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Spatial temporal variability of groundwater level and its constrains biological distribution over the Yamunanagar District of North-Eastern Haryana, India

Kulvinder Kaur[1] and Deepak Kumar*[2]

[1,2*]Department of Geography, IIHS, Kurukshetra University, Kurukshetra-136119, India
**Corresponding author Email: deepak.geo.earth@gmail.com*
Email Id: kulvinder.iihs@kuk.ac.in

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Abstract

Groundwater resources are used to offer irrigation water and industrial purposes in various parts of the world. Water security is now universally recognised as one of the most significant impediments to India's economic and social progress as a result of population growth and industrialisation. Therefore, groundwater variability about time and space directs attention globally to managing water resources sustainably. In the current study, spatial and temporal variability and trends of groundwater level have been evaluated over Yamunanagar district, north-eastern Haryana, India. The geographic information systems (GIS) and statistical tests, viz., the Sen's slope estimator, linear regression, and Mann-Kendall test method, have been used from 2010 to 2020. The groundwater data has been collected from India-WRIS (www.indiawris.nrsc.gov.in) from 2010 to 2020. As a result, the Mann-Kendall test reveals that 66.6% of the total number of wells has been increasing in water level depth, whereas the remaining 26.6% has been decreasing over the research period. The annual trend study shows an increasing trend in groundwater levels between 2010 and 2020, which emphasises overexploitation of groundwater and less rainfall infiltration in the study region. Places such as Jagadhari and Mustafabad blocks are most affected by the increasing trend of groundwater level depth. This study also shows that the northern and central regions of Yamunanagar district have good groundwater levels, while the southern region has been found vulnerable to groundwater conditions. Therefore, this study recommends that groundwater conservation techniques should be implemented, efficient organisations should be set up, and new strategies for groundwater use in the study region should be encouraged to ensure the safety of human life and the environment.

Keywords: Groundwater, Water security, Spatiotemporal variation, Correlation, GIS.

Introduction

Groundwater plays a crucial role in biological science, particularly in ecology, hydrology, and environmental science. Climate change has a direct impact on the hydrologic cycle and, eventually, the groundwater table. It has demonstrated the frequency of droughts, unprecedented rise in temperature, and irregularity of precipitation in time and space (Besser et al. 2018). Temperature promotes surface water evaporation and transpiration in wetlands region whereas, precipitation amounts, timings, and intensity are affecting the surface and subsurface water bodies (rivers, lakes, changes in volume and distribution of groundwater recharge process). Such a drastic changes in the long-term climate variables such as temperature, soil moisture content, precipitation, and evapo-transpiration increases the frequqncy of extreme events (Basavarajappa et al. 2015). Recently, the unpredictable rainfall (extreme) in different regions of the world is another significant element in inadequate recharging and the constant depletion of groundwater resources. Moreover, groundwater is a global concern in different regions of the world, especially in the arid and semi-arid regions (Abdelkarim et al. 2023). The high extraction rates of groundwater supplies and climate change is probably the reason of groundwater depletion in the near future period.

Groundwater is found in the soil, rock pores, and rock cracks beneath the surface of the earth. It is a key source of fresh water and vital to the long-term development of industries, agriculture, and the world's socio-economic conditions. It has emerged as the most important and dependable supply of water for reducing droughts due to its vast and ongoing availability, exceptional quality, low vulnerability, affordability, etc. (Rajaveni et al. 2013; Basavarajappa et al. 2015). Therefore, sustainable management of groundwater resorces is very necessery to fulfill the water availability of human needs, ensure agricultural productivity and to achieve a community development (Mende et al. 2007; Abdelkarim et al. 2023). However, a major fall in the groundwater levels has been detected due to various sectors like, agriculture, industrial and domestic which is expanding quickly and continuously in all over the world (Shamsudduha et al. 2009; Van et al. 2010; Machiwaland and Jha 2014). Furthermore, the groundwater recharge is very low in arid and semi-arid climatic conditions due to the lack of precipitation and high temperature rate which represents the most important factors in deteriorating the water quality (Agoubi 2018; Abdelkarim et al. 2022). These adverse effects can also directly or indirectly affect the environment through rise in extreme events, groundwater depletion, land subsidence, ecosystem disturbance, vegetation stress etc (Abdelkarim et al. 2023).

India is the world’s largest user of groundwater with over 80% of the rural and urban domestic water suppliesmet by available groundwater (Pal et al. 2022). In India, excessive groundwater use increased after the green revolution due to modern drilling techniques, electric-operated pumping equipment, cheap or free electricity, and a lack of comprehensive groundwater legislation, which encouraged the unrestrained exploitation of groundwater in areas with a developed agricultural sector. Moreover, groundwater resources have been depleted as a result of extensive groundwater development and its use in different parts of India, which has also led to an increase in the country's "grey" and "dark" areas (CGWB 2012). The country's "grey" and "dark" areas covering the state of Punjab, Delhi, Rajasthan, Haryana, Gujarat, Uttar Pradesh, Karnataka, and Tamil Nadu (CGWB 2012). Further, in India's Indo-Gangetic Plains (IGP), intensive agricultural and quick industrial growth have also increased pressure on groundwater resources. Therefore, it is essential to study the groundwater levels which have been dropping rapidly in numerous areas of agriculturally dominant states.

Keeping this in mind, the management of groundwater resources requires an understanding of spatiotemporal variability and its long-term trends (Hoque et al. 2007; Sreekanth et al. 2009). Various studies have been found in literature on the identification of trends in water resources, with a primary focus on surface water (Douglas et al. 2000; Mazvimaviand and Wolski 2006; Kumar et al. 2009; Tabari and Marofi 2011). However, very few studies have been found on groundwater level time series analysis and trends detection over the state of Haryana, India. The district of Yamuna Nagar is endowed with abundant water resources, including both surface and groundwater sources. Groundwater serves as a primary source of irrigation within the district and approximately 40 percent of the region's land is irrigated using canal water. However, the primary reason for groundwater decline in this district is over-extraction for irrigation, industrial, domestic purposes, rapid urbanization and agricultural expansion have led to increased demand for groundwater, surpassing the rate of natural recharge. Therefore, the present study have been investigated to identify the spatio-temporal variation in groundwater level and trends over the agricultural and industrial developed Yamunagar district of Haryana at regional and temporal scale. This study will help in regulatory measures of sustainable water management practices, promotion of water-efficient technologies, community participation, and awareness programs to ensure the long-term sustainability of groundwater resources.

Study Area

Yamunanagar is an administrative entity situated in the north-eastern region of the state Haryana. Geographically it is situated in between 29° 55' to 30° 31' north latitude and 77° 00' to 77° 35' east longitude. The district is characterized by fertile plains, agricultural prominence, religious significance, and industrial development, making it a region of socio-economic and cultural importance in northern India.The district is geographically demarcated by Himachal Pradesh to the north, Uttar Pradesh to the east, Ambala district to the west, and Karnal and Kurukshetra districts to the south (Fig.1). The district encompasses a total geographical area of 1756 km², which accounts for approximately 4% of the overall territory of the state. Yamunanagar district (YND) is geographically organised into a sub-division and six distinct development blocks, namely Bilaspur, Chachrauli, Jagadhri, Mustafabad, Radaur, and Sadhaura. The region is primarily included by the watercourses of the Yamuna River, Markanda River, and their respective tributaries. The river Markanda serves as a tributary to the Ghaggar River and is responsible for draining a significant portion of the district. The elevated terrain located between the Markanda River and the smaller tributaries of the Yamuna River serves as a delineating barrier between the westward-flowing rivers of the Indus river system and the eastward-flowing rivers of the Ganga basin. The River Yamuna serves as the eastern drainage system of the district and also as a natural boundary between the states of Haryana and Uttar Pradesh.

