Journal of Soil and Water Conservation **21**(3): 250-259, July-September 2022
ISSN: 022-457X (Print); 2455-7145 (Online); DOI: 10.5958/2455-7145.2022.00032.7

Decadal analysis of water level fluctuation using GIS in Jabalpur district of Madhya Pradesh

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Received: 20 October 2021; Accepted: 4 July 2022

ABSTRACT

The dynamics of groundwater depends upon lithology, landforms and the geological setups. If these factors are favourable then the aquifer condition is considered good for sufficient groundwater potential. In the current study, long-term trend detection and spatiotemporal variation of groundwater levels were analysed using Geographical Information System (GIS) and performed statistical tests for the Jabalpur district Madhya Pradesh, India. The significant decrease in the groundwater level was observed in 80 % observations wells during pre-monsoon and 90% for post-monsoon season. This study represents the groundwater level fluctuation and its trends on decadal basis for 20 years i.e., 2001-2010 and 2011-2020 in Jabalpur district, Madhya Pradesh. The previous reports showed that study area has been experiencing groundwater problems for the past few years, due to overexploitation of aquifers. The results indicated that the average depth to water level during pre-monsoon season ranges from 2.04 to 14.73 m, whereas in post-monsoon season, water level ranges from 0.83 to 11.96 m. The decadal analysis depicted that the mean water level during the period of 2001-2010 was 4.53 m, which got significantly decreased during the second decade(2011-2020), was recorded 4.84 m. During 2011-2020, the depletion was assessed, which was faster as compared to the preceding decade. The analysis of the result showed, mostly decreasing trends over the time period. This declination of groundwater level may affect most of the water-dependent activities, especially the agriculture sector. Therefore, the findings of this study may assist the decision makers and authorities for sustainable management of groundwater resource.

Key words: Geographical Information System (GIS), Groundwater level, Water level fluctuation, Trend, Decadal analysis, Irrigation

INTRODUCTION

Water is a valuable resource that is necessary for humanity's survival. Water quantity and quality concerns become increasingly important as demand grows. The occurrence of aquifer recharge and runoff into rivers is affected by water table fluctuations. In many parts of India, free or subsidised power has been highlighted as one of the primary causes of groundwater depletion (Shah *et al*., 2012). However, there has been no field validation of this qualitative evaluation of the connection between subsidy and groundwater depletion. Sustainable management of this resource should be a primary objective for future strategy planning (Trivedi *et al*., 2019; Gautam *et al*., 2020; Gautam and Awasthi, 2020). For the planning of any of the realistic policy for the sustainable groundwater management requires a comprehensive understanding of the climate change, prominently rainfall (its spatial and temporal availability and the variations), evaporative demand (solar radiation, wind speed and temperature) and currently available resources of water (Trivedi *et al*., 2021).

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 season and declines when pumping is undergoing in post-monsoon season (Gautam *et al*., 2020; Gautam *et al*., 2022). Water table fluctuation is one of the most widely used determination of water recharge (Kumar *et al*., 2018; Kumar and Rathnam, 2019). The delivery of groundwater is not limitless and, therefore, its use should be properly planned based on the understanding of the groundwater system behaviour to ensure its sustainable use. There is a lack of efforts to collect the rain water and recharge the basin area under Jabalpur district (Gautam *et al*., 2021).

The groundwater levels rise and fall rapidly as a result to recharging in the monsoon season (June–October) and pumping in the dry period (pre-

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monsoon) in the dry sub-humid crystalline aquifer areas of central India. The groundwater withdrawals and recharge have a major role in seasonal and yearly water level variations in these fractured aquifers. The analysis of spatio-temporal dynamics of the groundwater network and trend analysis time series data are important for sustainable management of groundwater resources (Sreekanth *et al*., 2009). Using 15 years (1996–2010) measured groundwater levels. Singh *et al*. (2015) investigated variations in groundwater storage over period in the semi-arid southern part of Andhra Pradesh. In the different parts of southern India, groundwater storage were detected both decline (1998–2004) and increase (2005–2008), respectively.

Hence for understanding the groundwater level behaviour in aquifer systems, the present study was carried out with the following specific objectives: (1) to study the spatio-temporal behaviour of groundwater levels in the study area during pre and post-monsoon seasons for two decades (2) to analyse the trend and magnitude of fluctuations at seasonal time period and decadal scale using statistical methods viz., Mann–Kendall test and Sen's slope estimator.

MATERIALS AND METHODS

Study area

Jabalpur is one of the central districts of Madhya Pradesh (Fig. 1). The district spans in the NE-SW direction, with a maximum length of 120 km along the NE-SW direction and a maximum width is around 100 km in the E-W to ENE-WSW direction. It is located between the latitudes of 22°49'-23.45°N and the longitudes of 79.20°-80°372 E. The area of the district is about 5211 km^2. The district falls in SOI toposheet Nos. 55 M, 64 A and 55 N on 1:250,000 scale. It has an average elevation of 411 m.

