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Trend analysis of groundwater level using Mann-Kendall test in Dhárwad district

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Abstract

Groundwater plays a major role in meeting the demands for water for various sectors in India. Over exploitation of groundwater is emerging as a serious problem in the country. Hence, detection of trends in groundwater levels is incredibly important for management of groundwater resources. In view of the importance of groundwater, the present study was undertaken in the 24 observation wells of the Dharwad district of Karnataka. To detect the trends in groundwater level, the techniques of the Mann-Kendall trend test and Sen's slope estimator test were employed, and the results revealed that both significant increasing and decreasing trends were obtained. These increasing trends were more prevalent in the study area. The most significant positive slope occurred at W15 in the month of April, and the most significant negative slope occurred at W17 in the month of November.

Keywords: Groundwater level, Mann Kendall, Sen's slope estimator, trend analysis

Introduction

Groundwater is a very important natural resource and has a significant role in the economy. It is the main source of water for irrigation and the food industry. In general, groundwater is a reliable source of water for agriculture and can be used in a flexible manner. Groundwater is critical to the environment in terms of maintaining water levels and flowing into rivers, lakes and wetlands. Especially during the drier months when there is little direct recharge from rainfall, it provides the environment with groundwater flow through the bottom of these water bodies and becomes essential for the wild life and plants living in these environments. Groundwater also plays a very relevant role in sustaining navigation through inland waters in the drier seasons. By discharging groundwater into the rivers, it helps keep the water levels higher.

Among the various forms of water resources, ground water has become an essential and most reliable source due to its several inherent qualities, such as widespread and continued availability, outstanding quality, limited susceptibility, cheap, drought dependability and so on. To keep up with the increased demand for water caused by rapid developments, it is necessary to assess the quality and quantity of groundwater. Sustainable management of groundwater resources is a fundamental task, especially in arid and semi-arid regions, since these places have fresh water shortages for the greater part of the year.

Material and Methods

Dharwad district is situated in the western sector of the northern half of Karnataka state. The district encompasses an area of 4263 square kilometers lying between the latitudinal parallels of 15°02' and 15°51' North and longitudes of 73°43' and 75°35' East. The district lies approximately about 800 meters above the sea level. The total geographical area of the district is 8,38,600 ha. Of this, the total cultivable area is 6,22,853 ha, which constitutes 78.27 per cent of the total geographical area. Agriculture is the main occupation in the district, which uses both surface and groundwater resources and employs the flood irrigation method. The major crops grown are jowar, paddy, wheat, maize, cotton, soybeans, chilli, onion and green gram. The south-west monsoon is most crucial for Dharwad district. Average annual rainfall of the district was 864 mm. The average temperature is 24.1 ^{0}C. The climate is mildly hot during the summer (April–May) and pleasant during rest of the year. The hot season begins from March with the maximum temperature of 38 ^{0}C and minimum temperature of Dharwad is 14 ^{0}C during the month of December, which is the coldest month.

Figure 1 shows the study area map with 24 observation well locations. The secondary data pertaining to groundwater level was collected from the Department of Mines and Geology, Dharwad from 2010 to 2020 (for some wells, data was available from 2010 to 2020 and for some wells from 2012 to 2020) and weather parameters (rainfall and temperature) were collected from the Karnataka State Natural Disaster Monitoring Center (KSNDMC), Bengaluru from 2010 to 2020. The description of the Twenty four observation wells are shown in Table 1.