The topography of Yamunanagar district is predominantly flat with occasional undulating terrain. It is part of the Indo-Gangetic plain, characterized by fertile alluvial soil deposited by the rivers flowing through the region. The terrain is suitable for agriculture, with extensive cultivation of crops such as wheat, rice, sugarcane, and vegetables. The district endowed with abundant water resources, including both surface and groundwater sources. Groundwater serves as a primary source of irrigation within the district. Approximately 40 percent of the region's land is irrigated using canal water. The length of the distributaries within the district measures 21.45 kilometres. The district is traversed by two significant canals, including the western Yamuna canal and the augmentation canal.

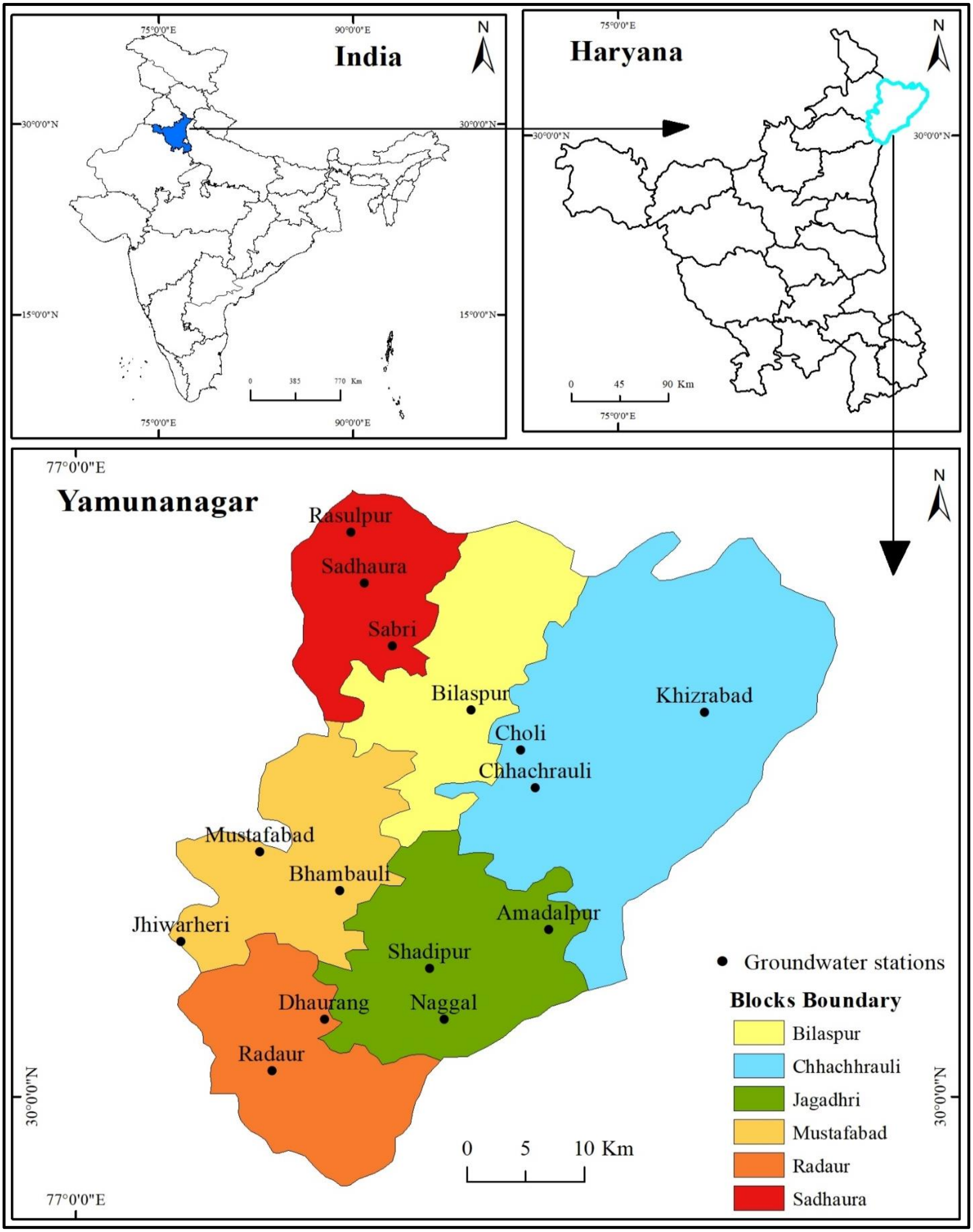


Fig. 1 Location map of the study area

Database and Methodology

Data Used

This study have used annual groundwater level data from the India-WRIS online portal (www.indiawris.nrsc.gov.in). The data of 15 wells has been taken for the period of 2010-2020 to cover the entire study area (Fig. 1 and Table 1). A total of 15 wells have been selected due to availability of continuous data of these time period only. Further, the data have used to examine the spatiotemporal changes of groundwater levels and water level fluctuations in different blocks of Yamunanagar district. Besides, several statistical methods and tools have been used in this study to analyse the changing pattern of groundwater levels over Yamunanagar district, Haryana. A detailed description of these methodological steps in terms of flow chart has been shown in Fig. 2.

Methodology

Geospatial analysis of groundwater level

The groundwater levels are changing both spatially and temporally, intending to develop water resources sustainably. Recently, groundwater management studies have used geospatial techniques as a key strategy. The spatiotemporal change in groundwater levels during 11 years (2010-2020) has been investigated using the Geographical Information System (GIS) (Karunanidhi et al. 2012; Subramani et al. 2013; Tiwari et al. 2015).

Inverse Distance Weighted Technique (IDW)

The acquired water depth data are very limited to a greater degree; thus, the variability of annual groundwater level has been interpolated with the Inverse Distance Weighted (IDW) method using the annual groundwater level data of 15 wells. The IDW approach is to highlight the values of surrounding areas with a measurement of their distance from the study region

Table 1 Shows the geographical position of selected groundwater station

Blocks	Stations	Latitude	Longitude	Data Availability
Bilaspur	Bilaspur	30˚18´	77˚18´	2010-2020
Chhachrauli	Chhachrauli	30˚14´	77˚21´	2010-2020
	Choli	30˚16´	77˚20´	2010-2020
	Khizrabad	30˚18´	77˚29´	2010-2020
Jagadhri	Amadalpur	30˚08´	77˚22´	2010-2020
	Naggal	30˚03´	77˚16´	2010-2020
	Shadipur	30˚06´	77˚16´	2010-2020
Mustafabad	Mustafabad	30˚11´	77˚08´	2010-2020
	Bhambauli	30˚09´	77˚12´	2010-2020
	Jhiwarheri	30˚07´	77˚04´	2010-2020
Radaur	Radaur	30˚01´	77˚09´	2010-2020
	Dhaurang	30˚03´	77˚11´	2010-2020
Sadhaura	Rasulpur	30˚26´	77˚12´	2010-2020
	Sadhaura	30˚24´	77˚13´	2010-2020
	Sabri	30˚21´	77˚14´	2010-2020

