Journal of Groundwater Science and Engineering
ISSN 2305-7068
Indexed by ESCI CABI CSA Scopus GeoRef AJ CNKI

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Citation:
Gautam VK, Kothari M, Singh P.K., *et al*. 2022. Analysis of groundwater level trend in Jakham River Basin of Southern Rajasthan. Journal of Groundwater Science and Engineering, 10(1): 1-9.

View online: https://doi.org/10.19637/j.cnki.2305-7068.2022.01.001

Journal homepage: http://gwse.iheg.org.cn

Analysis of groundwater level trend in Jakham River Basin of Southern Rajasthan

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Abstract: Groundwater accounts for about half of the water use for irrigation in India. The fluctuation pattern of the groundwater level is examined by observing rainfall replenishment and monitoring wells. The southern part of Rajasthan has experienced abrupt changes in rainfall and has been highly dependent on groundwater over decades. This study presents the impact of over-dependence on groundwater usage for irrigation and other purposes, spatially and temporally. Hence, the objective of this study is to examine the groundwater level trend by using statistical analysis and geospatial technique. Rainfall factor was also studied in groundwater level fluctuation during 2009-2019. To analyze the influence of each well during recharge or withdrawal of groundwater, thiessien polygonswere generated from them. In the Jakham River basin, 75 wells have been identified for water level trend study using the Mann-Kendall statistical test. The statistics of trend analysis show that 15% wells are experiencing water level decline in pre-monsoon, while very low percentage of wells have such trend during post-monsoon season. The average rate of water level decline is 0.245 m/a in pre-monsoon and 0.05 m/a in post-monsoon. The aquifer recharge potential is also decreasing by year.it is expected that such type of studies will help the policy makers to adopt advanced management practices to ensure sustainable groundwater resource management.

Keywords: Groundwater; Trend analysis; Rainfall; Kendal tau; Slope; p value; Recharge; Pre- and post-monsoon

Received: 07 May 2021/ Accepted: 12 Dec 2021

Introduction

Groundwater plays a critical role in meeting the ever-increasing water demands of the world' s population. It is used to irrigate about 61 percent of the net irrigated area (CGWB, 2012). Changes in rainfall pattern and temperature is pushing groundwater system to an alarming situation. Anthropogenic activities also have an adverse impact on groundwater recharge and discharge (Rivera et al. 2004), subsequently groundwater level has gone down in almost all countries and this seems to be worse for dry land agriculture. Sustainable management of this resource should be a primary objective for future strategy planning (Gautam et al. 2020; Gautam and Awasthi, 2020). Generally, groundwater level decline threatens the efficient functioning of aquifer (Akther et al. 2009). The Kendall rank correlation and linear regression test were used to analyze periodic trends in groundwater level in the Sagar, Madhya Pradesh District, India (Thomas et al. 2011).

The Jakham River Basin is characterized as sub-humid, hilly terrain and tribal area. According to CGWB (2013), the basin has experienced variability of rainfall in the past two decades, which influences the groundwater availability in terms of quantity as well as quality. Almost all the villages are facing water quality problem over these years and have groundwater scarcity during pre-monsoon and summers. There is a lack of efforts to collect the rain water and recharge the basin (Gautam et al. 2021). The farmers are solely depending on groundwater for irrigation , due to unavailability of surface water facilities. The groundwater system in semi-arid and sub-humid regions is highly dynamic due to the basaltic geology in the central and western parts of India, where water level rises quickly in the monsoon

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DOI: 10.19637/j.cnki.2305-7068.2022.01.001

Gautam VK, Kothari M, Singh P.K., et al. 2022. Analysis of groundwater level trend in Jakham River Basin of Southern Rajasthan. Journal of Groundwater Science and Engineering, 10(1): 1-9.

season and declines when pumping is undergoing in post-monsoon season (Gautam et al. 2020; Gautam et al. 2022). Seasonal fluctuation in groundwater level in such type of fractured rocks are caused by groundwater recharge and abstraction (Marechal et al. 2006; Pavelic et al. 2012). The groundwater department has conducted various groundwater level studies to measure the water level fluctuation trend in the southern part of Rajasthan (RGWD, 2013). Study on groundwater level trend analysis is carried out by Singh and Kansan (2017) for the wheat and rice field in Haryana, the result has shown the average decrease of groundwater level is about 0.31 m/a.

