed on the horizontal axis (X-axis) and second half (2013-2019) placed on the vertical axis (Y-axis) in a two-dimensional Cartesian coordinate system. After distribution of data, the points which are above the triage line show positive trend (increasing trend), similarly the data points which are scattered below the trend line represent negative trend (decreasing trend), while the data points which are scattered at the 1:1 line indicates no trend. For both seasons (pre-monsoon and post-monsoon), the results of the groundwater level trends for tehsil (representing point in each tehsil) were spatially interpolated using interpolation method of the Inverse Distance Weighted (IDW). A division with three classes was adopted, namely: low, moderate, and high-water levels. For pre-monsoon season it was observed that 32% groundwater wells were showing no trend, 61% with decreasing trend, and 7% with increasing trend. For post-monsoon season, 43% groundwater wells were showing no trend, 50% with decreasing trend, and 7% with increasing trend.

Keywords: Groundwater level, time series, Sen’s estimator, pre-monsoon, pro-monsoon.

Introduction

Climate changes could have severe implications on variability of hydro-metrological parameters such as temperature, precipitation, evaporation, among others (Mallick et al., 2021; Abbas et al., 2022). According to the Inter Government Panel on Climate Change

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(IPCC), surface temperature may change the cycle of hydrological parameters at local and global level (Guilyardi et al., 2018). Rainfall is the primary component of the hydrological cycle which needs to be monitored due to its major impact on climatological, agricultural and hydrological studies (Almazroui et al., 2012; Chatterjee et al., 2016; Ahmad et al., 2018; Amin et al., 2018; Bazame et al., 2018; Yang et al., 2019). The economy of countries like India and Pakistan, is deeply dependent on rainfall, because it provides a major water source for the use on agriculture (Zolina et al., 2010; Fatichi et al., 2013; Singh and Mal, 2014; Bakhsh et al., 2015; Caloiero, 2020).

In Pakistan, variation of surface and groundwater for agriculture may create food problems due to less water productivity; therefore, justifying the cultivation high value crops through high efficiency irrigation systems which is more costly than annual returns (Abbas et al., 2017). To preserve groundwater levels, rainfall is also a major component of the hydrological cycle for groundwater recharge (Aslam et al., 2021). The hydrological parameters like rainfall undergo temporal variations; therefore, this behavior can be evaluated by trend analysis (Foster and van der Gun, 2016; Phuong et al., 2022). During previous decades, it was observed that the trend of climate change on hydrological parameters has been increased drastically due to extreme seasonal and annual values (Tabari and Talaee, 2011; Garamhegyi et al., 2018).

In order to determine the trend of variation of hydrological parameters like rainfall, groundwater level, water quality, temperature, runoff, and recharge, non-parametric tests (Mann-Kendall test and Sen’s slope method) and parametric tests (innovative trend analysis – ITA) were used (Feng et al., 2011; Thakur and Thomas, 2011; Ahmad et al., 2014; Taye et al., 2015; Mittal et al., 2016; Zeleňáková et al., 2017; Yang et al., 2019). In the Ghat Parbha River Basin (India), regression analysis and Mann-Kendall test were used method to determine the relationship between the drought and groundwater level (Pathak and Dodamani, 2019). The effect of linear rainfall patterns was also evaluated using the Mann-Kendall approach in a Tawa command area in the India (Nema et al., 2016).

Innovative trend analysis also provides graphical and statistical representation (Şen, 2017), providing an easier, simple and quick approach about trend analysis. This method was used to determine the runoff extreme events (Tabari et al., 2017) and atmospheric rainfall patterns (Wu and Qian, 2017; Caloiero et al., 2018). It was determined that application of statistical approach could be facilitated by the comparative analysis of data sets on time series without assumptions of parametric and non-parametric tests (Sonali and Kumar, 2013; Kisi and Ay, 2014; Dabanlı et al., 2016). Statistical and parametric trend approach was also applied in north eastern parts of Romania, where Mann Kendal and Sen’s slope were used with regression analysis to estimate the significant variations in precipitations (Minea and Croitoru, 2017) and in the climatic water balance (Prăvălie et al., 2019) due to the long-term variation in climate changes.

To determine the trend analysis of groundwater level, innovative trend analysis is an informal and result oriented method which provides a precise approach to readers to analyze about groundwater level position over time series. Therefore, the main purpose of this study was evaluated the groundwater level trends at tehsil in study area (Rechna Doab) for pre-monsoon and post-monsoon seasons.

Material and Methods

Site description

Rechna Doab (Punjab Province, Pakistan) was selected to determine the groundwater level trends for period 2006-2019. Rechna Doab is an area between Ravi and Chenab rivers which is widely spread and covers major districts namely, Gujranwala, Narowal, Hafizabad, Sheikhupura, Faisalabad, Nankana Sahib, Chiniot, Jhang, and Toba Tek Singh. The geographical location of the study area is shown in Figure 1. It lies between 30°35' and 32°50' N and 71°50' and 75°3' E, which is uniformly spread between Ravi and Chenab boundaries.