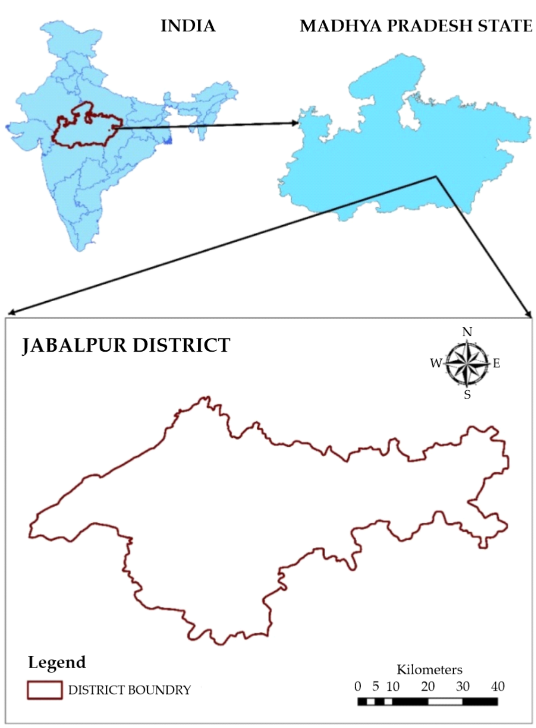

Fig. 1. Index map of Jabalpur District

Relationship between rainfall and groundwater

The previous studies showed that rainfall was not only the influencing factor of groundwater level, geomorphology also plays an important role on groundwater occurrence (Nyakundi *et al*., 2015; Patle *et al*., 2015; Trivedi and Awasthi, 2021). Other Factors which might have influenced the ground water level includes the land use and land cover, because major part of Jabalpur district is covered by hills and forest. Good amount of rainfall helps to stabilizing groundwater levels by enhanced recharge and reduction in groundwater over-exploitation. The occurrence of rainfall and groundwater level data plots indicate moderate uphill (positive) correlation and satisfactory response to incidence of rainfall for the decade 2001-2010 and 2011-2020 (Fig. 2 and 3).

Irrigation and Drainage

The total irrigated area by various sources is about 1100.42 km^2 and net sown area is 2726.60 km^2, which is 40.35% of net sown area in the district. The total area is irrigated by canals, wells, tube wells, ponds are 77.44 km^2 (2.76% of total area sown), 739.11 km^2 (27.10%), and 44 km^2 (0.04%), respectively. There are 8832 tube wells and 8010 dug wells in the district for irrigation.

The Jabalpur district lies at the Junction of the Vindhyan and Satpura range and forms part of the great central watershed of India. The Narmada and its tributaries, the Hiran, Gaur drain the district. Choti Mahanadi drains a very small area in the east, which is tributary of Son River falling in the Ganga basin. The general slope of the Narmada valley is towards west & of Hiran towards south west. The drainage in the district is generally of dendrite type except in the valley of Narmada, along the right banks of Hiran below Katangi, where it is of the straight trunk and trellis pattern. The total length of the Narmada River in the district is about 110 km.

Data sources

The pre and post monsoon data of 20 years (2001-2020) were acquired from the Department of

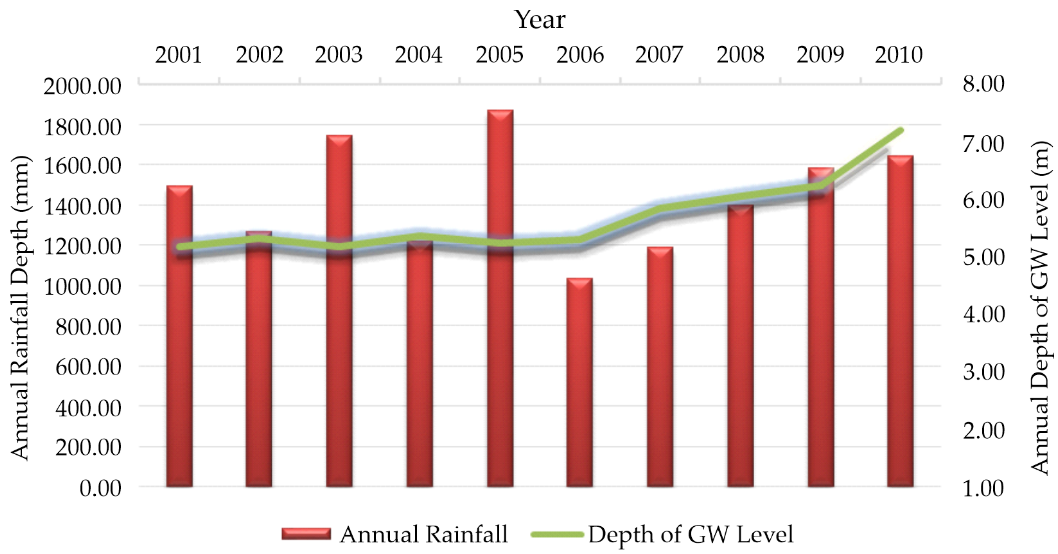

Fig. 2. Effect of rainfall on groundwater level fluctuation (2001-2010)