Mann-Kendall test is the most common non-parametric method for analyzing groundwater level trend, recharge and different climatic parameters (Patle et al. 2015). Pathak et al. (2018) has applied non-parametric method for detecting groundwater level trend and drought in Ghat Prabha River Basin, India. Using linear regression analysis and a non-parametric approach, a functional relationship between variables was developed. The Mann-Kendall test was applied to find a linear rainfall pattern for the study area (Nema et al. 2016). Estimation of annual recharge of groundwater can be done by Sen' s slope estimator. In general, fluctuation in groundwater level is a combined result of natural or manmade process.

The basic objective of this research is to evaluate the variability of groundwater level for pre and post monsoon seasonal trend analysis in the Jakham River Basin using the Mann-Kendall test. Monitoring is not possible in some parts of basin due to wildlife and dense forest near the dam site.

1 Study area

The study area has semi-arid climate and is mostly covered by hard rocks in the basaltic region, which is not considered good aquifer for recharge. The catchment area of Jakham River Basin is 953 km^2, lies between latitude 23°53′ and 24°30′ N and longitude 74°14′ and 74° 47′ E. The average annual rainfall of the region is 780 mm. The soils of the basin fall under the broad categories of red soil, black soil and clayey loam. The geological setup of the basin is represented by various igneous and meta-sedimentary rocks. Rocks in the Bhilwara Super Group of Archaean age comprising of granites are exposed in the southwestern part of the basin. Deccan Traps are exposed in major part of the basin. The water budget of Jakham River Basin reveals that groundwater availability in 2021 is 43.98 million m^3, while the demand is estimated to be 101.58, indicating the huge gap of 57.60 m^3 (Singh et al. 2020). The location of the study area is presented in Fig. 1.

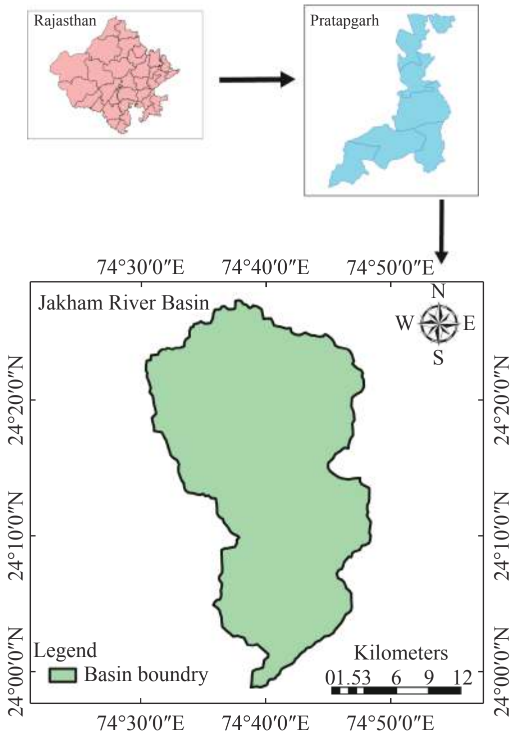

Fig. 1 Location map of study area

2 Data

The groundwater level data of 75 open wells were obtained from Rajasthan Groundwater Department, Jaipur. These wells are mainly used for irrigation and drinking purposes. Groundwater level data from 2009 to 2019 for the study area has been used. Monitoring of groundwater level was performed for the recent years (2018 to 2019), which were collected from the Department of Soil and Water Engineering, CTAE, Udaipur. The selected monitoring wells characterize the local groundwater level with particular hydrogeology and nominal pumping effect. Daily rainfall data from 2009 to 2019 for the study area was obtained from Rajasthan Water Resource Department. The groundwater level and rainfall data were recorded seasonally and interpreted graphically to understand the relation between rainfall and groundwater dynamics. The whole datasets are separated into two parts i.e. pre- and post-monsoon periods. The identified wells for groundwater level monitoring are depicted in the Fig. 2.