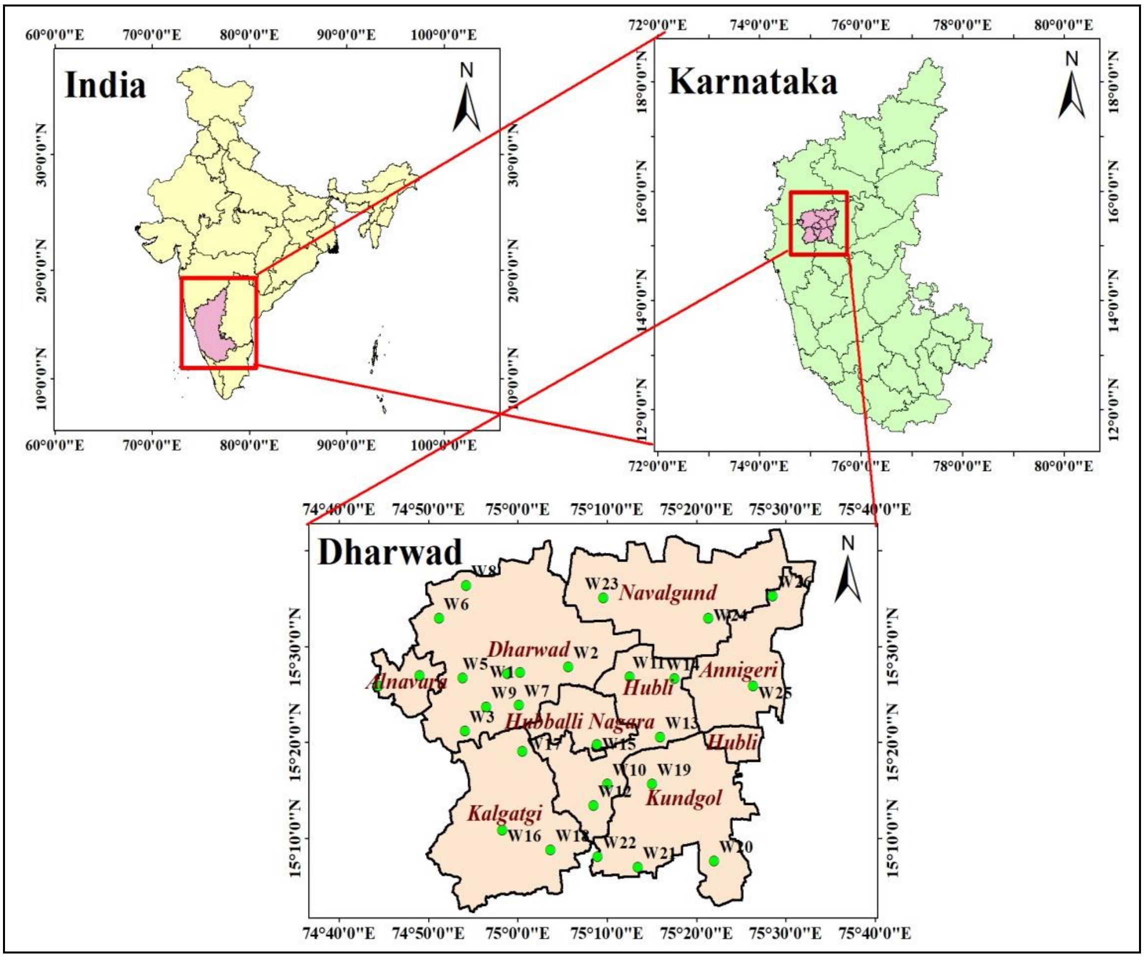

Fig 1: Location map of study area

Table 1: Observation wells of study area

Taluk	Well No	Well location	Well type
Dharwad	W1	Dharwad	Bore well
	W2	Somapur	Bore well
	W3	Banaduru	Bore well
	W4	Amminabhavi	Bore well
	W5	Mandihala	Bore well
	W6	Guledhakoppa	Bore well
	W7	Yarikoppa	Bore well
	W8	Thadakoda	Bore well
Hubbali	W9	Byahatti	Bore well
	W10	Chabbi	Bore well
	W11	Mantur	Bore well
	W12	Kiresur	Bore well
Hubbali Nagara	W13	Bidanala	Bore well
Kalaghatagi	W14	Kalaghatgi	Bore well
	W15	Dhummawad	Bore well
	W16	Tabakad Honnalli	Bore well
Kundagol	W17	Gudageri	Bore well
	W18	Hirebudihal	Bore well
	W19	Jigalur	Bore well
Navalagunda	W20	Navalagund	Bore well
Annigeri	W21	Annigeri	Bore well
	W22	Shelavadi	Bore well
Alnavara	W23	Alnavara	Bore well
	W24	Aravatagi	Bore well

Non-Parametric test

Nonparametric tests are methods of statistical analysis that do not require a distribution to meet the required assumptions to be analyzed (especially if the data is not normally distributed).The Mann-Kendall (Mann 1945; Kendall 1975) and Sen's slope estimator tests (Sen, 1968) were used for trend analysis and detection of slope of the trend line.