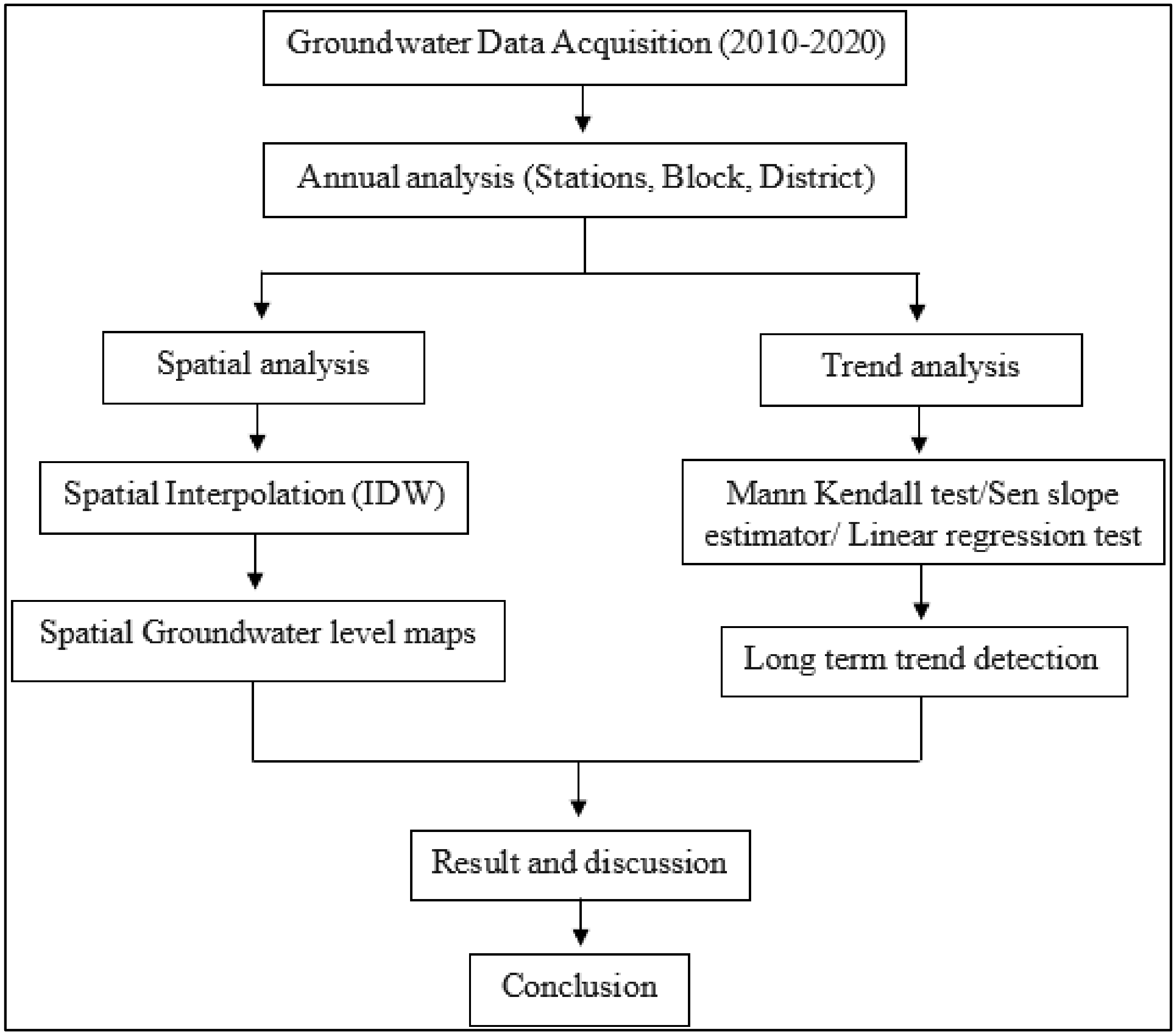


Fig. 2 Methodological Flow chart

(Goyal et al. 2010; Chen et al. 2013; Kumar et al. 2018). In comparison to other interpolation methods like kriging, natural neighbour, spline, and trend, IDW is the simplest. It has the benefit of being simple to define, making it simple to comprehend the outcomes. Because applying to Krige is typically not a good idea if you are unaware of how the outcomes will be reached. Additionally, kriging works best when there is a spatially associated bias in the distance or direction of the data (Burrough 1986; Heine 1986). The neighbouring remote points and adjacent points (wells) have an impact on the surface's interpolation and assumption of insertion (Gemmer et al. 2004). It has been found to be the best methodology for interpolation research based on the use of multiple inputs to observe groundwater level fluctuations over time and space (Gunarathana et al. 2016). In this study, the 15 well-sampling point variables were employed to regulate the impact of adjacent points.

Trend analysis of groundwater level

Mann-Kendall

The Mann-Kendall (MK) test is a popular rank-based, distribution-free test for studying long-term data trends. When looking at stream movement, water level, rainfall, and temperature over a period of time for climatological reasons, the standard Mann-Kendall test (MK test) is used to see how important cumulative deviations are (Mann 1945; Kendall 1955). Because (1) the data doesn't have to be distributed in a certain way (Tabari and Talaee 2011); (2) the information can support more than one explanation for each interval; (3) it allows skipped and changed integers in the sequential data series (Kundzewicz and Robson 2004); and (4) it has low sensitivity discontinuities because of the heterogeneous time series (Jagus 2006), the MK test was very good at finding temporal input trends. The MK test's main benefit is that it typically permits mathematical dispersal, which is necessary for the parametric technique. In the current investigation, the significance level was determined to be 0.05 with a 95% level of confidence. As a result, the data on groundwater levels has been used to identify any downward or upward trends.

Sen’s slope estimator

Sen's slope estimator is used to handle the unbiased estimator of trends when the data are significantly skewed since it is reliable (Hirsh et al. 1982). In this study, the trend line slope has been calculated using this method based on the drop rate in water level (m/year). The positive Sen's slope component shows an increase in groundwater level and continues the increasing trend, whereas the negative Sen's slope component denotes a decreasing tendency. Over the past 11 years, the groundwater level fluctuation in the research region has not been consistent. A time series of data with an evenly spaced design is required for the slope measurement approach. If the trend is linear, a simple non-parametric approach was used to estimate the calculated slope variation of the measurement per time (Sen 1968).

Simple linear regression

It is a parametric method and is most commonly used to detect a trend. The linear regression method has been widely used in the literature (Immerzeel et al. 2009; Gurung et al. 2011). The trend of groundwater has been computed using the linear regression test at a 95 percent confidence level at the annual and seasonal time scales. The p-value has been utilised in this study to detect the significance level of the observed patterns. To examine the short-term trend, linear regression has been applied to the average groundwater data. The linear trend has been calculated by the least squares method as follows:

$$b = \frac{\sum_i^n X_i t_i - \frac{1}{n}(\sum_i^n X_i)(\sum_i^n t_i)}{\sum_i^n {t_i}^2 - \frac{1}{n}(\sum_i^n t_i)^2} \qquad (1)$$

where n where n is the number of study years, i is the serial number of the year (i = 1, . . ., n = 17), xi represents the groundwater of each pixel for year I, t is corresponding time, b > 0 means upward trend in groundwater, b = 0 means no trend and b < 0 represents downward trend in groundwater.