3 Materials and methods

3.1 Mann-Kendall test

This non-parametric test is an extensively app-

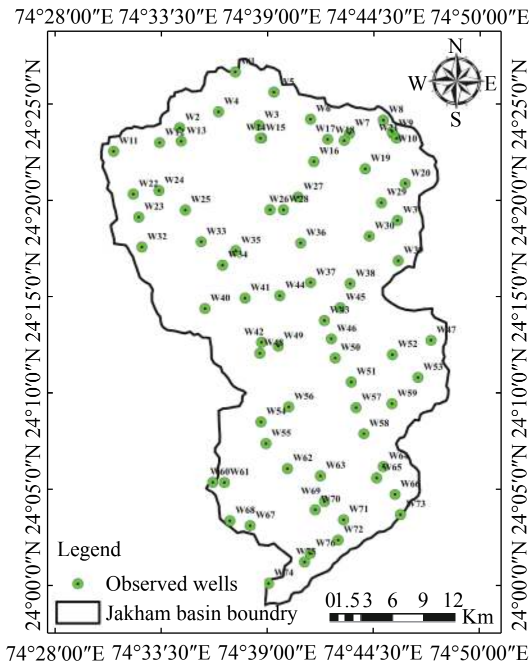

Fig. 2 Identified wells for groundwater level monitoring

licable tool for identifying patterns in various climatic and water resource studies. For time series analysis, it also recognizes missing observations and censored data (Helsel and Hirsch, 2002). Mann (1945) developed this test for trend detection, and Kendall (1975) formulated it as a test statistic. There are two hypotheses in the Mann-Kendall test, viz. Null Hypothesis (H_0), which means no trend in the data, and hypothesis (H_1), which means positive or negative trend with in observation data. The Mann-Kendall test statistics can be given as:

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i) \cdots . \quad (1)$$

Where: S= Mann-Kendall Test statistics
sgn= signum function
X_j and X_i = sequential data value
N= record length

Where:

$$\operatorname{sgn}(X_j - X_i) = \begin{bmatrix} 1 \text{ if } (X_j - X_i) > 0 \\ 0 \text{ if } (X_j - X_i) = 0 \\ -1 \text{ if } (X_j - X_i) < 0 \end{bmatrix} \quad (2)$$

Positive value of test statistics (S) represents increasing trend and negative value indicates decreasing trend.

Significance of trend can be tested by standardized variable u, given below,

$$u = \frac{(S + m)}{\sqrt{V}(S)} \quad (3)$$

Where:

$$m = \begin{bmatrix} -1, S > 0 \\ 0, S = 0 \\ 1, S < 0 \end{bmatrix}$$

For n=10, test statistics (S) will be normally distributed. So, variance of statistics S can be written as:

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i - 1)(2t_i + 5)] \quad (4)$$

Where: t_i= number of ties up to sample *i*.

In Mann-Kendall test, presence of significant trend is estimated by using the Z_c.

To indicate the strength of trend, level of significance is used, which is 5% for this test. Positive value of statistics (Z_c) shows increasing trend and negative value of test statistics (Z_c) shows decreasing trend. Z_c is normally distributed.

$$Z_c = \begin{cases} \dfrac{(S-1)}{\sqrt{V(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{(S+1)}{\sqrt{V(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

3.2 Sen's slope estimator

The Sen's Slope estimator was used to estimate the groundwater level trend. Sen's estimator is a non-parametric tool for evaluating the magnitude of trend in a hydrologic time series (Sen, 1968). This approach does not need a normal distribution; instead, it calculates the median of all the slopes determined from all available pairs of time series datasets (Zhang et al. 2001). The time series is assumed to have a linear pattern in this process. The slopes of all data sets were determined using Sen's Slope, given below:

$$Q_i = \frac{X_j - X_i}{j - i}(i = 1, 2, 3 \cdots\cdots N) \quad (6)$$

Where: X_j and X_i = data values from sample of n identically distributed random variable at time *j* and *i*

$$Q_s = \begin{Bmatrix} Q_{i(N+1)/2} \\ 1/2\left[Q_{i(N/2)} + Q_{i(N+2)/2}\right] \end{Bmatrix} \quad (7)$$

Where: N is odd for $Q_{i\,(N+1)/2}$ and N is even for ½($Q_{i\,(N/2)}$ +$Q_{i\,(N+2)/2)}$)

Positive value of Q_i shows water level decline and negative value of Q_i shows water level rise.