Mann-Kendall Test

The Mann-Kendall test is a non-parametric method used for trend analysis of time series data (Kendall, 1975). Major advantage of Mann-Kendall test is that it is free from statistical distributions which are required for parametric method. The null hypothesis (H_0) for the Mann- Kendall test is that there is no trend or serial correlation among the analyzed population against the alternative hypothesis (H_1), which assumes increasing or decreasing monotonic trend.

The Mann-Kendall statistic S is given as

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

Where, S is Mann-Kendall statistic and sgn is the signum function. The application of trend test is done to a time series

x_i that is ranked from i=1, 2, n-1 and x_j, which is ranked from j = i+1, 2, n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that, when n < 10, the value of |S| is compared directly with theoretical distribution of S, derived by Mann and Kendall. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive value of S indicates an upward trend and negative value indicates downward trend. For n ≥10, the statistic S is approximately normally distributed with mean E(S) = 0 and variance (Var (S)).The variance is given as

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}.$$

Where, t_i is considered as the number of ties up to sample i.

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

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

A positive value of Zc indicates an increasing trend and negative value indicates decreasing trend. The statistic Zc is normally distributed. To test an increasing or decreasing monotone trend, a two-tailed test at α level of significance is used. Null hypothesis (H0) is rejected if the absolute value of Zc is greater than $Z_{1-\alpha/2}$ where, $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In this the null hypothesis (H0) was that "there is no trend in time series of groundwater levels". Where, α is the level of significance for the test and ± $Z_{1-\alpha/2}$ are the standard normal deviates. In this study, α and $Z_{1-\alpha/2}$ were taken as 5% and ±1.96, respectively.

Sen's Slope Estimator Test

True slope in time series data (change per unit time) is estimated by procedure described by Sen (1968) in case the trend is linear. The magnitude of trend is predicted by the Sen's slope estimator (Qi).

$$(Q_i) = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1,2 \ldots\ldots\ldots\ldots, N$$

Where, xj and xk are data values at times j and k (j > k) respectively. The median of these N values of Qi is represented as Sen's estimator. $Q_{med} = Q_{(N+1)/2}$ if N is odd, and

$$Q_{med} = [Q_{N/2} + Q_{(N+1)/2}]/2$$

if N is even. Positive value of Qi indicates an increasing trend and a negative value of Qi shows decreasing trend in the time series.

Results and Discussion

The statistical techniques of the Mann-Kendall test and Sen's slope estimator have been applied to evaluate groundwater level trends for all the observation wells in the study area. Each of the observation wells displays the groundwater fluctuation of the nearby areas. Thus, the trend value reflects the overall groundwater fluctuation characteristics of the entire area during the study time.

The positive sign indicates that groundwater level depths were increasing with respect to the ground surface, indicating that groundwater is decreasing. The results of the Mann- Kendall test are shown in Table 2. After determining the trend, the slope of the trend line was determined using Sen's slope estimator (Table 3). The Mann-Kendall statistics values range from -0.75 to 0.96. The results reveal that around 161 cases show an increasing trend (both significant and non-significant), while 126 cases show a decreasing trend and only 1 case shows no trend out of 288 cases.

The Sen's slope varied from -1.45 to 4.09 and the most significant positive slope occurred at W15 (4.09 m/month) in the month of April. The most significant negative slope occurred at the W17 (-1.15 m/month) in the month of November. Except for ten wells (W4, W5, W8, W10, W11, W13, W16, W18, W20 and W21), all the wells showed a significant trend. W1, W9, W12, W17, W22, and W24 showed significant decreasing trends with an average decreasing rate of 0.50, 0.37, 0.13, 1.14, 0.23 and 0.93 m/month, respectively this may be because W1 and W24 receives almost high rainfall and W9, W12, W17 and W22 receives moderate rainfall but having black clay soil which may helps in recharging of groundwater hence in these regions groundwater level depth is decreasing indicating that groundwater is increasing.