Results and discussion

Spatial variability of groundwater level at different stations

A spatial variation map of the average depth of groundwater level has been generated based on the 15 observed stations (Fig. 3). In the Yamunanagar district, the range of the average groundwater level has been observed from 1.78 to 31.91 metres from 2010 to 2020 (Fig. 4). The examination of groundwater data reveals that about 47% of wells' groundwater levels have been found above 8 metres, and about 53% of wells' groundwater levels have been found below 8 metres in the Yamunanagar district. During the study period, the maximum water depth has been observed at Jhiwarheri station, while the minimum water depth has been observed at Choli station (Figs. 3 and 4). In the research region, the lowest area lies below the water level, which has been observed below 4 m and over 20 m, while most of the areas lie below the underwater level, which falls between 8 and 12 m. The spatial variability maps show that the maximum depth of groundwater level (above 16 m) has been found in the southwestern part and minor areas of the north-eastern parts of the study region. However, the water level in the district's north, northeastern, and southern regions is less than 8 m. The study region has a moderate depth of groundwater level (8 and 12 m) in the centre and north-eastern regions of the study region. Overall analysis of the spatial variability of groundwater has shown that the groundwater is in good condition in the northern and central regions of the district, whereas in the southern region of the district there has been higher groundwater depletion and it is in vulnerable conditions. This

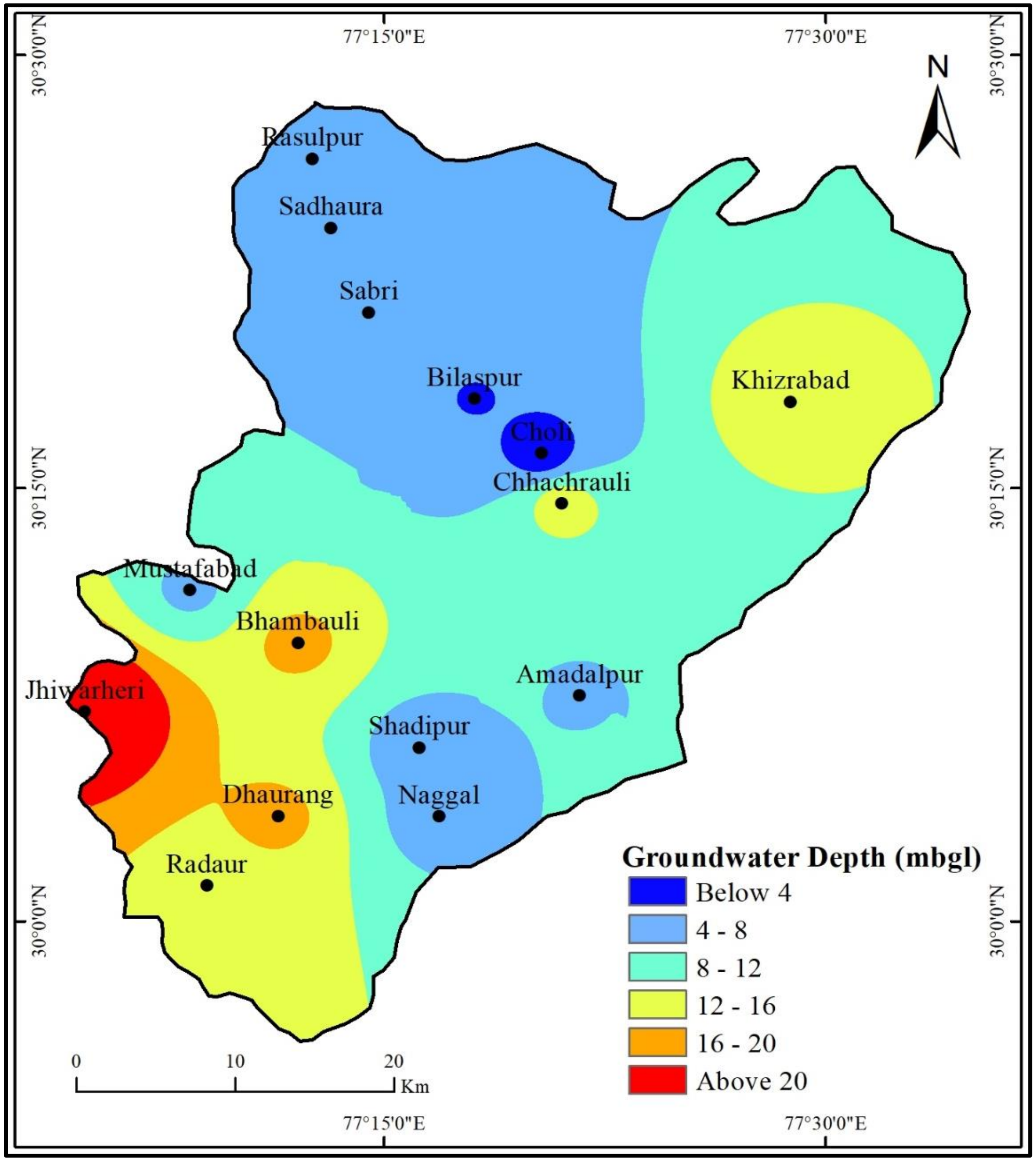


Fig. 3 Spatial variation of mean underground water level during 2010 to 2020

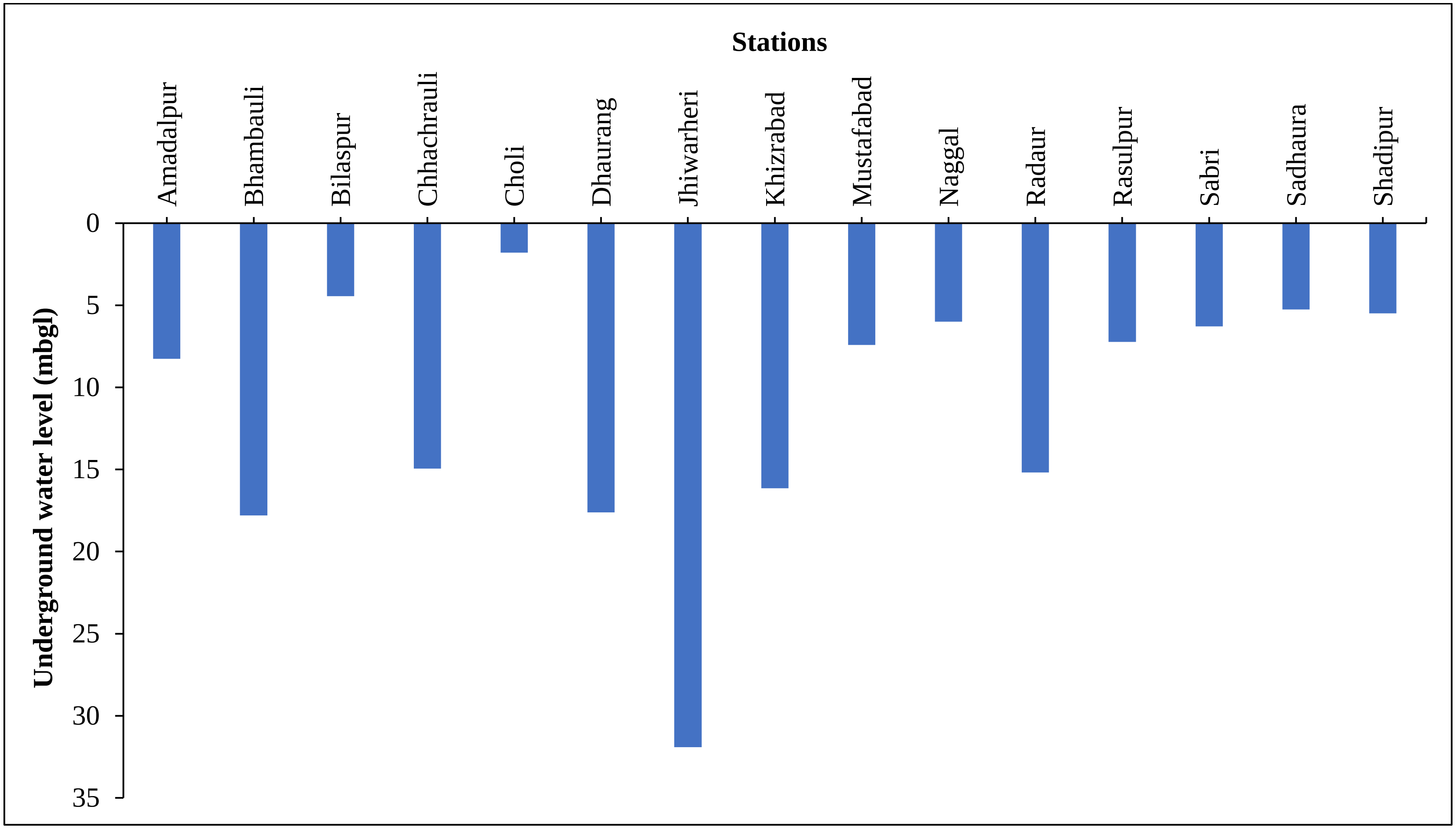


Fig. 4 Average depth and variabilty of underground water level at different stations from 2010 to 2020