3.3 Inverse distance weighted method (IDW)

To deal with data with a continuous distribution of variables that estimate the parameter value at unsampled locations, GIS-based interpolation approaches have been used (Charizopoulos et al. 2018). Inverse Distance Weighted method is an interpolation tool in the ArcGIS 10.4 software, which is used for interpolating the point data in the particular location. Spatial maps are generated through this technique. In this tool, the weight of a known point is inversely proportional to its distance from the measured point (Kumar et al. 2018; Gautam et al. 2022). The IDW is generally suitable for the studies where spatial continuity is required to determine through interpolation (Ketata et al. 2012; Selvam et al. 2016).

4 Results and discussion

4.1 Impact of rainfall variability on groundwater level

Relationship between annual rainfall and pre, post-monsoon groundwater level during 2009-2019 is clearly depicted in the Fig. 2. In this study rainfall plays moderate role on groundwater level fluctuation. In the pre-monsoon period, water level and the variability of rainfall has low correlation coefficient ($r_1 = 0.17$). Some other human activities like over-extraction of groundwater for agriculture and industrial purposes may be the reason behind the water level variation. However, post-monsoon period shows the positive evidence of groundwater correlation with rainfall, as moderate correlation coefficient ($r_2 = 0.53$) is achieved. Hence, in this study, the relation between the pre-monsoon groundwater level and rainfall was found less obvious than post-monsoon season.

4.2 Groundwater behavior in pre and post-monsoon season

Spatial map of GW level was developed for each season (pre and post-monsoon) from 2009 to 2019. Water level fluctuation was calculated using this 11-year dataset. Pre and post-monsson groundwater levels are presented in Fig. 4 together with annual rainfall in the same period. The pre-monsoon seasonal average groundwater level depth varies from 3.5 m to 30.05 m, while the post-monsoon water level ranges from 3.5 m to 25.5 m. The minimum and maximum water level fluctuation was −0.36 m and 5.64 m, respectively.

Spatially analyzed maps were presented on the basis of mean groundwater level for pre and post-monsoon seasons from all 75 wells during 2009-2019. The maps were prepared using IDW technique in ArcMap 10.5 depicted in Fig. 5.

The Mann-Kendall (MK) trend analysis has been used with significance level (α = 5%) to analyze the pre and post- monsoon groundwater level trend for the selected wells in the basin. The test statistics of MK trend analysis along with Sen’s slopes magnitude are presented in Table 1. The result shows the significant trend ($p<0.05$) for both seasons. The trends of groundwater level for the basin during pre and post-monsoon is presented in the graph (Fig. 4). The over pumping effect is clearly visible in the years (from 2008 to 2020) in the pre-monsoon season (left in Fig. 4). In post-monsoon season (right in Fig. 4), due to recharge activities (natural as well as artificial) in the study area, water levels in the wells have slightly recovered. This graph depicts the anthropogenic impact on the groundwater recourses over these years (2008-2020).

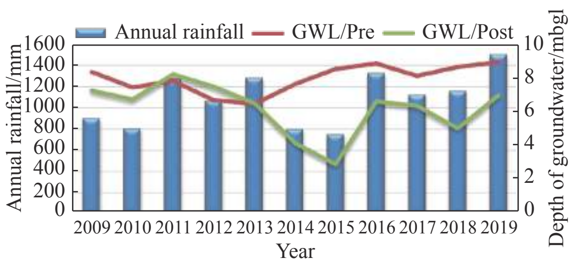

Fig. 3 Graphical representation of groundwater level in relation with annual rainfall

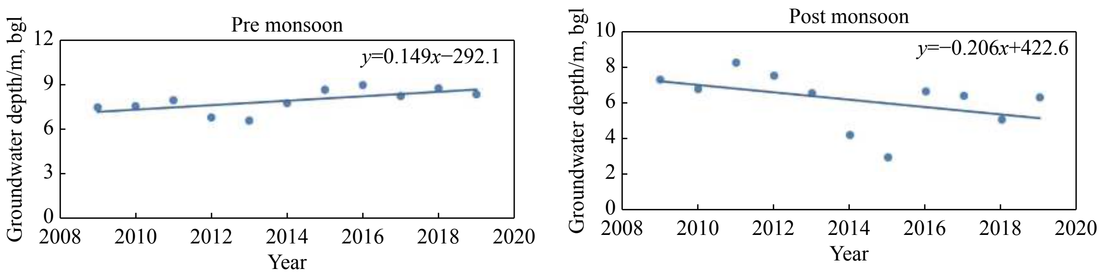

Fig. 4 Trend of groundwater level during pre- and post-monsoon

To our knowledge, none study has been conducted within Jakham basin using groundwater data. For Mann-Kendall trend analysis, XLSTAT software has been executed. The trend was analyzed at 5% of significance level and 95% of confidence level. To understand the magnitude and intensity of trend, Sen's slope was also estimated. The Kendal tau, slope and p value are presented in Table 1.