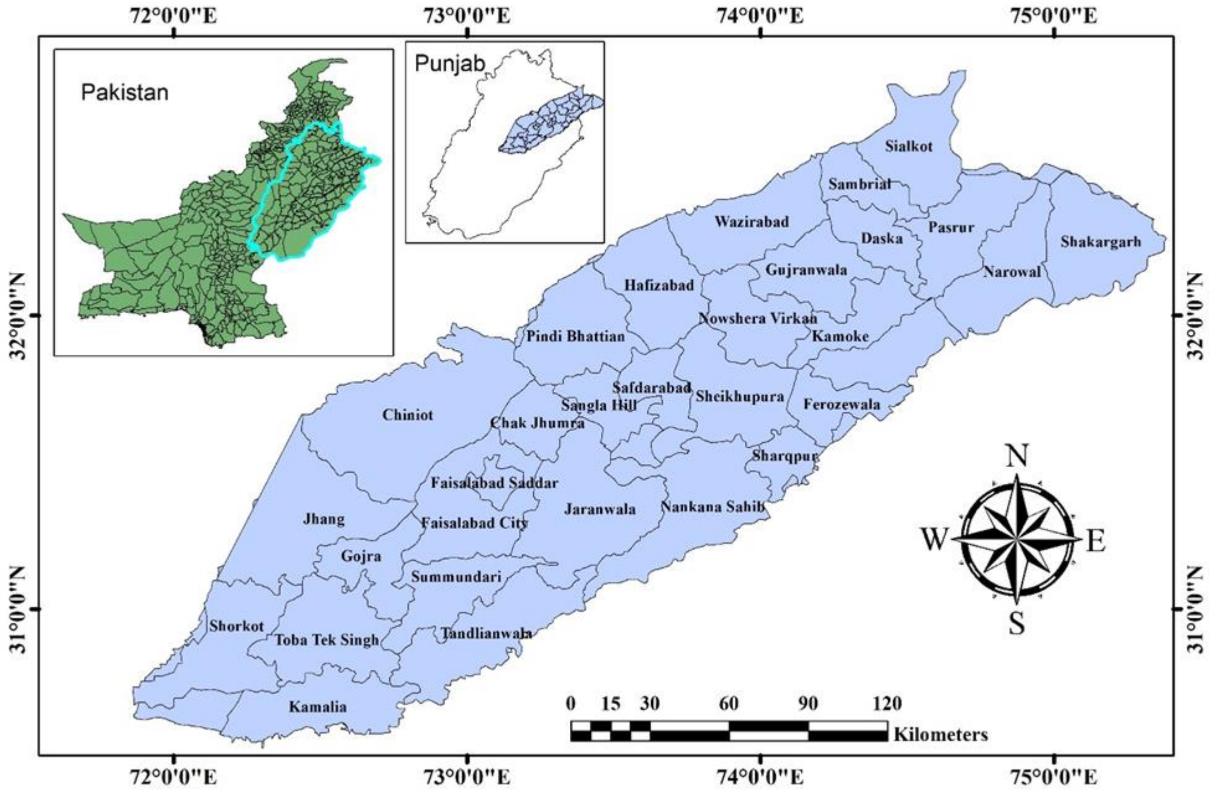


Figure 1: Location map of the study area.

Total area in Doab is about 28,500 km^2 being major part of this area well fertile; therefore, suitable for agriculture production. As for the texture of the soils, they are classified as fine (sandy clay, silt clay, and clay), medium fine (loam, silt loam, and silt), moderately coarse (fine sandy loam and sandy loam), and coarse (sand and sandy loam). It consists alluvial deposits which were transported by Indus River and its tributaries. Topography of area is flat and uniformly distributed from north to northeast.

The study area is characterized by variations of rainfall in rainy and dry seasons, classified as pre-monsoon and post-monsoon. Mean annual rainfall (1980-2020) ranges from 200 to 778 mm. During dry season the crops water needs is artificially supplied by irrigation; therefore, for that purpose groundwater is over-exploited. According to Ashraf and Ahmad (2008), the groundwater is mainly utilized to supplement irrigation canal water supplies where these are not adequately met especially during summer season when river discharges are at their lowest. In addition to precipitation, seasonal fluctuations in temperature are registered in the study area. The summer season is considered as long and hot which starts from April and ends in September, with maximum temperature ranges from 33 to 48°C; winter season starts from December and ends in February, with maximum temperature ranges from 19 to 27°C (Arshad et al., 2019).

Data acquisition

Data of the water level in tube wells were collected two times in a single year in pre-monsoon and post-monsoon seasons for period 2006 to 2019 from the Punjab Irrigation Department. Collected data of tube wells were initially segregated at the tehsil level according to Swain et al. (2022). In the present study, data of 130 tube wells were obtained and organized at the tehsil level (Table 1). For that purpose, with the number of wells in each tehsil an average was calculated to determine a unique value for variation of water level in a respective year.

Table 1: Distribution of the wells for analysis of groundwater level trends

Latitude	Longitude	Tehsil	District	Wells number
31.7178	72.9944	Chiniot	Chiniot	3
31.2588	72.338	Jhang	Jhang	4
30.8222	72.1484	Shorkot		6
31.5737	73.1851	Chak Jhumra	Faisalabad	2
31.4297	73.0649	Faisalabad		7
31.3394	73.4324	Jaranwala		13
31.0676	72.9659	Samundri		7
31.0284	73.1256	Tandla		2
32.1541	74.1912	Gujrawala	Gujrawala	4
31.9787	74.2184	Kamoki		1
31.9655	73.9741	Noushera		1
32.4411	74.1189	Wazerzabad		5
32.0793	73.6912	Hafizabad	Hafizabad	7
31.9006	73.2725	Pindi Bhattian		4
31.445	73.6987	Nankana	Nankana	6
31.7149	73.375	Sangla		4
31.5784	73.4799	Shahkot		1
32.1019	74.8733	Narowal	Narowal	6
32.2632	75.1623	Shakarghar		1
31.7107	73.9939	Sheikupura	Sheikupura	11
31.727	73.5767	Safdarabd		3
32.3354	74.3528	Daska	Sialkot	1
32.2675	74.6645	Pasroor		1
32.4789	74.361	Sambrial		1
32.4939	74.5433	Sialkot		1
31.1477	72.686	Gojra	TTSingh	5
30.7266	72.6489	Kamalia		19
30.9701	72.4827	TTSingh		4
			Total of wells	130

Innovative trend analysis (ITA)

The ITA method was used to analyze trends in groundwater level over the 2006-2019 time series. Was considered for the application of the ITA method representations of variation of water level at season basis like pre-monsoon and post-monsoon. In Pakistan, the major source of groundwater recharge is through rainfall, being maximum recharge to groundwater observed in post-monsoon. Therefore, this division was to evaluate the statistical behavior in terms of trend analysis for both seasons.

The ITA method divides a time series in steps, and it sorts both sub-series in ascending order. In first step is selection of data set on a yearly basis and duration of time series is accounted for. In second step, two sets of data were arranged namely, first half (from 2006 to 2012) and second half (from 2013 to 2019) of the data. In third step, the first half is placed on the horizontal axis (X-axis) and second half is placed on the vertical axis (Y-axis) in a two-dimensional Cartesian coordinate system; being the scatter points compared on the 1:1 trend (45°) line. After distribution of data, the points which are above the triage line show positive trend (increasing trend), similarly the data points which are scattered below the trend line represent negative trend (decreasing trend), while the data points which are scattered at the 1:1 line indicates no trend (Şen, 2012; Şen, 2017), as shown in Figure 2 below.