high groundwater variation may be related to the over-exploitation of groundwater for agricultural and industrial usage and the uneven pattern of rainfall over the study period. The issue has been made worse by adoption of continuous rice-wheat (RW) cropping systems, and crops like sugarcane and the early transplanting of rice in some places (Arora et al. 2005; Machiwaland Jha 2014). It seems that the southern region of the study area should be in need of groundwater conservation practices. Therefore, to ensure its long-term use, underground water consumption should be well planned based on an understanding of groundwater system activity. Establishing operational bodies and advocating for new groundwater use guidelines and standards are essential. Modern irrigation methods and altered farming practises are needed to lessen groundwater depletion. Artificial groundwater recharge facilities built in low-lying agricultural areas are one possible method of reducing flood water damage. In these low-lying places, artificial groundwater recharge can effectively decrease excess flood water by redirecting excess water into aquifers to enhance groundwater recharge (Rajaveni et al. 2013; Basavarajappa et al. 2015).

Trend analysis of groundwater level at different stations

The statistical test results have been verified by estimations of trends in groundwater levels in Yamunanagar district. The Mann-Kendall test has been employed to examine trends in groundwater level data from 2010 to 2020 at the 95% confidence level. (Fig. 5). Among the 15 monitoring wells (stations), Sadhaura, Choli, and Mustafabad have seen a significant decrease in groundwater levels between 2010 and 2020. It demonstrates that the area around these stations is in good condition in terms of groundwater level and provides a clear indication for the future. A non-significant decreasing trend has been observed in Dhaurang. However, a significant increasing trend has been observed in Jhiwarheri, Bhambauli, and Basulpur during the study

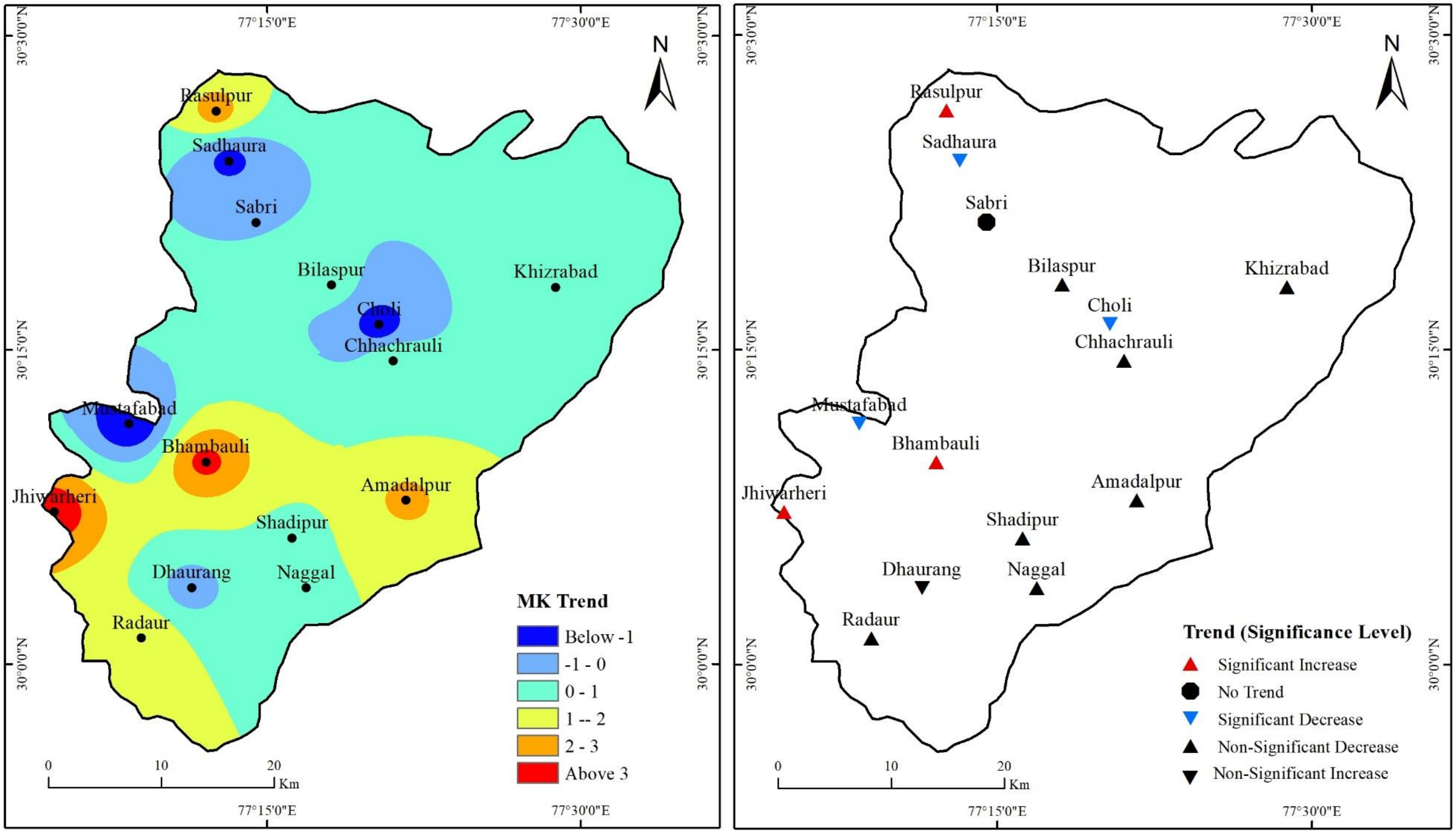


Fig. 5 Trend variation in the groundwater levels at various station during 2010 to 2020

period. These stations are the most vulnerable in the context of groundwater levels in the district. A non-significant increasing trend has been observed in Bilaspur, Khizrabad, Chhachrauli, Amadalpur, Shadipur, Naggal, and Rahaur. These regions are also vulnerable to the groundwater level in the Yamunanagar district. In the analysis of 11 years of underground water level data, no trend has been observed in Sabri, so it seems there is no change in the water level in this area. The overall groundwater trend analysis of 15 wells in the study region shows that 4 wells have a decreasing trend, which represents 26.6% of the total wells. Canal irrigation, irrigation utilising river water, and rainfall are the main factors contributing to the decreasing trend of the underground water level. However, 10 wells have observed an increasing trend, which is 66.6% of the total wells. The majority of the Yamunanagar district appears to be in a vulnerable situation with respect to groundwater levels from 2010 to 2020. Groundwater is a key component of agricultural practice in the research area and one of the influencing reasons for the increasing trend. Only 1 well found no trend out of the 15 wells (Fig. 6). An overall analysis revealed that the underground water level in the Yamunanagar district is in a vulnerable state. So, groundwater conservation practices should be implemented in the study region to ensure the safety of human life and the environment. As a result, underground water use should be adequately planned based on an understanding of groundwater system activity to assure its long-term use. It is vital to establish functional organisations and promote new groundwater use rules and standards. To reduce groundwater depletion, farming patterns must change and modern irrigation systems must be implemented. One of the conceivable strategies for controlling flood water damage is groundwater recharge via artificial groundwater recharge structures erected in low-lying agricultural areas. Artificial groundwater recharge can successfully reduce surplus flood water in these low-lying areas by diverting excess water into aquifers to increase groundwater recharge (Rajaveni et al. 2013; Basavarajappa et al. 2015).