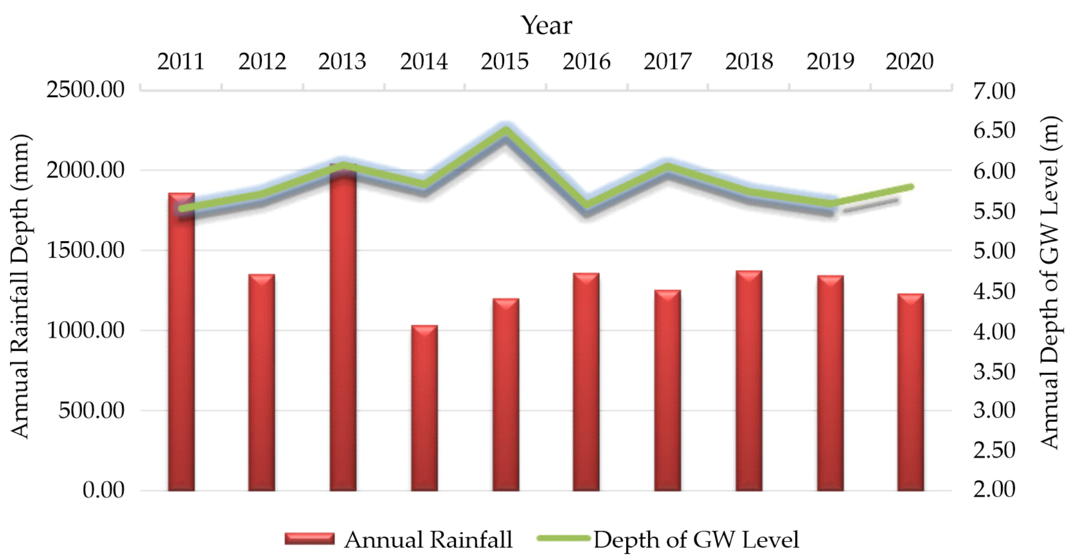

Fig. 3. Effect of rainfall on groundwater level fluctuation (2011-2020)

Irrigation & Water Resource, Madhya Pradesh at the block and village levels. The dataset is composed of 36 observation wells (depth of water table and yield) in the aquifer. The measurements were made between 2001 and 2020. The dataset also includes pre monsoon and post monsoon observations of the water level. Fig. 4 shows the location of observation wells in the study area.

Spatial analysis of groundwater level

The data were analysed to determine the long-term trend of groundwater level. The spatial variations of mean groundwater level fluctuations from the observed data were also analysed.

Statistical tests for trend analysis

Statistical approaches such as, Mann–Kendall and Sen's Slope estimators have been used to determine the trend and magnitude of groundwater level. The process flow chart of trend analysis is shown in Fig. 5.

Mann Kendall Test (MK test)

The Mann-Kendall test is a non-parametric approach for detecting the trends in time series data. The MK test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One advantage of this test is that, there is no need of data confirmation to any particular distribution. Furthermore, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The data values are evaluated as an ordered time series.