W2, W3, W6, W7, W14, W15, W19, and W23 showed significant increasing trends with an average increasing rate of 0.38, 0.98, 1.94, 2.61, 0.45, 3.65, 0.57 and 1.22 m/month, respectively this may be because the groundwater quality is good in these regions and in some of the regions they grow paddy and sugarcane which requires more water may be overexploitation of groundwater or pumping of groundwater was more in these regions for irrigation, domestic and industrial purpose. Hence groundwater level depth was increasing which means groundwater was decreasing in these regions, which is a matter of concern for the sustainability of the study area since, in the long run, the domestic and industrial developments will be at stake.

The Violin plot of Sen's slopes, which represents a time series of groundwater levels on a monthly time scale, is plotted and shown in Figure 2. Notably, the white dot inside the boxes in all the months represents the median. Whereas the 25th percentile is the lower and the 75th percentile is the upper end of the boxes, the whiskers (vertical lines) at the lower and upper end represent the slope of the minimum and maximum groundwater level time series. The high variation was seen in the months from January to July, which may be because it was a period of pre-monsoon and initial stage of the monsoon where rainfall was less and water requirements were greater, hence pumping of groundwater may have been more. The least variation was seen in the month of August to December, which may be because it was a period of monsoon and post-monsoon where rainfall was greater and water requirements would be met through rainfall and recharge of groundwater may have taken place.

Table 2: Mann-Kendall statistics (Tau) values for groundwater level of observation wells

Wells	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W1	0.04	-0.22	-0.37	-0.27	-0.35	-0.53	-0.45	-0.45	-0.16	-0.37	-0.27	-0.27
W2	0.38	0.45	0.49	0.51	0.31	0.20	0.18	-0.09	0.02	-0.02	-0.07	0.05
W3	0.89	0.82	0.75	0.60	0.67	0.75	0.70	0.85	0.85	0.78	0.89	0.96
W4	0.02	0.05	0.09	0.06	0.13	-0.09	-0.24	-0.35	-0.35	-0.31	-0.20	-0.18
W5	0.16	0.13	0.31	0.09	0.24	0.27	0.02	-0.16	-0.16	-0.05	-0.09	-0.15
W6	0.39	0.44	0.50	0.56	0.60	0.56	0.69	0.54	0.20	0.07	0.16	0.24
W7	0.61	0.61	0.61	0.50	0.69	0.73	0.51	0.69	0.56	0.42	0.38	0.42
W8	0.31	0.17	0.33	0.33	0.38	0.47	0.42	0.07	-0.02	0.13	0.07	0.11
W9	-0.44	-0.50	-0.44	-0.42	-0.38	-0.51	-0.57	-0.56	-0.67	-0.63	-0.56	-0.49
W10	-0.06	0.28	0.39	0.22	0.20	0.16	-0.02	-0.42	-0.24	-0.16	-0.20	-0.07
W11	-0.06	-0.22	-0.08	-0.28	-0.11	0.11	0.00	-0.18	-0.09	-0.20	-0.11	-0.16
W12	0.09	-0.09	-0.15	-0.16	-0.49	-0.24	0.15	-0.18	-0.07	-0.15	-0.24	-0.39
W13	0.33	0.16	0.16	0.38	0.24	0.24	0.29	-0.29	-0.11	-0.16	0.07	0.07
W14	0.51	0.42	0.42	0.22	0.29	0.16	-0.07	-0.07	0.24	0.37	0.37	0.27
W15	0.28	0.56	0.50	0.61	0.60	0.73	0.64	0.38	0.38	0.33	0.11	0.16
W16	0.33	0.39	0.44	0.39	0.47	0.47	0.29	0.20	0.07	0.20	0.11	0.02
W17	-0.33	-0.50	-0.39	-0.50	-0.16	-0.24	-0.24	-0.49	-0.42	-0.42	-0.56	-0.60
W18	0.33	0.33	0.22	0.28	0.38	0.38	0.42	0.29	0.24	0.24	-0.07	0.07
W19	0.33	0.44	0.44	0.22	0.51	0.42	-0.11	-0.11	-0.16	-0.02	0.02	0.02
W20	-0.37	-0.42	-0.08	-0.28	-0.09	-0.27	-0.36	-0.36	-0.34	-0.45	-0.36	-0.27
W21	0.35	0.29	0.13	0.31	0.20	0.38	0.24	0.11	0.09	0.42	0.18	0.24
W22	-0.55	-0.31	-0.31	-0.31	-0.33	-0.24	-0.40	-0.38	-0.27	-0.35	-0.44	-0.31
W23	0.33	0.44	0.56	0.33	0.51	0.56	0.51	0.42	0.16	-0.07	0.24	-0.02
W24	-0.39	-0.28	-0.22	-0.31	-0.29	-0.38	-0.56	-0.63	-0.75	-0.72	-0.51	-0.69