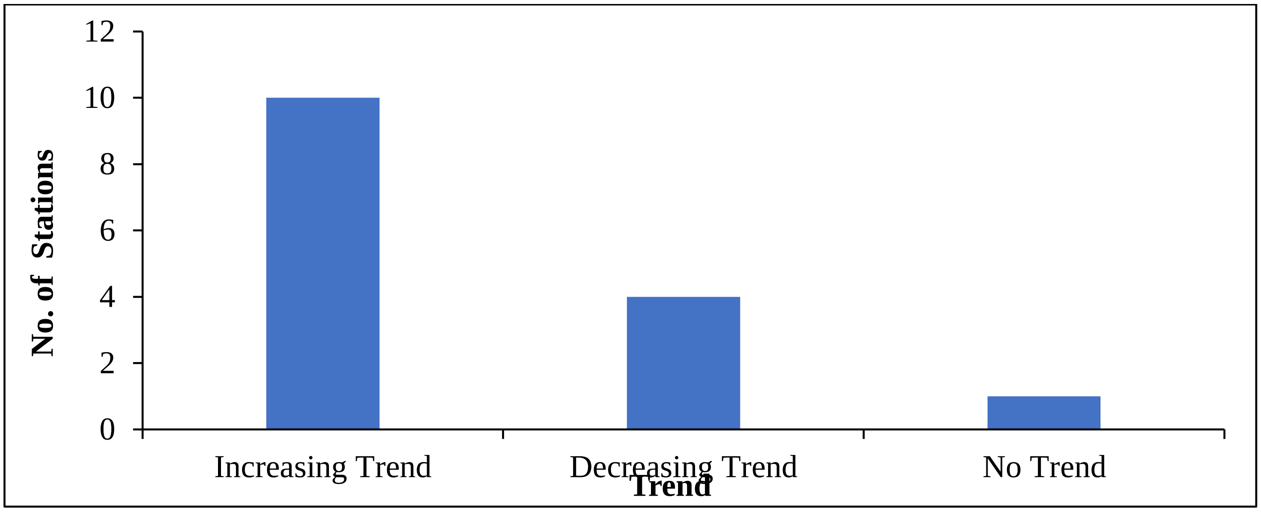
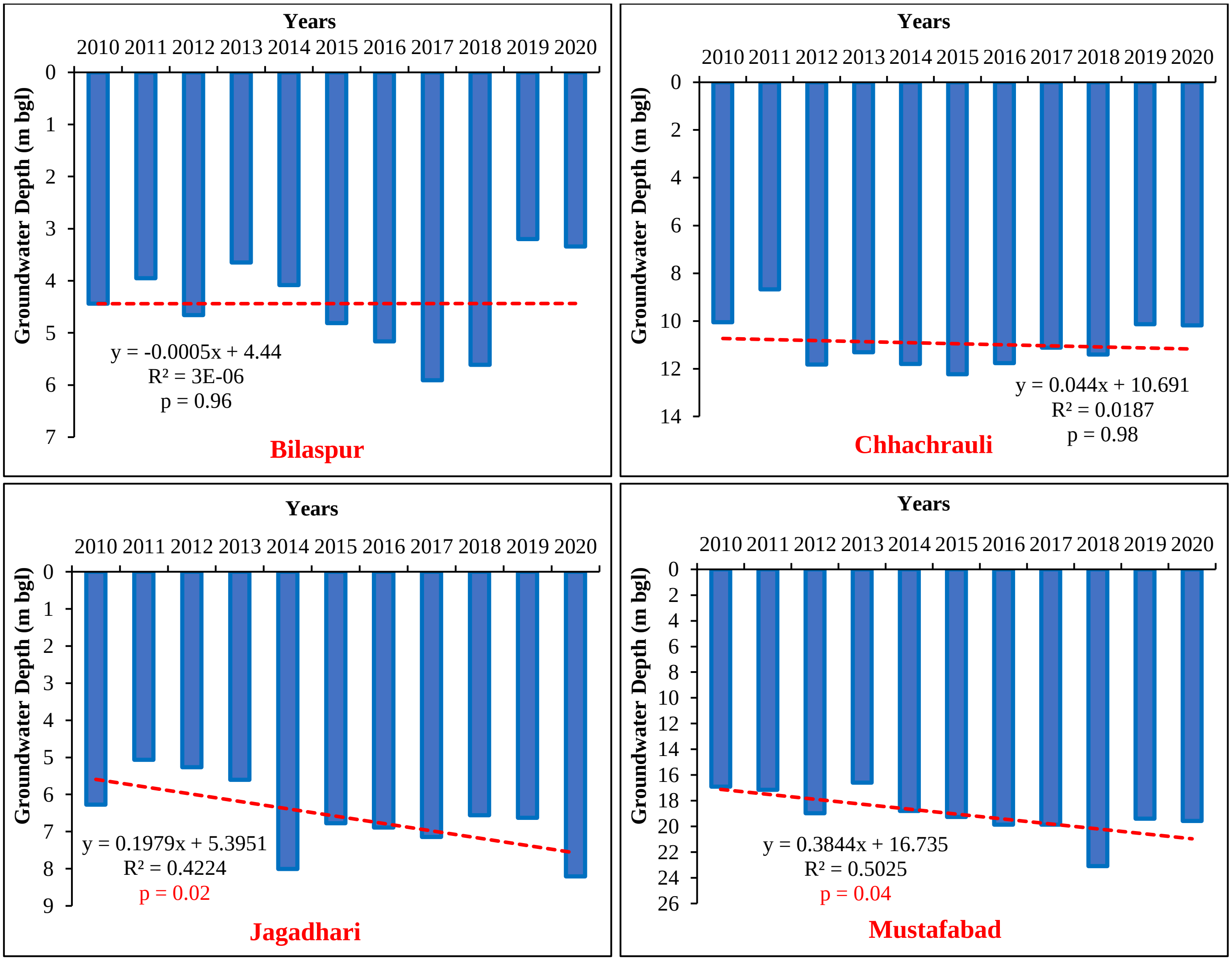


Fig. 6 Trend variation in the groundwater levels at various station during 2010 to 2020.

Blockwise variability and trend analysis of groundwater depth

The variability and trend analysis of groundwater levels in different blocks of the Yamunanagar district have been calculated from 2010 to 2020. The block-wise comparison of groundwater depth has been shown in Figure 7. During the study period (2010-2020), the average groundwater depth of blocks was 4.43m in Bilaspur, 10.95 m in Chhachrauli, 6.58 m in Jagadhari, 19.04 m in Mustafabad, 16.39 m in Radaur, and 6.25 m in Sadhaura. An examination of groundwater depth reveals the deepest groundwater is found in the Mustafabad (19.04 m) and Radaur (16.39 m) blocks, while the shallowest is found in the Bilaspur (4.43 m) and Sadhaura (6.25 m) blocks (Fig. 7). The most negative change in groundwater depth has been found in Mustafabad (2.66 m) block and Jagadhri (1.93 m) block, while the most positive change has been