In pre-monsoon season, 10 wells are showing an increasing trend, only two wells are showing decreasing trend, while the rest 63 are showing no significant trend. Increasing trend means water level is going down continuously over the period. There is no substantial change in the trend analysis of groundwater level in pre- and post-monsoon periods. This indicates that groundwater recharge by rainfall is inadequate. During the pre-monsoon period, groundwater level in the study area declines at the rate of 0.245 m/a. This may be attributed to decreased runoff or overuse of groundwater. The Jakham River Basin is a hilly and agrarian area mainly augmented with highly valued and sensitive crop like opium. There is very low availability of surface water, due to undulating terrain, therefore all the water requirement, such as irrigation, domestic and industry are depending on groundwater. Hence, groundwater resources in this basin playa critical role on agriculture and socio-economic activities.

During post monsoon season, it shows the magnitude of recharge occurring in the basin after rainfall. Most of the wells are showing decreasing trends, indicating the rise of groundwater level. For the years from 2009 to 2019, groundwater fluctuation was determined by deducting the pre-monsoon groundwater level from the post-monsoon groundwater level. It leads to a better understanding of the susceptibility of aquifer recharge to various hydrogeological and anthropogenic activities.

Pre-monsoon water level is the main indicator of groundwater withdrawal in the dry season (Dec to May). The higher amount of pumping can be clearly observed in the pre-monsoon period. As per trend analysis, more wells have statistically significant drops in water level in pre-monsoon period than the post-monsoon period. This shows the comparatively mild groundwater replenishment from rainfall and lower pumping during the post-monsoon period. The average pre- and post-monsoon groundwater levels are also seen in Fig. 5.

To interpret the spatial variation of recharge in the basin, a trend map is presented in Fig. 6 . Sen's slope values from the Mann-Kendall test on mean pre- and post-monsoon groundwater level data were used to generate this map. Every well has its own influencing area inthe basin, generated by the thiessien polygon method. This demarcation may help to find the contribution of recharge through each well.

The Sen's slope estimator was used for detection of trend in groundwater level. Slope value also shows rate of water rise or water fall annually. The positive values of the Sen's slope show the

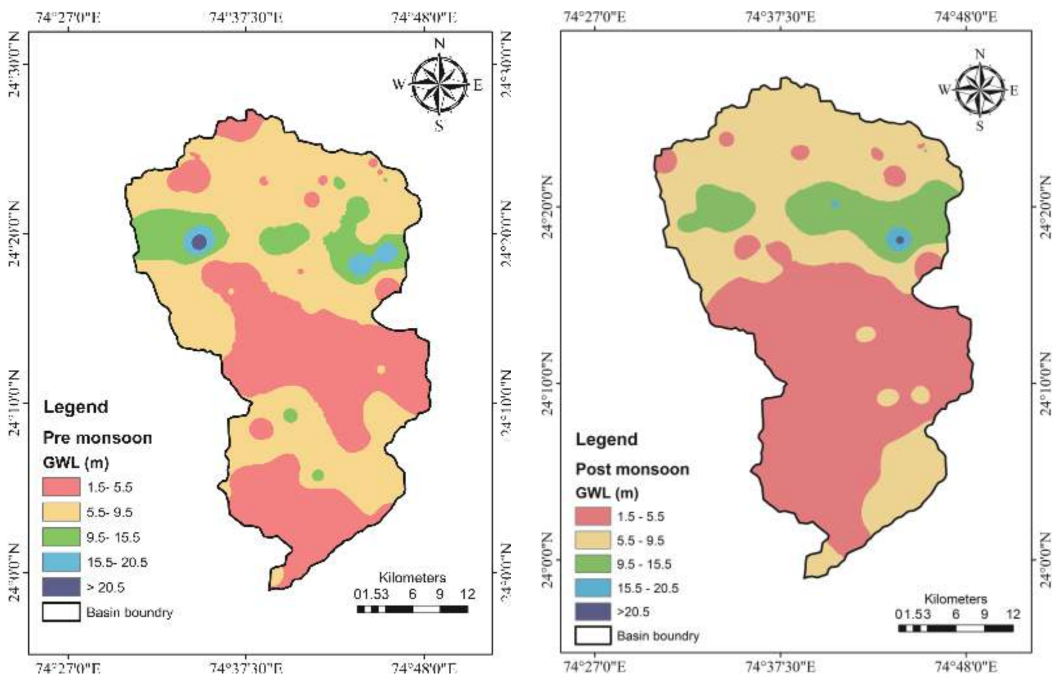

Fig. 5 Mean groundwater level fluctuation (2009-2019) for pre- and post-monsoon periods