Bold numbers indicate significant at 5 per cent.

Table 3: Sen's slope values (m/month) for groundwater level of observation wells

Wells	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W1	0.03	-0.21	-0.25	-0.31	-0.21	-0.50	-0.44	-0.61	-0.47	-0.48	-0.50	-0.47
W2	0.40	0.48	0.40	0.36	0.29	0.25	0.19	-0.12	0.02	-0.03	-0.13	0.04
W3	1.01	1.10	0.90	0.56	0.93	0.87	0.81	1.09	1.23	1.15	1.00	1.13
W4	0.18	0.10	0.10	0.18	0.29	-0.21	-0.34	-0.67	-0.57	-0.66	-0.33	-0.44
W5	0.23	0.60	0.48	0.30	0.52	0.60	0.09	-0.47	-0.70	-0.28	-0.47	-0.51
W6	2.02	1.80	2.51	2.34	1.95	2.18	2.30	0.94	0.50	0.37	0.54	0.45
W7	3.03	3.02	2.98	2.81	2.60	3.11	2.29	1.65	2.21	2.38	2.23	2.50
W8	1.15	1.15	1.25	1.20	1.81	1.47	1.30	0.28	-0.08	0.19	0.35	0.35
W9	-0.22	-0.36	-0.45	-0.20	-0.25	-0.24	-0.26	-0.38	-0.45	-0.45	-0.42	-0.41
W10	-0.38	0.39	0.54	0.48	0.71	0.43	-0.30	-1.45	-1.08	-0.63	-0.30	-0.13
W11	-0.15	-0.19	-0.25	-0.14	-0.07	0.11	0.00	-0.05	-0.09	-0.06	-0.11	-0.28
W12	0.04	-0.04	-0.05	-0.05	-0.13	-0.07	0.03	-0.07	-0.05	-0.06	-0.13	-0.18
W13	0.73	0.46	0.35	0.52	0.30	0.45	0.29	-0.58	-0.25	-0.40	0.13	0.12
W14	0.45	0.46	0.51	0.51	0.63	0.36	-0.01	-0.03	0.19	0.28	0.29	0.12
W15	1.19	3.32	3.74	4.09	3.10	4.01	3.75	1.88	1.43	2.51	1.24	1.39
W16	2.44	3.27	3.25	3.11	3.83	2.78	2.09	1.15	0.18	1.21	1.23	0.60
W17	-1.06	-0.95	-1.00	-0.61	-0.58	-0.39	-0.66	-1.17	-1.17	-1.02	-1.15	-1.12
W18	0.41	0.37	0.33	0.27	0.63	0.38	0.60	0.25	0.20	0.38	-0.08	0.31
W19	0.53	0.57	0.67	0.50	0.57	0.62	-0.04	-0.20	-0.28	-0.11	0.04	0.10
W20	-0.14	-0.22	-0.07	-0.25	-0.02	-0.10	-0.15	-0.12	-0.14	-0.20	-0.09	-0.13
W21	0.30	0.40	0.19	0.29	0.35	0.56	0.35	0.28	0.21	0.40	0.23	0.35
W22	-0.23	-0.15	-0.22	-0.17	-0.24	-0.11	-0.17	-0.30	-0.12	-0.23	-0.13	-0.14
W23	0.56	0.91	1.31	1.51	1.21	1.59	0.75	0.05	0.03	-0.02	0.10	0.00
W24	-0.77	-0.57	-0.52	-0.48	-0.58	-0.76	-1.05	-1.05	-1.02	-0.83	-0.71	-0.90

Bold numbers indicate significant at 5 per cent.