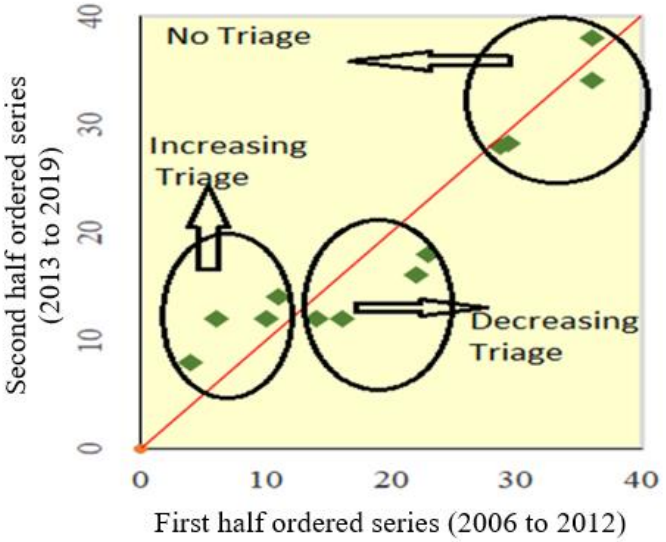


Figure 2: Illustration of the ITA method.

After the completion of the above steps, was calculated the slope 'S' of the trend line according to the Equation 1 and your confidence limit (CL) by Equation 2 (Şen, 2017).

$$S = \frac{2\,(\bar{y}2 - \bar{y}1)}{n} \quad (1)$$

$$CL(1\text{-}\alpha) = 0 \pm S_{crit}\sigma_S \quad (2)$$

Where: $\bar{y}_2$ and $\bar{y}_1$ are the arithmetic means of second and first series; *n* total number of data sets; α percentage of significance level (5% value was used); S_{cri} standard deviation of the mean; σ_S slope standard deviation. When alternate hypothesis is adopted indicate the existence of trends, i.e., when values are found outside the confidence interval.

Spatial interpolation of groundwater level

Based on trend analyses of the water level in tube wells, spatial interpolations were conducted using the interpolation method of the Inverse Distance Weighted (IDW) as used by other authors for the same purpose (Silva et al., 2013; Khouni et al., 2021). Therefore, water level variations were mapped using GIS to incorporate the results of both seasons (pre-monsoon and post-monsoon). A division with three classes was adopted, namely: low, moderate, and high-water levels.

Results and Discussion

Seasonal variations in rainfall directly impact the demands by water supplies (Ahmad and Choi, 2021). Therefore, due to the scarcity of surface water resources the groundwater has been the main water source for different uses in various countries (Akther et al., 2009; Mehmood et al., 2022), including Pakistan (Anjum et al., 2016; Zakir-Hassan et al., 2022). In the agricultural sector, the area irrigated by groundwater has increased in recent years (Sishodia et al., 2016; Kang and Kaur, 2017; Hasan et al., 2021; Ali et al., 2022; Tavares Filho et al., 2022).

Groundwater level fluctuations and trends can be used to estimate changes in aquifer storage resulting from the effects of groundwater withdrawal and recharge (Thakur and Thomas, 2011). In the present study, an innovative trend analysis (ITA) was performed for determination of behavior of groundwater level data over time in two seasons (pre-monsoon and post-monsoon). Groundwater level increasing trends indicates recharge of water bodies, while decreasing trends indicates the decline of groundwater level over time. The ITA method has been applied in different regions, as in Shaanxi in the China (Wu and Qian, 2017), in the southern Italy (Caloiero et al., 2018) and South Island of New Zealand (Caloiero, 2020) to evaluate rainfall trends.

The trend analysis of the pre-monsoon season is shown in Figure 3. It was observed that 32% groundwater wells were showing no trend, 61% with decreasing trend, and 7% with increasing trend of groundwater level. Out of 28 tehsils, 17 showed decreasing trend, nine no trend, and two with increasing trend, respectively (Table 2). A wide decreasing variation has been found at Faisalabad, Gujranwala, Sialkot, and Sheikhupura districts due to higher consumption of water.

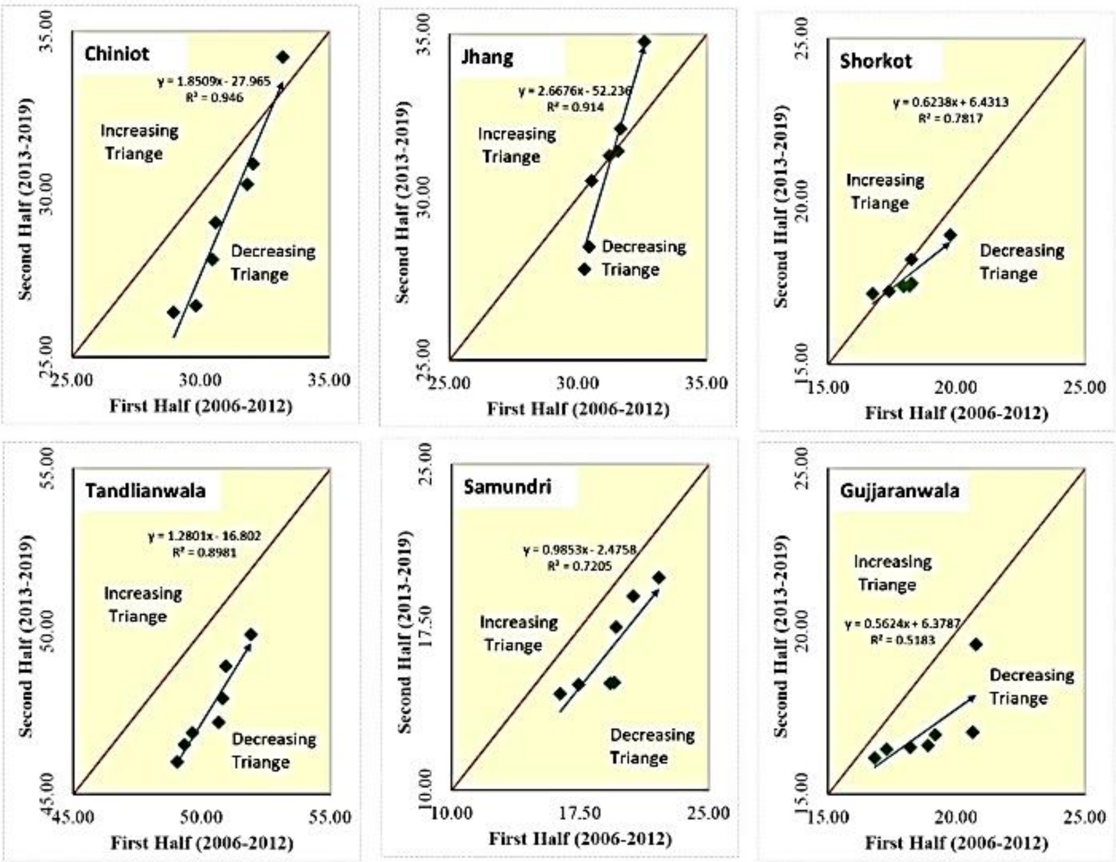


Figure 3: Groundwater level trends using innovative trend analysis method for pre-monsoon season at tehsil level.