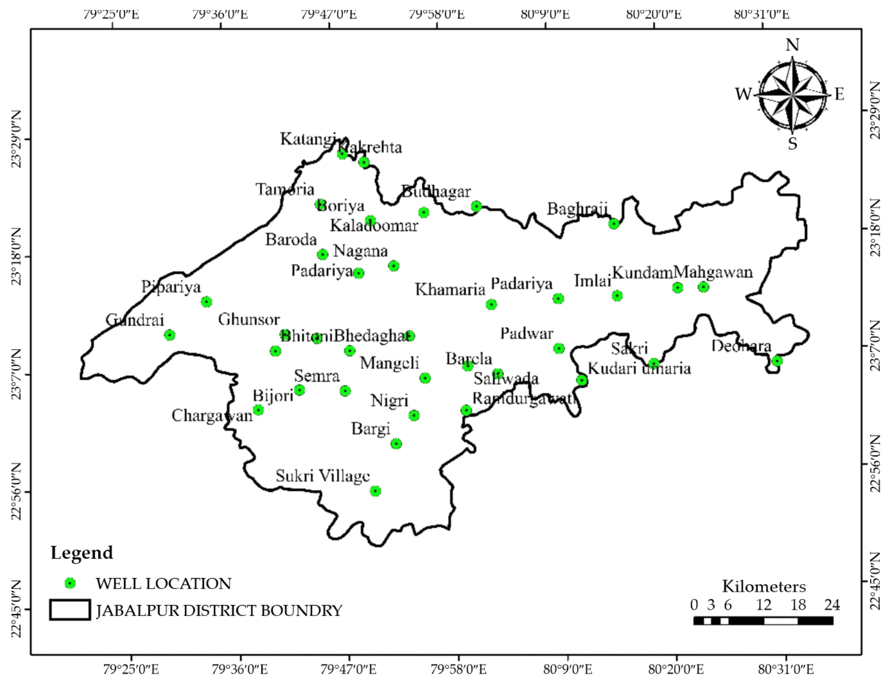

Fig. 4. Location map of observation wells

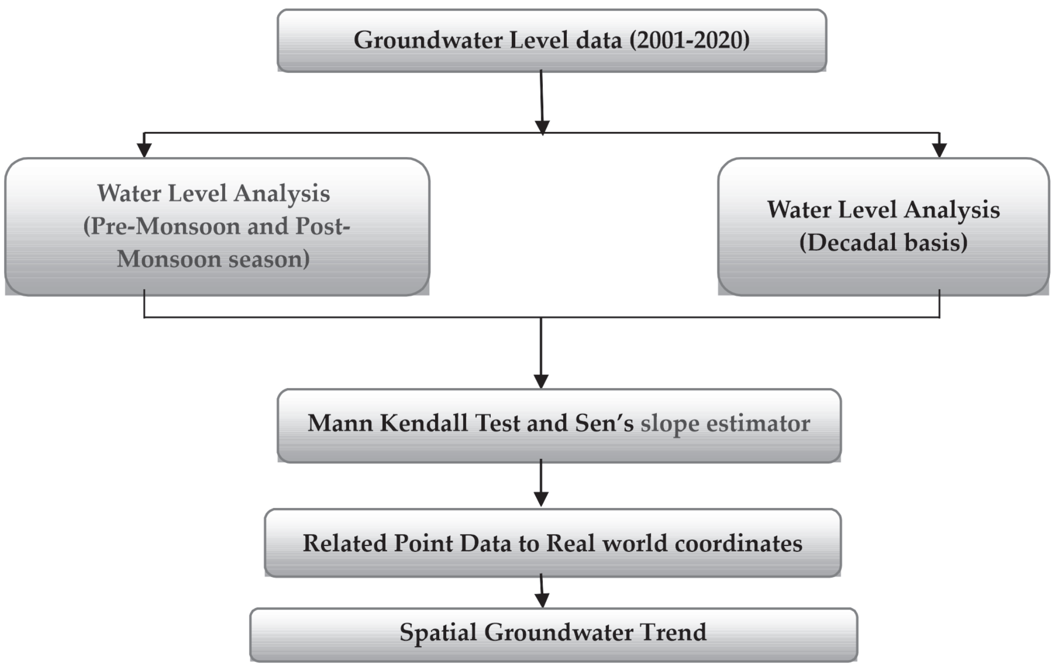

Fig. 5. Research methodology flowchart

Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (e.g., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The standard normal deviation (Z Value) is computed as

$$Z = \begin{cases} \frac{s-1}{\sigma} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \frac{s+1}{\sigma} & \text{if } s < 0 \end{cases} \qquad \ldots(1)$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. When Z > +1.96 or Z< -1.96 then null hypothesis (H_o) is rejected at 95% level of significance level. Significance of positive and negative trend is found by the Z values at 95% level of significance. If Z value is greater than +1.96 it shows significant rising trend and if Z value is less than -1.96 it shows significant falling trend.

Sen's slope estimator test

The Sen's Slope estimator was used to monitor 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. The time series is assumed to have a linear pattern in this process. If the trend is linear, the computed slope variation of measurement per time was estimated by modest nonparametric procedure (Sen, 1968). Equation (2) shows

$$Q = \frac{x_j - x_k}{j - k} \quad \ldots(2)$$

Where, Q determines the slope of the data points between x_j and x_k. Therefore, denotes data dimension at certain time interval of j, denotes the data quantity at the time interval of k, j and after time k.

Inverse Distance Weighted method (IDW)

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.

RESULTS AND DISCUSSION

Mann Kendall and Sen's slope estimator Statistical Analysis

Mann–Kendall (MK) test statistics, Sen's slope helped to identify the trends in groundwater levels of the study area at spatial and temporal scale. Each monitoring well reflects the groundwater dynamics of the surrounding area; therefore, its trend value provides an idea about the water level fluctuations of that area over the time period. Results of analysis of MK test for each monitoring well along with Z statistics are shown in Table 1. The Sen's slope and linear regression slope computed for the pre-monsoon season are shown in Fig. 6.

Table 1. Mann–Kendall Z statistics and Sen's slope estimate for the year 2001-2020

Year	Data	Sen's slope estimate(m/yr)	99 % conf. min	99 % conf. max	95 % conf. min	95 % conf. max	Residual (Z value)
2001	5.172083	-0.25	0.45	0.08	0.44	0.15	0.13
2002	5.317917	-0.31	0.44	0.11	0.43	0.17	-0.02
2003	5.171667	-0.32	0.43	0.14	0.42	0.19	-0.23
2004	5.362917	-0.32	0.42	0.17	0.41	0.21	0.10
2005	5.230556	-0.33	0.41	0.19	0.40	0.23	0.13
2006	5.295833	-0.33	0.40	0.22	0.39	0.25	0.13
2007	5.841667	-0.34	0.39	0.25	0.39	0.27	-0.08
2008	6.05625	-0.34	0.38	0.28	0.38	0.29	0.04
2009	6.239306	-0.35	0.37	0.31	0.37	0.32	0.08
2010	7.215278	-0.35	0.36	0.34	0.36	0.34	-0.02
2011	5.527	-0.36	0.34	0.36	0.35	0.36	-0.16
2012	5.709	-0.36	0.33	0.39	0.34	0.38	-0.15
2013	6.068833	-0.37	0.32	0.42	0.34	0.40	-0.11
2014	5.826333	-0.37	0.31	0.45	0.33	0.42	0.00
2015	6.517	-0.38	0.30	0.48	0.32	0.44	-0.05
2016	5.580667	-0.38	0.29	0.51	0.31	0.46	-0.18
2017	6.065833	-0.39	0.28	0.53	0.30	0.48	0.13
2018	5.736667	-0.39	0.27	0.56	0.29	0.50	0.50
2019	5.597367	-0.40	0.26	0.59	0.29	0.52	0.11
2020	5.809739	-0.40	0.25	0.62	0.28	0.54	0.31