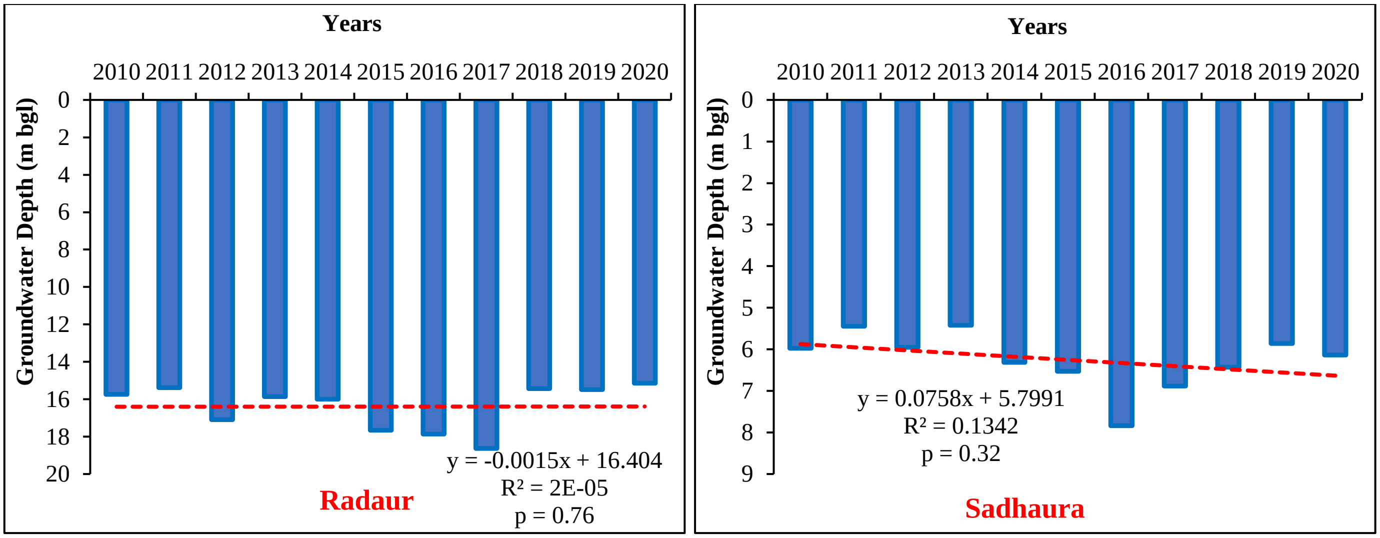


Fig. 7 Block wise trend analysis of underground water level from 2010 to 2020

Table 2 Trend variation in the groundwater levels at various Blocks of the Yamunanagar district during 2010 to 2020

Blocks	MK Z value	Regression p value	Trend	Significance level	Sen’s slope
Bilaspur	0.31	0.96	Increasing	Non-significant	0.074
Chhachrauli	-0.16	0.98	Decreasing	Non-significant	-0.015
Jagadhari	2.02	0.02	Increasing	Significant	0.195
Mustafabad	2.65	0.04	Increasing	Significant	0.359
Radaur	0.00	0.76	Increasing	Non-significant	0.007
Sadhaura	0.93	0.32	Increasing	Non-significant	0.077

observed in Bilaspur (-1.1 m) and Radhaur (-0.6 m) blocks during 2010–2020. The regression and MK trend analysis reveal that a non-significant decreasing and stable trend of groundwater depth has been observed in Chhachrauli, Radhaur, and Bilaspur blocks during the study period. However, a significant increase in groundwater depth has been observed in the Jagadhari and Mustafabad blocks (Table 2). These blocks of Yamunanagar district reveal a negative impact on groundwater levels, and it may be due to excessive use of groundwater in agriculture and industrial activities. The issue has been made worse by adoption of continuous rice-wheat (RW) cropping systems, and crops like sugarcane and the early transplanting of rice in some places (Arora et al. 2005; Machiwaland and Jha 2014). The slope estimator method has been used to compute the slope of the groundwater-level trend line (Table 2). The slope values of different blocks range from 0.015 to 0.359 m/year. However, Sen’s slope values have been revealing the steep decline in water depth of the Jagadhari and Mustafabad blocks from 2010 to 2020. The change in these blocks' average water levels also shows that these blocks experienced a greater increase in water depth over the study period than the other blocks.

Annual average depth and trend analysis of groundwater level

The temporal variability of average annual groundwater levels observed in the Yamunanagar district from 2010 to 2020 (Fig. 8). Annual analysis reveals that the minimum groundwater level has been observed at 9.58 m bgl in 2011 and the maximum depth has been observed at 11.99 m bgl in 2016 (Fig. 9). The water levels range from below 4 m bgl to above 20 m bgl. Similarly, the GIS technique has been used to construct spatial variability maps of average annual groundwater levels based on 11 years of data. (Fig. 8). The average depth of the annual underground water level below ground level has been mapped for 11 years (2010 to 2020) to provide a good picture of the water level on an annual basis. The spatial variability

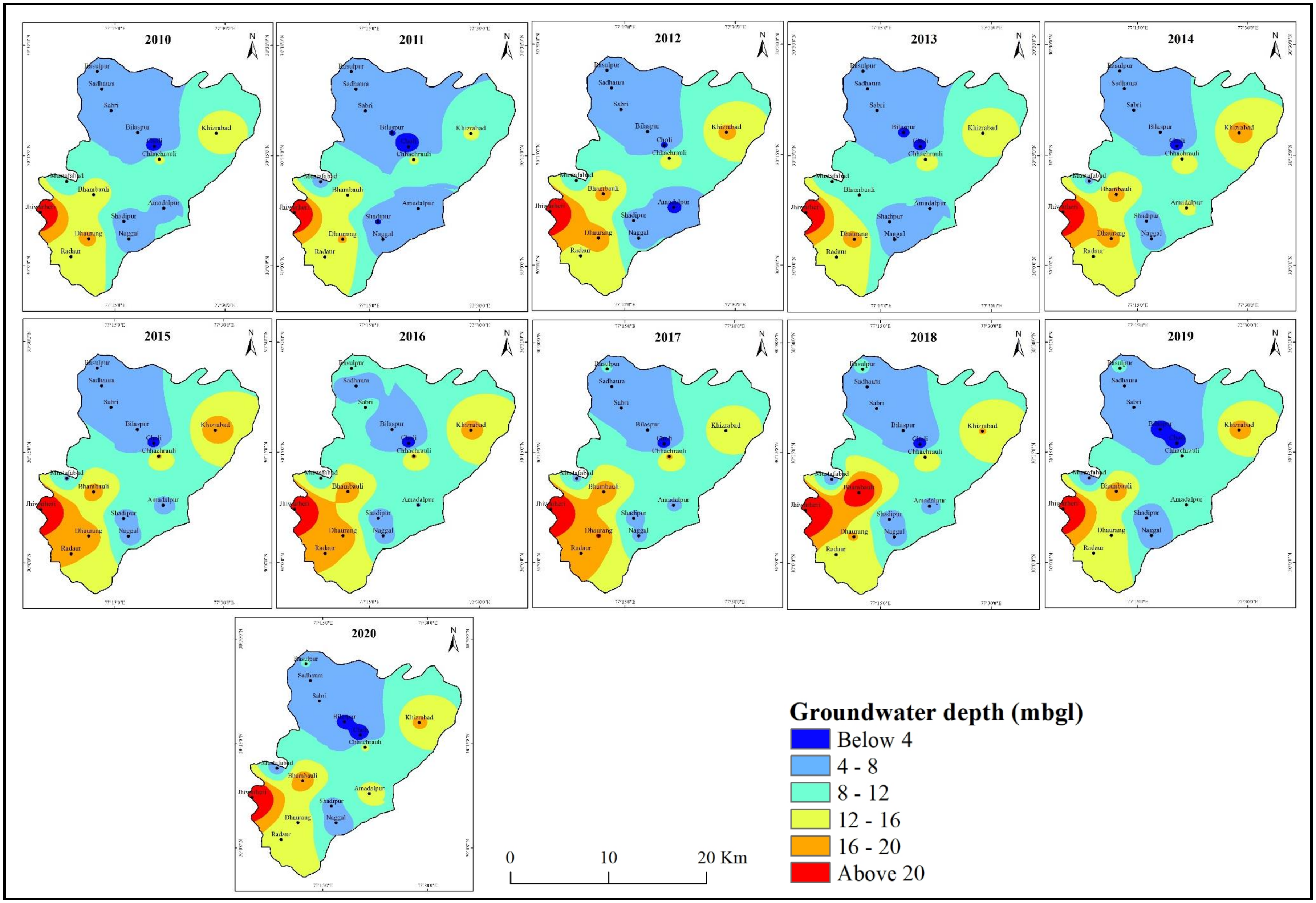


Fig. 8 Spatial variation of average annual underground water level during 2010 to 2020