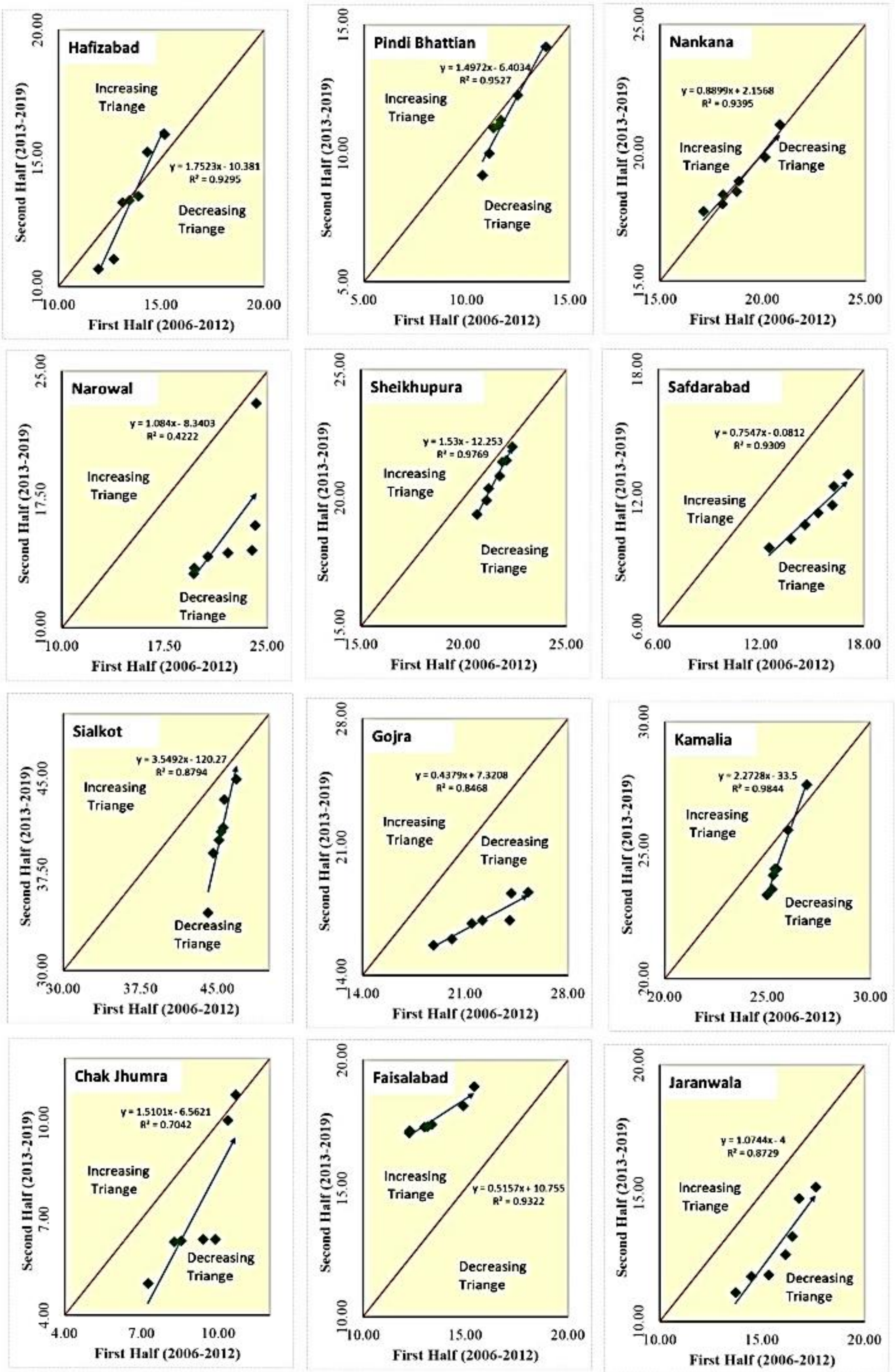


Figure 3: (Continued)