Table 1 Results of Mann-Kendal test statistics for pre- and post monsoon season (2009-2020)

Well No.	Latitude	Longitude	Pre-monsoon				Post-monsoon			
			Kendal tau	p-value	Slope	Trend	Kendal tau	p-value	Slope	Trend
1	74.716	24.057	0.564	0.020	0.314	Increasing	0.019	0.150	0.080	No
2	74.791	24.212	−0.073	0.815	−0.037	No	0.787	0.001	0.603	Increasing
3	74.645	24.210	0.477	0.050	0.394	Increasing	−0.087	0.050	−0.320	Decreasing
4	74.557	24.383	−0.241	0.347	−0.350	No	0.537	0.028	0.657	Increasing
5	74.721	24.391	0.225	0.333	0.493	No	−0.507	0.028	−0.457	Decreasing
6	74.622	24.444	−0.261	0.350	−0.227	No	0.294	0.241	0.530	No
7	74.642	24.398	−0.500	0.400	−0.483	No	0.290	0.180	0.350	No
8	74.738	24.302	−0.450	0.035	−0.253	Decreasing	0.241	0.347	0.100	No
9	74.652	24.325	0.611	0.012	0.625	Increasing	0.153	0.034	0.105	Increasing
10	74.541	24.293	0.400	0.022	0.455	Increasing	0.000	1.000	0.000	No
11	74.596	24.239	−0.077	0.251	−0.194	No	0.750	0.093	0.180	No
12	74.713	24.240	−0.093	0.073	−0.754	No	0.436	0.060	0.331	No
13	74.733	24.131	−0.047	0.213	−0.014	No	−0.020	0.036	−0.354	Decreasing
14	74.644	24.141	0.019	1.000	0.000	No	0.110	0.696	0.062	No
15	74.603	24.089	0.600	0.013	0.763	Increasing	0.019	1.000	0.000	No
16	74.635	24.052	0.477	0.051	0.394	Increasing	0.220	0.390	0.250	No
17	74.687	24.027	−0.485	0.200	−0.353	No	−0.093	0.754	−0.036	No
18	74.651	24.002	−0.019	1.000	0.000	No	0.661	0.006	0.913	Increasing
19	74.617	24.056	0.167	0.531	0.390	No	0.198	0.390	0.210	No
20	74.765	24.061	−0.404	0.101	−0.384	No	−0.019	1.000	0.000	No
21	74.711	24.039	−0.073	0.815	−0.037	No	0.304	0.235	0.489	No
22	74.691	24.065	−0.294	0.241	−0.285	No	0.367	0.138	0.300	No
23	74.699	24.072	−0.073	0.815	−0.037	No	−0.092	0.734	−0.139	No
24	74.760	24.079	−0.352	0.159	−2.262	No	−0.200	0.436	−0.400	No
25	74.744	24.093	−0.073	0.315	−0.045	No	−0.074	0.035	−0.283	Decreasing
26	74.750	24.103	−0.204	0.433	−0.793	No	−0.611	0.012	−0.621	Decreasing
27	74.696	24.095	−0.073	0.815	−0.037	No	−0.035	0.018	−0.210	Decreasing
28	74.758	24.157	−0.278	0.273	−0.464	No	0.374	0.135	0.383	No
29	74.726	24.154	−0.035	0.815	−0.037	No	0.035	0.018	0.210	Increasing
30	74.667	24.101	−0.278	0.273	−0.870	No	0.661	0.006	0.599	Increasing
31	74.613	24.089	−0.073	0.435	−0.327	No	0.350	0.319	0.452	No
32	74.668	24.154	0.167	0.531	0.390	No	0.382	0.119	0.800	No
33	74.649	24.123	−0.073	0.815	−0.037	No	0.210	0.390	0.207	No
34	74.659	24.207	0.575	0.019	0.900	Increasing	0.491	0.043	0.200	Decreasing
35	74.643	24.201	−0.015	0.210	−0.150	No	0.374	0.135	0.383	No
36	74.661	24.250	−0.426	0.085	−0.565	No	0.440	0.072	0.550	No
37	74.631	24.248	−0.294	0.241	−0.484	No	0.350	0.105	0.303	No
38	74.687	24.262	−0.352	0.159	−0.490	No	0.220	0.390	0.257	No
39	74.758	24.200	0.167	0.531	0.390	No	0.641	0.009	0.605	Increasing
40	74.722	24.176	−0.167	0.231	−0.050	No	0.055	0.876	0.023	No
41	74.708	24.197	0.025	1.000	0.000	No	0.481	0.033	0.195	Increasing
42	74.705	24.213	−0.315	0.210	−0.150	No	−0.093	0.754	−0.036	No
43	74.699	24.229	−0.400	0.085	−0.505	No	−0.091	0.040	−0.201	Decreasing
44	74.721	24.261	−0.278	0.273	−0.293	No	−0.514	0.035	−0.637	Decreasing
45	74.780	24.180	0.165	0.525	0.300	No	−0.553	0.015	−0.557	Decreasing