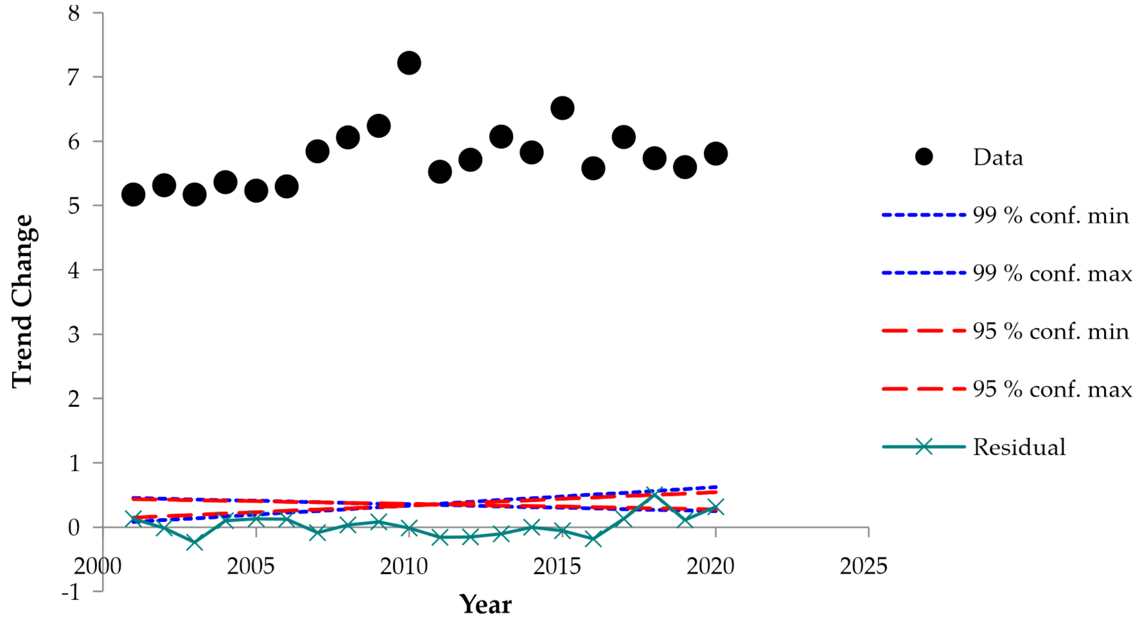

Fig. 6. Mann–Kendall Z statistics for the year 2001-2020

The trend line slopes of groundwater level in the study area using Sen's estimator and method were presented in Table 1. It was found from the results that the slopes using Sen's estimator vary from- 0.25 to -0.40 m/year in the period of 2001-2020.

In general, results of the present study indicated that the groundwater level declined during the time passing. During the monsoon season, in spite of monsoon rainfall with irrigation support from surface water resources, the decline in ground water level indicates over-exploitation of groundwater. The Trends identified through statistical tests raise concern about the sustainability of the groundwater resources in the study area.

Decadal Analysis of Water Level of Observation wells

Groundwater behaviour in first decade during 2001-2010

Using these 10 years of data, average depth to water level and water level fluctuation in the study area were prepared. The analysis of first decade (2001-2010) depth to water level is shown in Fig. 7. Mean water level depth computed for the study period during the period ranges from 1.50 to 13.50 m. Significant declining trend in the groundwater levels at 95 % significance level was witnessed in most of the stations across the study area. Most of the time series indicates the decline of groundwater levels in most areas. Gradual increase in groundwater depletion in the study area is evident from Fig. 7 and nearly 80 % of the study area showed water level beyond 10 m in the year 2010. Groundwater level trend line slopes in the study area computed using Sen's slope estimator method are presented in the Table 1. Slopes obtained by Sen's estimator varied from -0.25 to -0.35 m/year.

Groundwater behaviour in second decade during 2011-2020

Using these 10 years of data, average depth to water level and water level fluctuation in the study area were prepared. The analysis of second decade (2011-2020) depth to water level is shown in Fig. 8. Mean water level depth computed for the study period during the period ranges from 1.50 to 11.50 m. Significant declining trend in the groundwater levels at 95 % significance level was witnessed in most of the stations across the study area. Gradual increase in groundwater depletion in the study area is evident from Fig. 8 and nearly 90 % of the study area showed water level beyond 10 m in the year 2020. Groundwater level trend line slopes in the study area computed using Sen's slope estimator method are presented in the Table 1. Slopes obtained by Sen's estimator varied from -0.35 to -0.40 m/year. This decrease in groundwater level may have an impact on water-dependent activities in the study area, particularly irrigation management practices.

Groundwater behaviour in pre-monsoon season during 2001-2010

The depth to water level maps was generated for each season, i.e., pre and post-monsoon seasons, for the study period (2001-2020). Using these 20