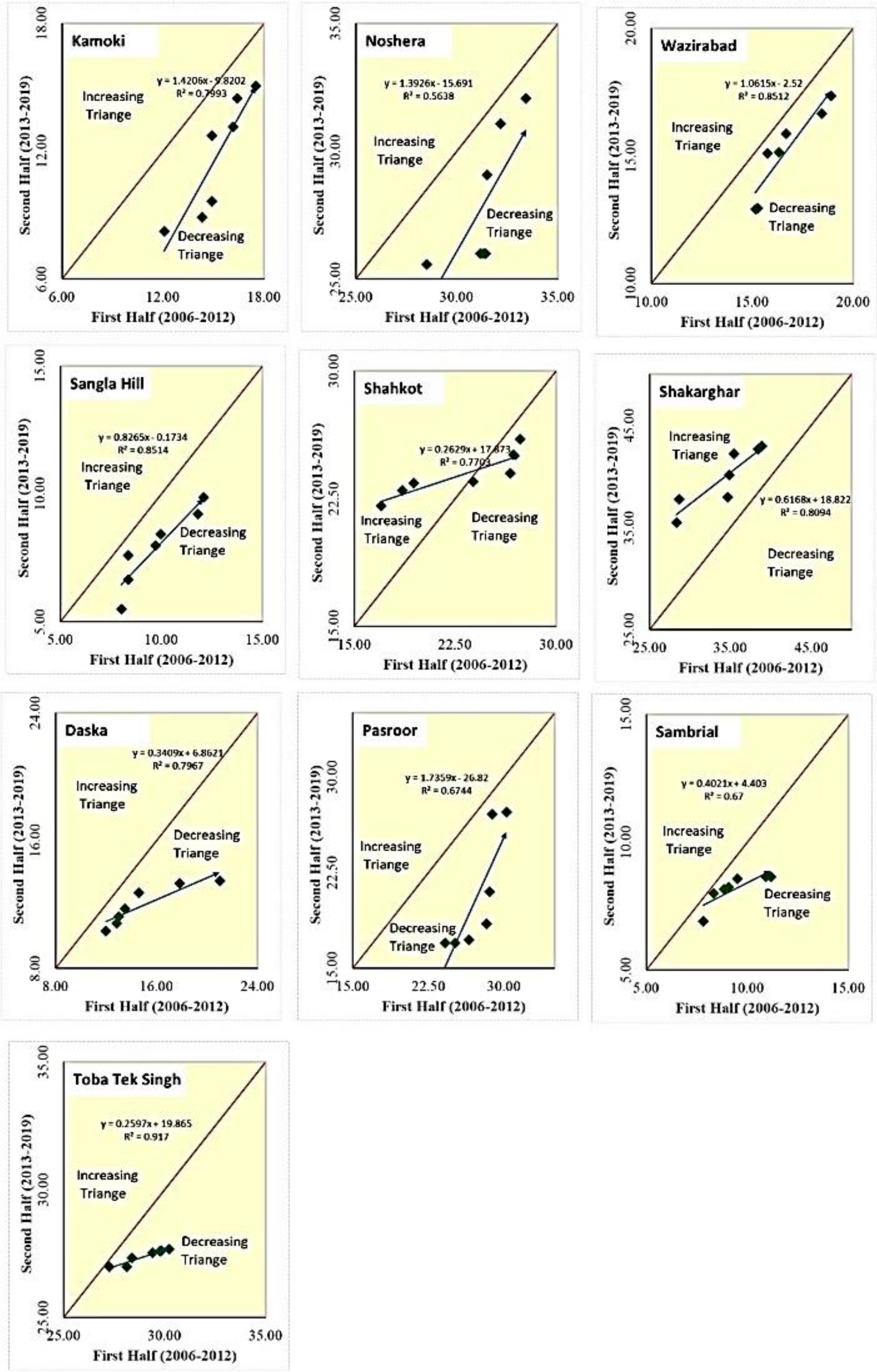


Figure 3: (continued).

Table 2: Description of the innovative trend analysis method for pre-monsoon season (period (2006-2019) at tehsil level

Tehsil	Mean y1	Mean y2	Centroid Y1	Centroid Y2	Y2-Y1	Slope	ITA slope	Linear regression slope	Trend
Chiniot	30.98	29.37	31.81	28.00	-3.81	-0.38	-0.23	-0.14	No
Jhang	31.17	30.92	31.65	28.50	-3.15	-0.31	-0.04	0.04	No
Shorkot	18.08	17.71	17.38	17.17	-0.21	**-0.02**	-0.05	-0.05	No
Chak Jhumra	9.20	7.33	9.88	5.00	-4.88	-0.49	-0.27	-0.15	No
Faisalabad	16.23	13.48	16.96	12.29	-4.68	-0.47	-0.39	-0.34	Increasing
Jaranwala	15.79	12.97	16.13	11.77	-4.36	-0.44	-0.40	-0.28	Decreasing
Samundri	19.26	16.50	19.59	14.86	-4.74	-0.47	-0.39	-0.28	Decreasing
Tandla	50.34	47.63	50.80	46.00	-4.80	-0.48	-0.39	-0.22	Decreasing
Gujrawala	18.83	16.97	18.21	16.91	-1.30	**-0.13**	-0.27	-0.19	Decreasing
Kamoki	15.19	11.76	16.16	13.16	-3.00	**-0.30**	-0.49	-0.37	Decreasing
Noushera	31.36	27.97	31.33	26.00	-5.33	-0.53	-0.48	-0.46	Decreasing
Wazerzabad	16.65	15.15	15.28	12.97	-2.32	-0.23	-0.21	-0.14	Decreasing
Hafizabad	13.52	13.31	13.88	10.70	-3.18	-0.32	-0.03	0.08	No
Pindi Bhattian	11.82	11.29	12.47	9.17	-3.31	-0.33	-0.08	0.02	No
Nankana	18.83	18.91	20.13	18.36	-1.77	-0.18	0.01	0.08	No
Sangla	9.76	7.89	8.36	5.50	-2.86	-0.29	-0.27	-0.22	Decreasing
Shahkot	22.80	23.87	23.83	23.00	-0.83	**-0.08**	0.15	0.29	No
Narowal	22.04	15.55	22.13	13.16	-8.97	**-0.90**	-0.93	-0.72	Decreasing
Shakarghar	34.18	39.90	34.83	37.75	2.92	0.29	0.82	0.80	Increasing
Sheikupura	21.58	20.77	20.67	19.91	-0.76	**-0.08**	-0.12	-0.08	Decreasing
Safdarabd	15.09	11.30	14.55	9.67	-4.89	**-0.49**	-0.54	-0.45	Decreasing
Daska	14.96	11.96	17.83	10.83	-7.00	-0.70	-0.43	-0.23	Decreasing
Pasroor	27.39	20.73	28.83	17.25	-11.58	-1.16	-0.95	-0.86	Decreasing
Sambrial	9.38	8.17	9.50	8.00	-1.50	**-0.15**	-0.17	-0.17	Decreasing
Sialkot	45.32	40.58	45.58	39.16	-6.42	**-0.64**	-0.68	-0.51	Decreasing
Gojra	22.29	17.08	22.17	15.67	-6.50	**-0.65**	-0.74	-0.65	Decreasing
Kamalia	25.60	24.67	25.98	23.26	-2.71	-0.27	-0.13	-0.04	No
TTSingh	29.01	27.40	30.23	27.00	-3.23	-0.32	-0.23	-0.13	Decreasing

Similarly, ITA method was used for determination of behavior of groundwater level data over time for post-monsoon season (Figure 4). It was observed that 43% groundwater wells were showing no trend, 50% with decreasing trend, and 7% with increasing trend of groundwater level. Out of 28 tehsils, 14 showed decreasing trend, 11 no trend, and two with increasing trend, respectively (Table 3). As at the pre-monsoon season due to higher consumption of water, a wide decreasing variation has been found at Faisalabad, Gujranwala, Sialkot, and Sheikhupura districts.

Similarly to the present study, groundwater level trends varied according to the season of year using ITA method in the north-eastern of Romania (Minea et al., 2020). After incorporation of data of groundwater wells, the average bore wells data log was developed using mean method; therefore, representing a point in each tehsil. The groundwater level trends shown in Tables 2 and 3 were also spatially interpolated (Figure 5) for the study region.