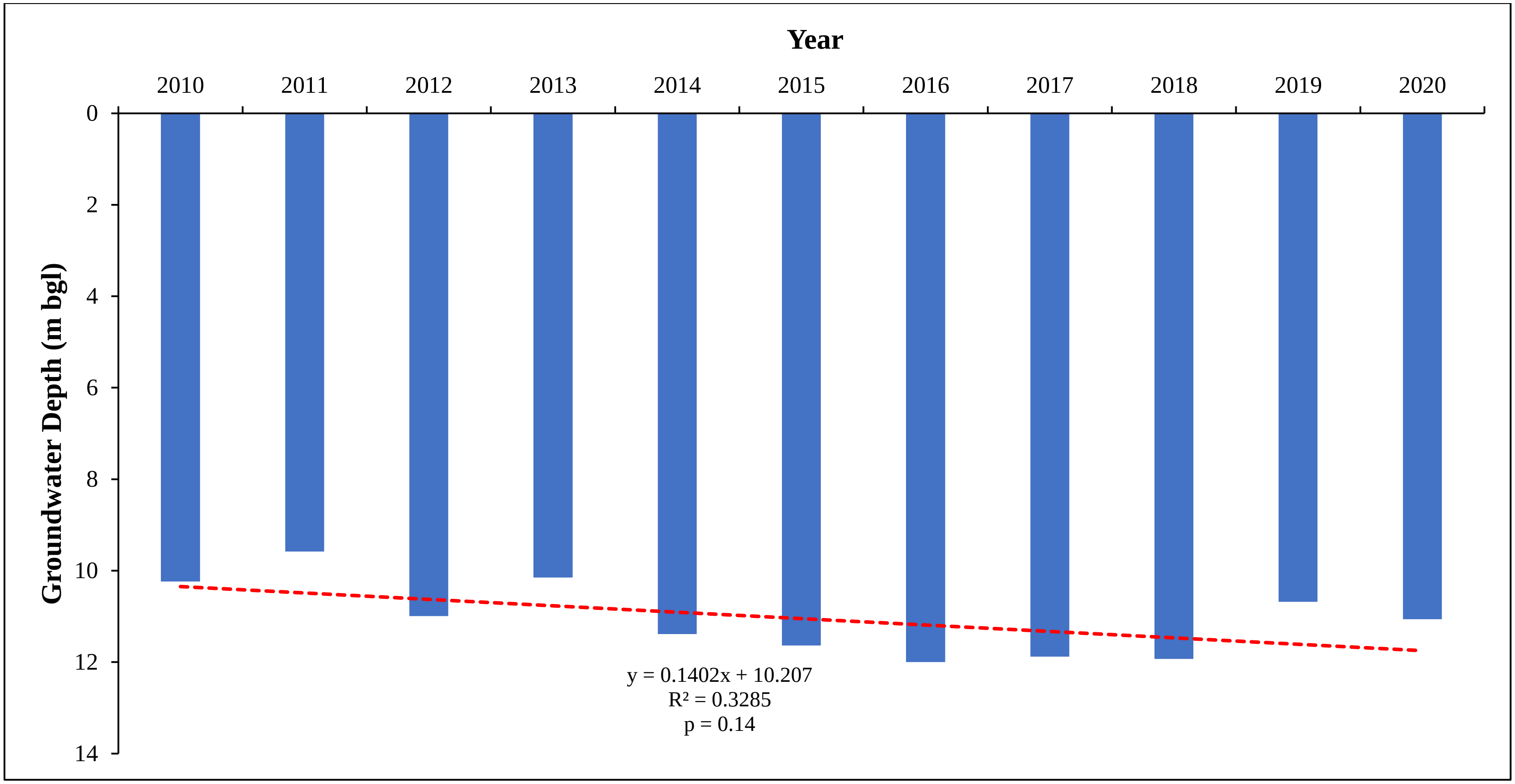


Fig. 9 Average depth and trend analysis of annual groundwater level during 2010 to 2020

maps show that the groundwater level has dropped more than 6 m bgl in the southern region, while less than 4 m bgl variation has been found in the central region of the Yamunanagar district. The annual trend analysis shows an increasing trend has been observed in groundwater levels from 2010 to 2020. The results show the water depth was less than 11 m during 2010, 2011, 2013, and 2019, and the rest of the year has been observed at more than 11 m. The groundwater level in the Yamunanagar district appears to be fluctuating and the depth increasing, and the likely explanation for the fluctuation and increased depth is excessive groundwater consumption in agriculture and industry, as well as variability in rainfall over the research period.

Conclusion

In this study, spatial and temporal analysis of groundwater level has been investigated utilising statistical methods including Mann-Kendall, Sen's slope estimator, and linear regression method for the years 2010-2020. According to the data, 46.7% of wells have water levels over 8 metres, and 53.3% of wells have water levels below 8 metres. According to the spatial variation maps, the southwestern and a small portion of the north-eastern region of the study area have been determined to have the deepest groundwater levels (over 16 m). However, the water level is less than 8 metres in the northern and southern parts of the Yamunanagar district. The centre and northeastern parts of the study area have moderately deep groundwater levels (8 and 12 m). In terms of general groundwater geographic variability, it has been noticed that the northern and central parts of the district's groundwater levels are in good condition; however, the southern part of the district has encountered vulnerable groundwater circumstances. The Mann-Kendall test reveals that 66.6% of the total number of wells has been increasing in water level depth, whereas the remaining 26.6% has been decreasing over the research period. A significant increasing trend has been observed in the Jhiwarheri, Bhambauli, and Basulpur groundwater depths during the study period, and it is due to over-exploitation of groundwater. The annual trend study reveals a rising tendency in groundwater levels between 2010 and 2020. However, block-wise trend analysis also suggests that the depth of the groundwater has been trending significantly in the Jagadhariand Mustafabad blocks. Sen's slope values also suggest that the water depth in the Jagadhari and Mustafabad blocks has increased from 2010 to 2020.

A comprehensive investigation showed that the underground water level in the Yamunanagar district is in a vulnerable state. As a result, groundwater conservation techniques should be implemented in the study area to ensure the safety of human life and the environment. Therefore, in order to ensure its sustainable use, underground water consumption needs to be carefully planned based on an understanding of the behaviour of the groundwater system. Establishing operational organisations and advocating for new standards and recommendations regarding groundwater use is crucial. In order to better regulate extra flood water, artificial groundwater recharge systems can be installed in these low-lying areas. These systems work by allowing excess water to drain into aquifers. To stop groundwater depletion, it is required to establish operational organisations and encourage new standards and rules on groundwater use, such as changing the existing cropping pattern and implementing modern irrigation systems to prevent depletion of groundwater.

Declarations

Confict of interest: There are no conflicts of interest in this study report, authorship, or publishing of the work.

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