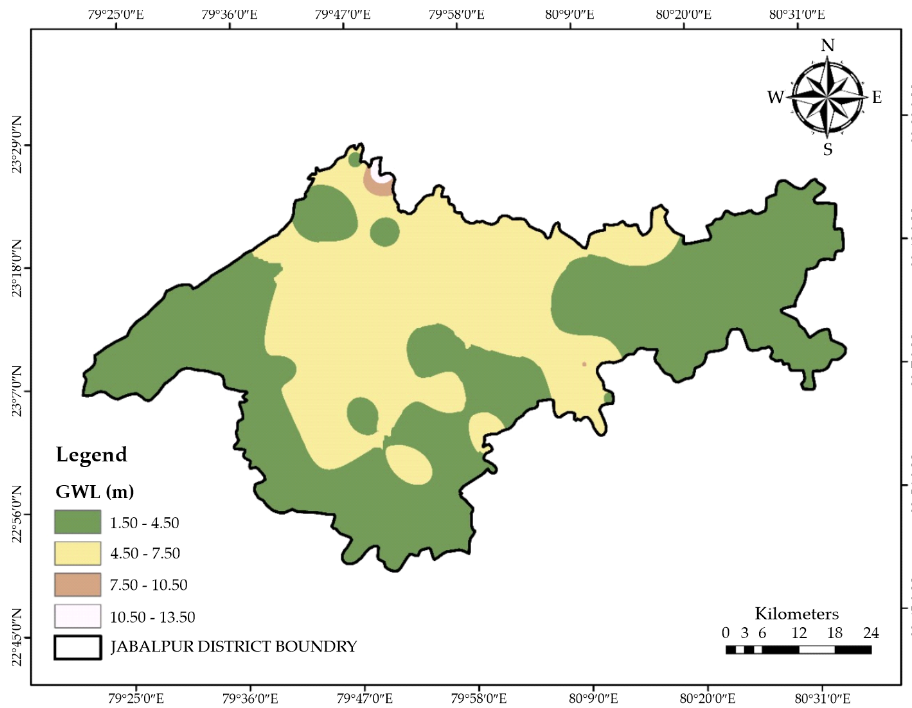

Fig. 7. Decadal variation of depth to water level (m) in the year 2001-2010

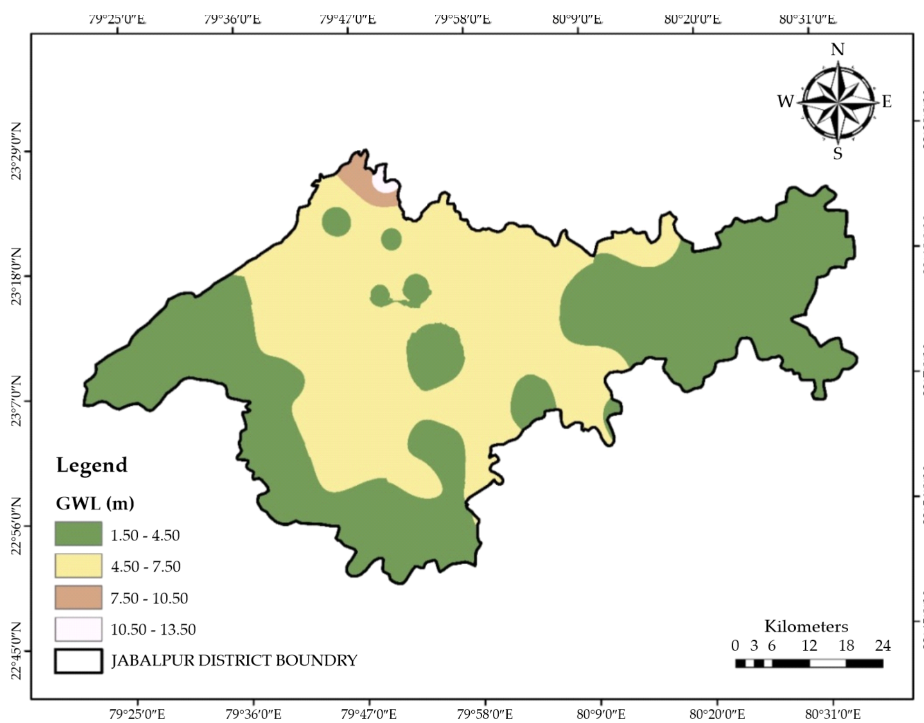

Fig. 8. Decadal variation of depth to water level (m) in the year 2011-2020

years of data, average depth to water level and water level fluctuation in pre-monsoon were prepared. Average depth to water level map for both pre and post-monsoon was prepared by taking the average of all 20 years. Mean water level depth computed for the study period 2001-2010, in pre-monsoon season ranges from 2.04 to 14.73 m (Fig. 9). The groundwater level in pre-monsoon season has maximum, minimum and mean value *viz*., 14.73m, 2.04m and 5.57m, respectively.

Groundwater behaviour in pre-monsoon season during 2011-2020

The analysis of pre-monsoon depth to water level for second (2011-2020) decade is shown in Fig.