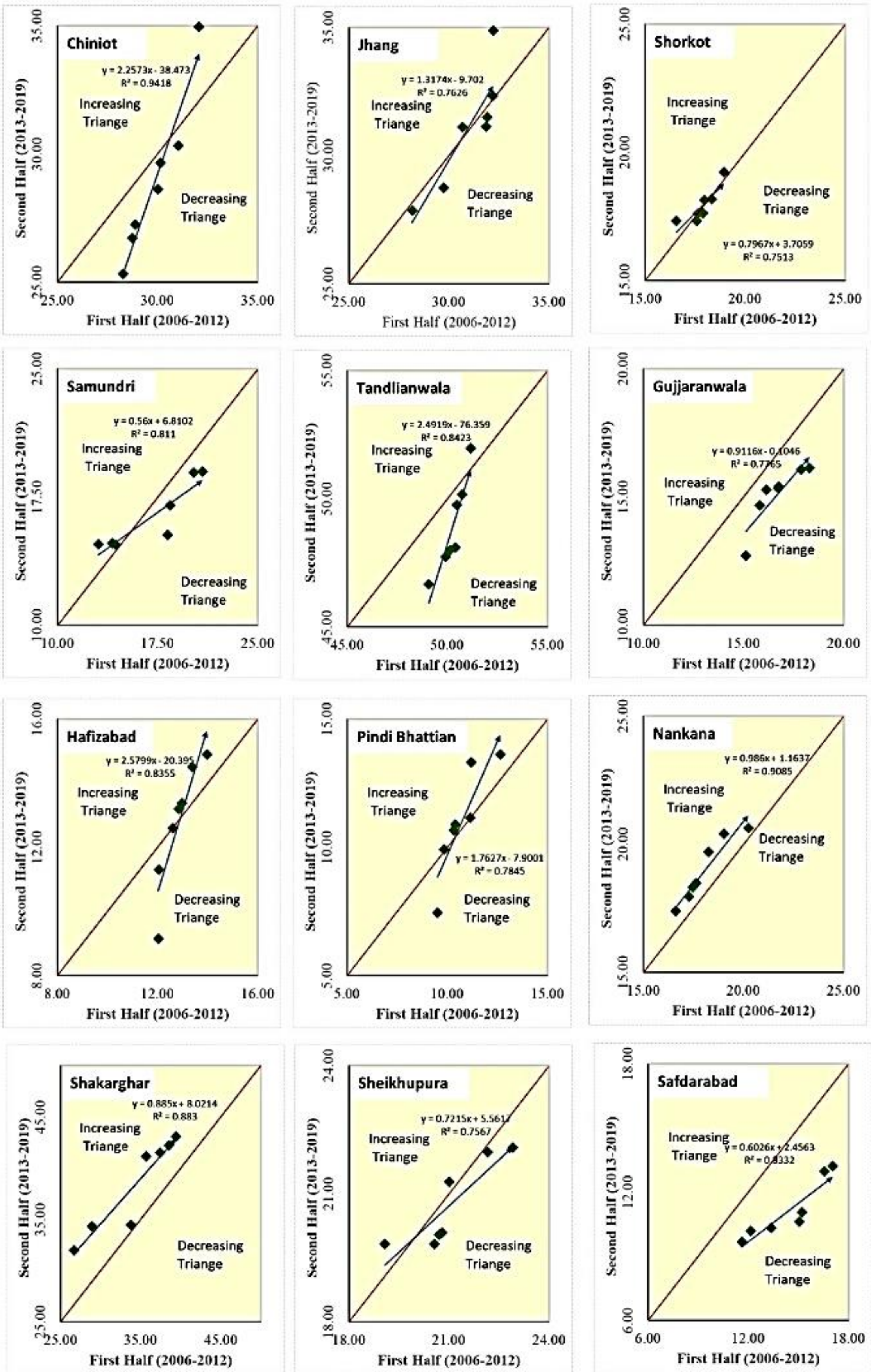
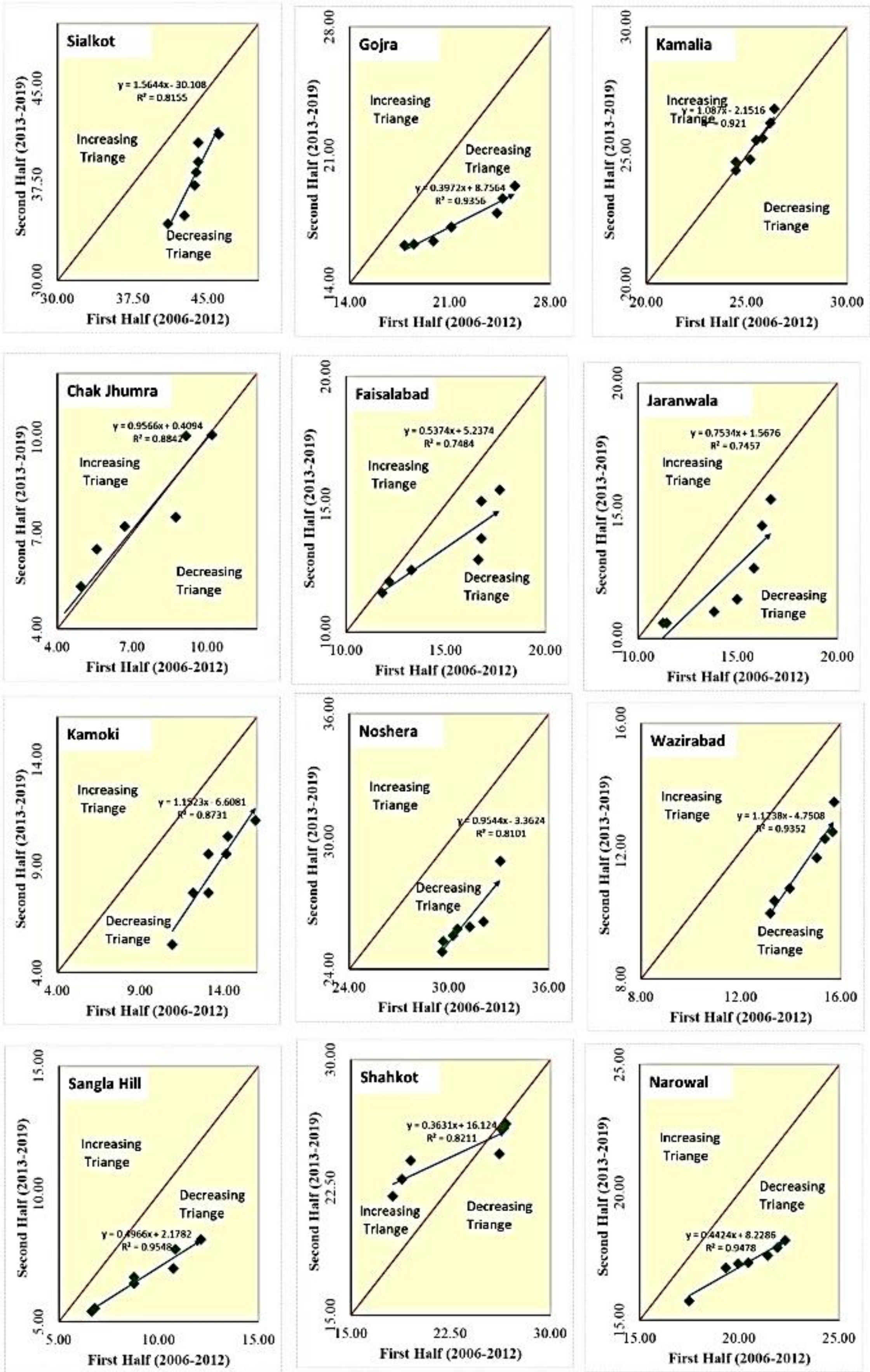