continued Table1

Well No.	Latitude	Longitude	Pre-monsoon				Post-monsoon			
46	74.763	24.281	−0.224	0.387	−0.217	No	0.073	0.815	0.033	No
47	74.762	24.316	−0.294	0.241	−0.484	No	0.050	0.105	0.065	No
48	74.748	24.331	0.056	0.876	0.014	No	0.000	1.000	0.000	No
49	74.769	24.348	0.256	0.376	0.210	No	0.000	1.000	0.000	No
50	74.679	24.296	−0.093	0.050	−0.080	Decreasing	−0.037	0.938	0.002	No
51	74.622	24.290	0.017	0.376	0.250	No	0.032	0.088	0.335	No
52	74.611	24.277	0.056	0.879	0.015	No	0.404	0.101	0.450	No
53	74.664	24.325	0.056	0.376	0.250	No	0.031	0.098	0.305	No
54	74.676	24.336	0.167	0.528	0.250	No	0.110	0.696	100.000	No
55	74.593	24.297	0.056	0.376	0.250	No	0.035	0.058	0.210	Decreasing
56	74.579	24.325	0.130	0.038	0.080	Increasing	0.404	0.101	0.671	No
57	74.556	24.341	0.035	0.835	0.000	No	0.031	0.098	0.305	No
58	74.539	24.319	0.426	0.085	0.242	No	0.019	1.000	0.000	No
59	74.534	24.338	0.062	0.231	0.090	No	0.110	0.696	0.250	No
60	74.575	24.384	0.241	0.347	0.150	No	0.147	0.585	0.300	No
61	74.517	24.375	0.019	1.000	0.000	No	0.205	0.325	0.185	No
62	74.574	24.396	0.241	0.347	0.210	No	0.000	1.000	0.000	No
63	74.690	24.367	−0.094	0.341	−0.084	No	0.350	0.250	0.152	No
64	74.644	24.387	−0.367	0.138	−0.387	No	0.455	0.062	0.883	No
65	74.645	24.387	0.056	0.015	0.230	Increasing	−0.205	0.019	−0.250	Decreasing
66	74.687	24.403	−0.330	0.184	−0.655	No	0.404	0.101	0.391	No
67	74.656	24.427	0.056	0.256	0.214	No	0.031	0.098	0.305	No
68	74.608	24.410	0.019	1.000	0.000	No	0.440	0.072	0.320	No
69	74.762	24.387	0.030	0.046	0.314	Increasing	0.600	0.013	0.550	Increasing
70	74.734	24.360	−0.120	0.689	−0.035	No	0.095	0.765	0.045	No
71	74.716	24.385	0.056	0.876	0.014	No	−0.091	0.040	−0.225	Decreasing
72	74.702	24.386	−0.241	0.347	−0.252	No	0.521	0.030	0.609	Increasing
73	74.758	24.393	0.150	0.252	0.050	No	−0.553	0.020	−0.557	Decreasing
74	74.758	24.391	−0.294	0.241	−0.484	No	0.076	0.820	0.044	No
75	74.750	24.403	−0.110	0.696	−0.036	No	−0.050	0.105	−0.065	No

*(Here, α= 0.05 and confidence level=95%)

increased water level to bgl (below ground level) for most of the wells in the basin during pre-monsoon season (left in Fig. 6). Fig. 6 (right) shows fewer negative slope values for post-monsoon season. 63 out of 75 wells have positive and 12 have negative values for pre-monsoon season, while 45 have positive slope values and 30 have negative values for post-monsoon season.