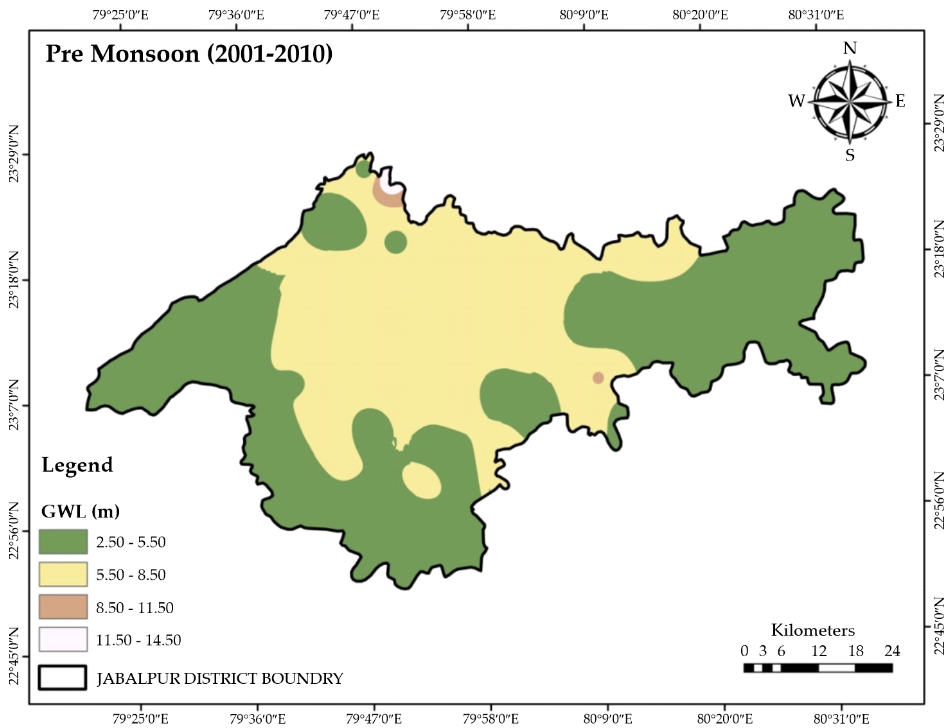

Fig. 9. Pre-monsoon variation of depth to water level (m) in the year 2001-2010

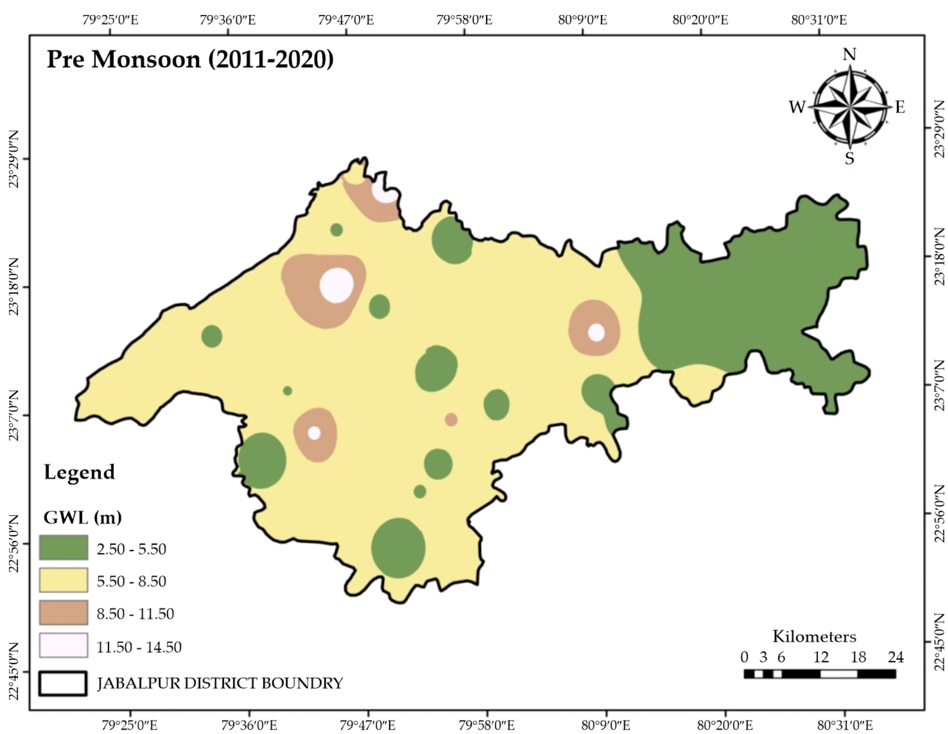

Fig. 10. Pre-monsoon variation of depth to water level (m) in the year 2011-2020

10. Mean water level depth computed for the study period 2001-2010, in pre-monsoon season ranges from 3.73 to 14.50 m. The groundwater level in pre-monsoon season has maximum, minimum and mean value *viz.*, 14.50m, 3.73m and 6.60m, respectively.

Groundwater behaviour in post-monsoon season during 2001-2010

Similar to the pre-monsoon analysis of groundwater behaviour, post-monsoon analysis was also carried out (Fig. 11). The average depth to water level during post-monsoon season for the first