Figure 4: Groundwater level trends using innovative trend analysis method for pos-monsoon season at tehsil level.



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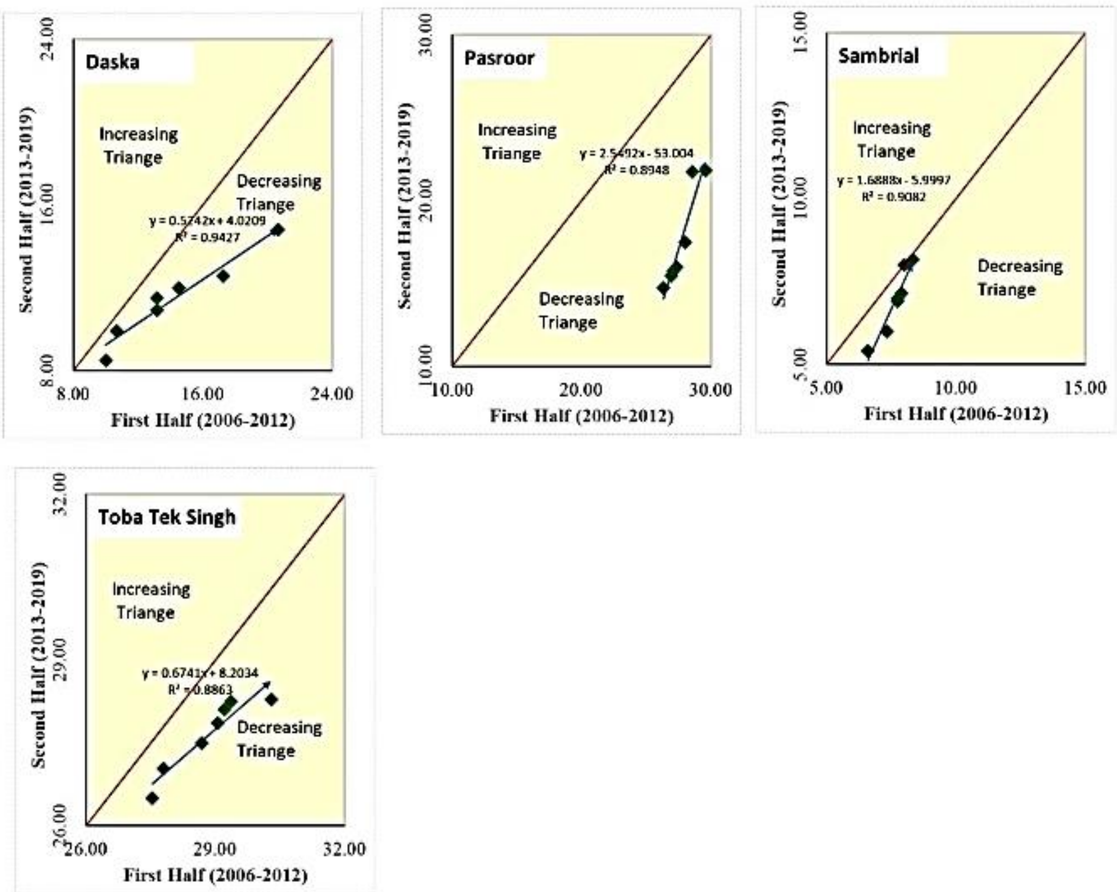


Figure 4: (continued).

Innovative trend analysis provided the variation of groundwater level over period (2006-2019) at tehsil level in Rechna Doab, which generated the extent of decrease of groundwater levels. Based on mean water level data, map of variation of groundwater level was made to locate the vulnerability index in terms of low, moderate and high). Figure 6 clearly indicates the groundwater level decreasing trend was observed in middle part of Doab, i.e., Gujranwala, Kamoki, Wazirabad, Sheikhupura, Noshehra, Chiniot, Chak jhumra, Jaranwala, Tandlianwala, and Samundri districts at pre-monsoon season. The water level was observed at improvement at post-monsoon in Shakargarh and Nankana due to recharge of rainfall in post-monsoon season.

Table 3: Description of the innovative trend analysis method for post-monsoon season (period 2006-2019) at tehsil level