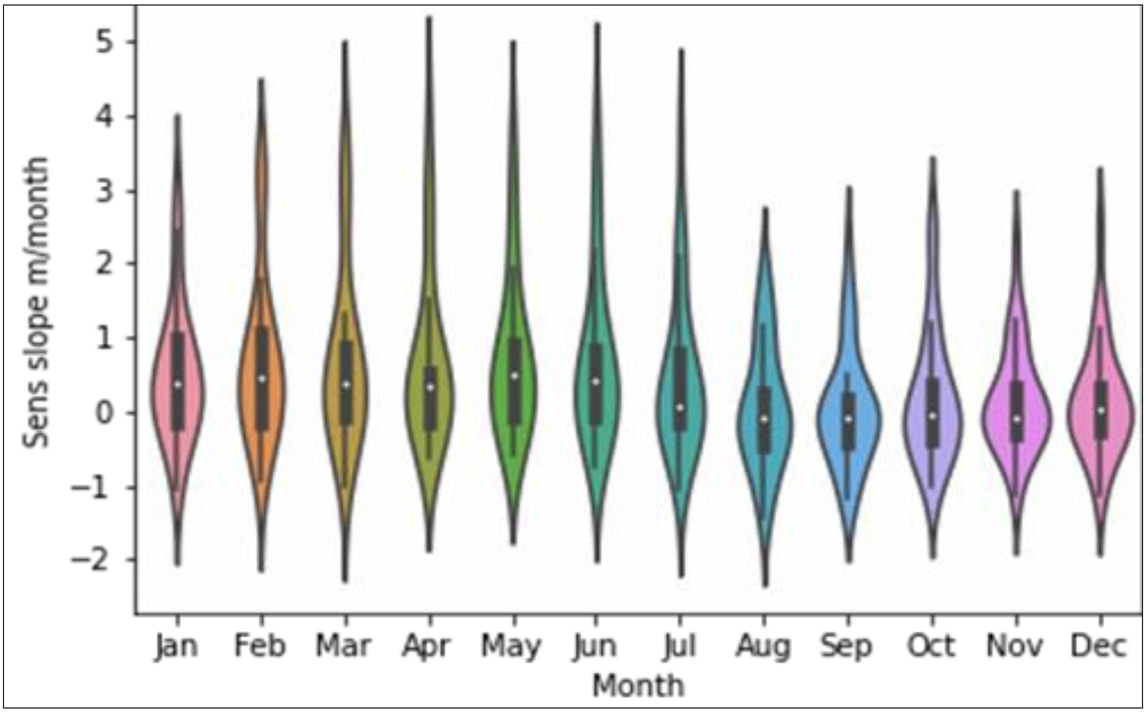

Fig 2: Violin plot of Sen's slope for groundwater levels

Conclusion

Groundwater level trends of 24 observation wells were investigated. The present study concludes that, significant increasing trends were shown by W2, W3, W6, W7, W14, W15, W19 and W23, while W1, W9, W12, W17, W22, and W24 showed significant decreasing trends. The most significant positive slope occurred at W15 in the month of April and the most significant negative slope occurred at W17 in the month of November. According to Violin plot of Sen's slopes (Figure 2), the highest variation was seen in the month from January to July, and the month from August to December showed less variation. Significant increasing trends dominated in the study area. Hence groundwater level depth was increasing which means groundwater was decreasing in these regions, which is a matter of concern for the sustainability of the study area since, in the long run, the domestic and industrial developments will be at stake.

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