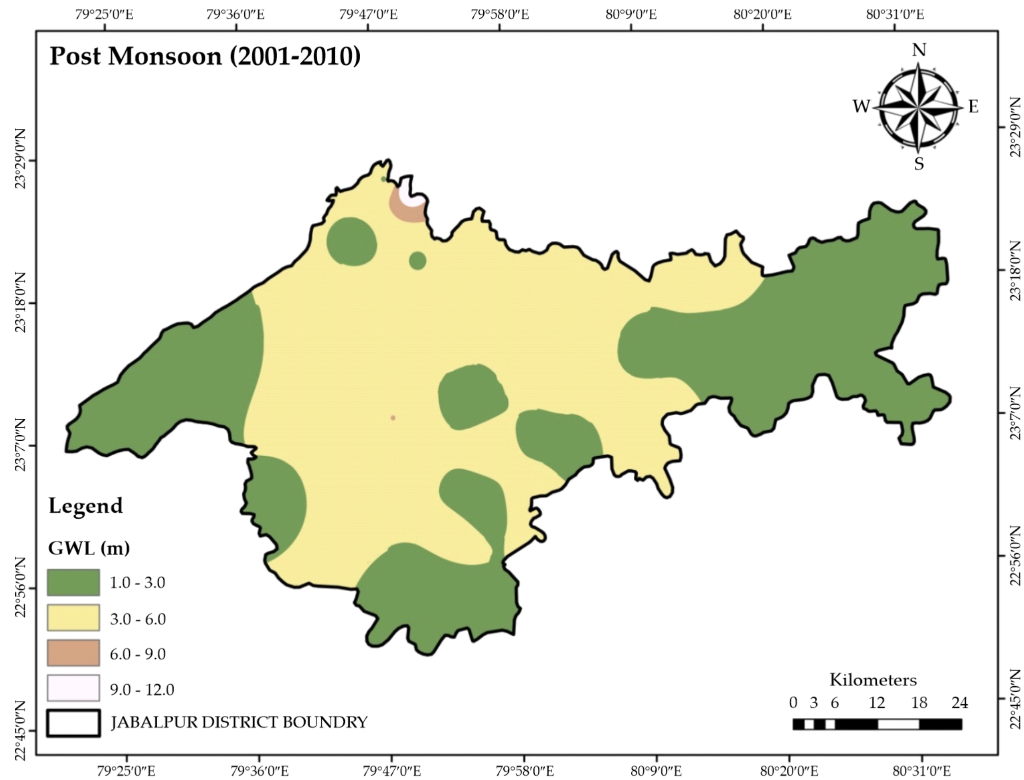

Fig. 11. Post-monsoon variation of depth to water level (m) in the year 2001-2010

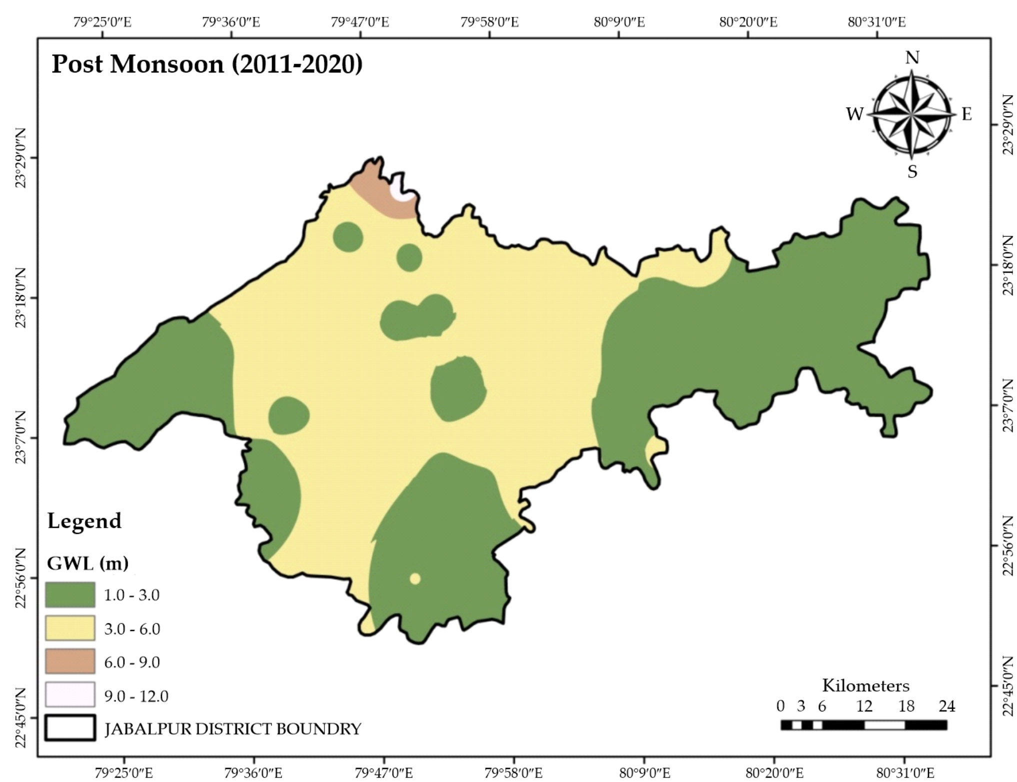

Fig. 12. Post-monsoon variation of depth to water level (m) in the year 2011-2020

decade (2001-2010) ranges from 0.83 to 11.96 m (Fig. 11). The groundwater level in pre-monsoon season has maximum, minimum and mean value viz., 11.96m, 0.83 m and 3.39m, respectively.

Groundwater behaviour in post-monsoon season during 2011-2020

The average depth to water level during post-monsoon season for the first decade (2011-2020) ranges from 1.03 to 10.80 m (Fig. 12). The groundwater level in pre-monsoon season has maximum, minimum and mean value *viz*., 10.80m, 1.03m and 3.38m, respectively.

CONCLUSION

The decadal variations of seasonal groundwater level were investigated in the present study using the Mann–Kendall test and Sen's slope estimator method. Significant declining trends are witnessed in the groundwater levels which, indicates over-exploitation of groundwater at the district. Such decline in groundwater levels may be attributed mainly due to the expansion in the irrigated cropped area in the study area. The percentage of wells characterized by significant decrease in the groundwater level was found to be 80 % for the pre-monsoon and 90 % for post-monsoon season. The study concludes that declining trends dominate positive trends in most of the observation wells. The decadal analysis depicted that the mean water level during 2001-2010 got significantly decreased. The depletion in 2011-2020, was faster as compared to the preceding decade. This high water level was observed in central part of the district, during all the seasons. It is necessary to optimize the current cropping pattern and adoption of advanced irrigation techniques to mitigate the groundwater scarcity in the district. Hence, it is important to augment the groundwater resources in the deficit areas through the installation of suitable artificial recharge structures.

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