5 Conclusions

This groundwater trend study describes groundwater fluctuations in aquifer storage induced by recharge or withdrawal. The correlation analysis between rainfall and groundwater level (pre- and post-monsoon) does not show a strong relation, but indicates a little influence of rainfall on post-monsoon water level. This supports the fact that rapid groundwater level decline occurs in the basin due to increasing consumption of groundwater resources. The statistics of trend analysis shows that 15% wells are having declined water level in pre-monsoon, while during post-monsoon season very low percentage of wells have that trend. The average rate of water level decline in the wells is 0.245 m/a in pre-monsoon and 0.050 m/a in post-monsoon. Furthermore, higher dependency on groundwater leads to the drop in water level. It is also noticed that, there is no major surface irrigation scheme/program incorporated in the upper reach of the basin during the past decade. Also, the anthropogenic influence is considered a

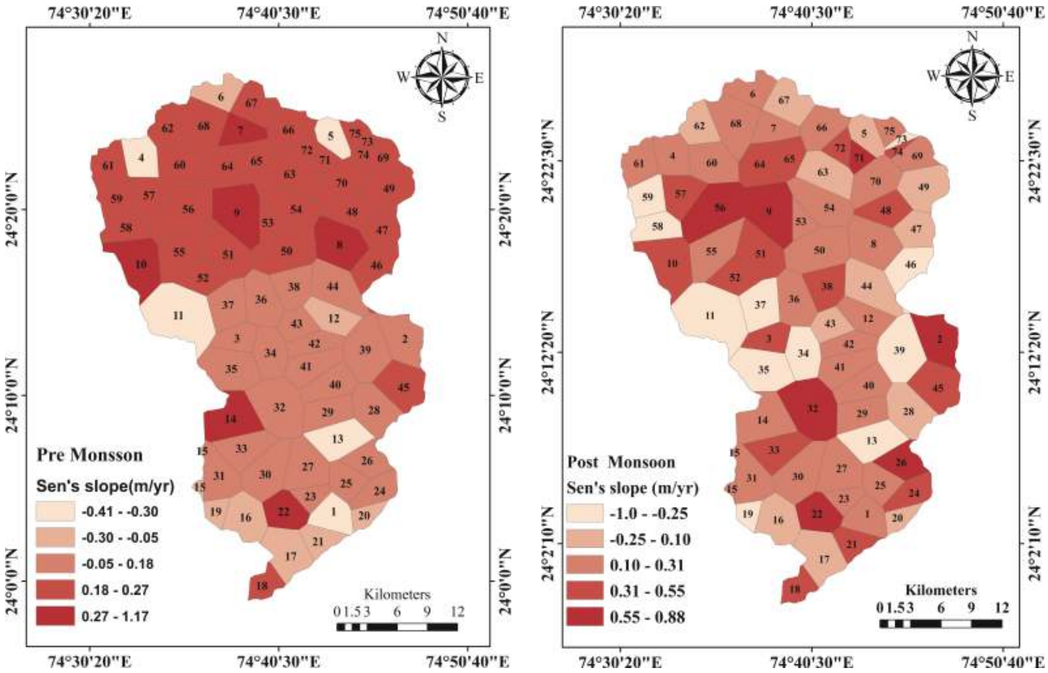

Fig. 6 Groundwater recharge indicator, Sen's slope map for pre and post monsoon season

main concern for groundwater resources in terms of both quantity and quality. Therefore, it is time to make the policy for judicious utilization of water resources, so that groundwater resources can be sustainably utilized to avoid further over exploitation. The results of this study may be useful for solving problems related to groundwater yield and recharge. Consistent monitoring of wells can be an elementary step to protect and augment the groundwater resources in the study area.

Acknowledgements

All the authors sincerely thank the RGWD, Udaipur and Department of Soil and Water Engineering, CTAE, Udaipur, India.

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