Tehsil	Mean y1	Mean y2	Centroid Y1	Centroid Y2	Y2-Y1	Slope	ITA slope	Linear regression slope	Trend
Chiniot	29.89	28.99	-0.13	32.07	29.67	**-0.24**	-0.34	-0.0529	No
Jhang	30.96	31.09	0.02	32.19	28.75	**-0.34**	-0.49	0.1264	No
Shorkot	17.85	17.93	0.01	17.65	17.33	**-0.03**	-0.05	0.0106	No
Chak Jhumra	7.10	7.20	0.01	8.75	7.50	**-0.13**	-0.18	0.0207	No
Faisalabad	15.03	13.31	-0.25	16.79	12.43	**-0.44**	-0.62	-0.2369	Decreasing
Jaranwala	14.32	12.35	-0.28	16.67	11.54	**-0.51**	-0.73	-0.2183	Decreasing
Samundri	17.05	16.36	-0.10	18.45	15.29	**-0.32**	-0.45	-0.1450	No
Tandla	50.28	48.92	-0.19	50.75	46.67	**-0.41**	-0.58	-0.0950	No
Gujrawala	16.68	15.10	-0.23	16.73	15.41	**-0.13**	-0.19	-0.0787	Decreasing
Kamoki	13.37	8.79	-0.65	15.92	7.75	**-0.82**	-1.17	-0.3948	Decreasing
Noushera	30.91	26.14	-0.68	30.50	24.84	**-0.57**	-0.81	-0.5020	Decreasing
Wazerzabad	14.62	11.67	-0.42	15.05	13.55	**-0.15**	-0.21	-0.2285	Decreasing
Hafizabad	12.84	12.73	-0.02	13.97	12.60	**-0.14**	-0.20	0.0902	No
Pindi Bhattian	10.73	11.01	0.04	12.65	10.67	**-0.20**	-0.28	0.1067	No
Nankana	18.08	18.99	0.13	20.25	18.33	**-0.19**	-0.27	0.1525	Increasing
Sangla	9.24	6.77	-0.35	8.77	6.50	**-0.23**	-0.32	-0.3090	Decreasing
Shahkot	23.16	24.54	0.20	26.33	23.00	**-0.33**	-0.48	0.0295	No
Narowal	20.41	17.26	-0.45	21.42	18.12	**-0.33**	-0.47	-0.2484	Decreasing
Shakarghar	34.33	38.41	0.58	37.42	43.10	0.57	0.81	0.8423	Increasing
Sheikupura	21.03	20.73	-0.04	20.70	20.05	**-0.07**	-0.09	0.0108	No
Safdarabd	14.43	11.15	-0.47	15.06	9.67	**-0.54**	-0.77	-0.3966	Decreasing
Daska	14.20	11.46	-0.39	20.66	12.58	**-0.81**	-1.15	-0.1620	Decreasing
Pasroor	27.69	17.58	-1.44	29.58	16.00	**-1.36**	-1.94	-1.1830	Decreasing
Sambrial	7.67	6.95	-0.10	8.00	8.16	0.02	0.02	-0.1294	No
Sialkot	43.60	38.11	-0.79	46.08	38.42	**-0.77**	-1.09	-0.4559	Decreasing
Gojra	21.67	17.37	-0.62	21.11	16.17	**-0.49**	-0.71	-0.5900	Decreasing
Kamalia	25.42	25.48	0.01	26.38	24.42	**-0.20**	-0.28	0.0243	No
TTSingh	28.85	27.65	-0.17	30.29	26.50	**-0.38**	-0.54	-0.1182	Decreasing

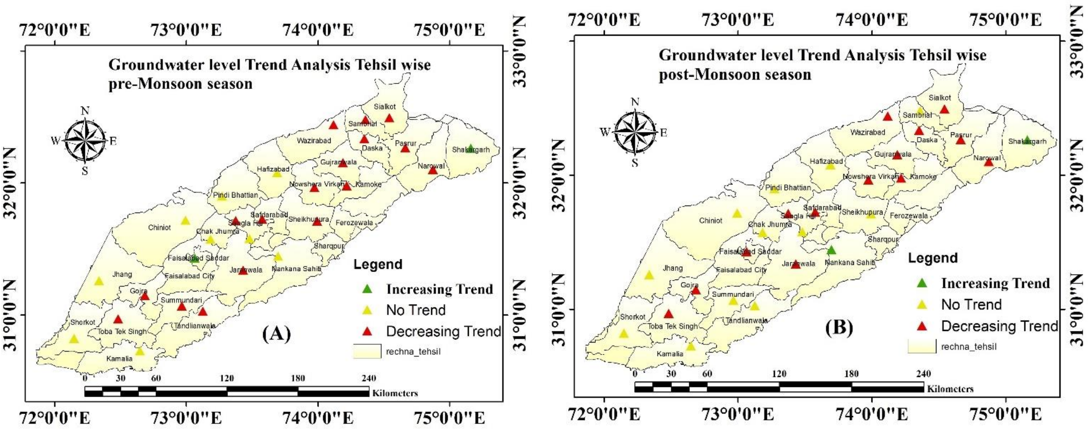
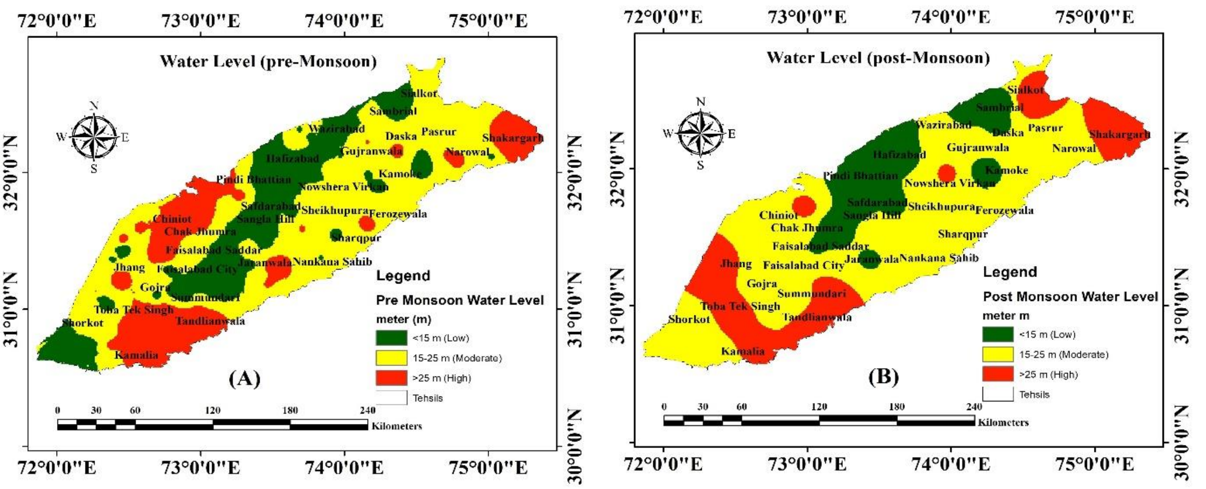


Figure 5: Spatial analysis of the groundwater level trends using ITA method for pre-monsoon (A) and post-monsoon (B) seasons.



Comparison of Water level for pre-monsoon and post-Monsoon seasons tehsil wise at Rechna doab

Figure 6: Spatial analysis of the groundwater levels for pre-monsoon (A) and post-monsoon (B) seasons.

Conclusions

The innovative trend analysis (ITA) method was used to investigate the behavior of groundwater level over period (2006-2019) for zoning of groundwater level in terms of low, moderate, and high-water level zones tehsil wise in Rechna Doab.

A greater number of tehsil with decreasing trend was observed in pre-monsoon (61%) in the relation to the post-monsoon season (50%); while in both seasons it was observed that 7% groundwater wells were showing increasing trend.

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