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Research Article

Analysing Principal Components Of Physiographic And Non-Physiographic Factors Affecting Groundwater Level In Yamunanagar District, Haryana, India

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ARTICLE INFO **ABSTRACT**

Groundwater management and sustainability are seriously threatened by the spatiotemporal decline in groundwater level. In India's Indo-Gangetic Plains (IGP), intensive agricultural and quick industrial growth has increased the stress on groundwater. In this study, we will examine the variability of underground water and how it relates to physiographic and non-physiographic variables in the Yamunanagar district from 2010 to 2020. The dataset has been used to analyse the spatial, and temporal variations of groundwater levels and their relationship with physiographic and non-physiographic aspects. The results of the study revealed that the northern and centre regions of the district exhibit favourable groundwater conditions. The analysis revealed a notable linear relationship between rainfall variability and fluctuations in the groundwater table. The water demand and groundwater levels show a strong relationship because they are directly related to groundwater extraction. It indicates that the increasing trend of groundwater depth or groundwater stress in the southeastern part of the study region is due to the excess use of water in industrial and domestic practices during the study period. Excessive use of groundwater for agriculture has led to groundwater depletion between 2010 and 2020. To enhance the current fixed irrigation system, it is recommended to advocate for an alternative irrigation system. The findings emphasize the need for adaptation and mitigation methods, standardization of groundwater management regulations, and the need for adequate supervision of well drilling practices. Climate change also plays a significant role in groundwater dynamics.

Keywords: Groundwater, Land use and land cover, Rainfall, Water demand, GIS, Water table fluctuation, Mann-Kendall trend test.

1. Introduction

Water in saturated areas below the soil's surface is referred to as groundwater. It is the most widely used freshwater supply on the planet (Lall et al. 2020). Groundwater sustainability is largely dependent on groundwater recharge, which is "the rate at which aquifers are replenished" (Ajami 2021). The phenomenon of climate change, along with other human activities, exerts a substantial influence on the process of groundwater recharge (Wang et al. 2018). A significant anthropogenic intervention is the changing of land use and land cover (LULC). LULC reflects the features that are spread both naturally and man-made on the surface of the Earth, including vegetation in forests, human structures, and water bodies. (Mahmon et al. 2015). Groundwater is affected by LULC changes via changes in the composition of the water balance (Poelmans et al. 2010, Sun et al. 2018, Wang et al. 2019). There is considerable consensus among academics and governments that the dynamic variability of groundwater levels is also impacted by climate change (Prasad et al. 2008, Senthil & Shankar 2014). Currently, a great number of research have demonstrated that the difficult process of climate change has become a significant factor affecting groundwater resources

(Touhami et al. 2015, Soares et al. 2019, Salis et al. 2019). According to pertinent research findings, climate change is readily affecting groundwater recharge. In particular, climate warming and a decrease in rainfall have been significant causes driving decreasing groundwater levels (Reidel et al. 2012). Groundwater recharge and discharge can balance in the ideal situation (stable climatic conditions, sustainable exploitation rate). If not, many areas of the world are concerned about whether the balance can be maintained. Additionally, groundwater extraction is the main cause of its depletion, and lower rainfall has resulted in declining groundwater levels (Soares et al. 2019, Salis et al. 2019). Groundwater management and sustainability are seriously threatened by the spatiotemporal decline in groundwater level. There are imbalances in groundwater recharge in many parts of the world (Gandhi et al. 2011, Salem et al. 2018).

India is one of the countries that uses the most groundwater globally (Chinnasamy & Agoramoorthy 2015). Groundwater will be less accessible due to rising agricultural, domestic, and industrial demands, which will increase the rate of water level drop. In India's Indo-Gangetic Plains (IGP), intensive agricultural and quick industrial growth has increased the stress on groundwater. The level of groundwater is dropping in certain parts of the IGP. Due to this, shallow drilled and tube wells have dried up and the production of the aquifer has decreased. The exhaustion of groundwater levels is also a result of the rice-wheat cropping system used in the area. Additionally, the agricultural sector uses more than 60% of the groundwater (Hoekstra 2013). Most of India's geographical areas can be classified as having a severe water shortage based on the ratio of annual groundwater availability and withdrawal (CGWB 2014, Poddar et al. 2014). There has been significant groundwater depletion in north and north-western India, according to new research based on Gravity Recovery and Climate Experiment from 2002 to 2008 (Rodell et al. 2009). It has become crucial for water researchers and policymakers to quantify the available water resources for their wise usage given the paucity of available water resources in the near future and its looming risks (Sreekanth et al. 2009). The use of groundwater for agriculture has increased dramatically over the past few decades in many Indian states, particularly Haryana, which is in the northwest of the country (Bhalla 2007, Hira 2009). The level of groundwater has been rapidly dropping in several districts of Haryana. In this investigation, we will examine the variability of underground water and how it relates to climate and human-made variables in the Yamunangar district. In the monsoon season, the Yamunanagar district is renowned for producing export-quality basmati rice, which is followed by wheat in the winter. About 70% of the entire area is watered by groundwater irrigation in the Yamunanagar district. Additionally, groundwater supplies are essential for ensuring food production, particularly in irrigated agricultural areas in dry and semi-arid regions. Therefore, it is important to research how the climate is changing in these areas, where human activity has a big impact on groundwater dynamics.

2. Study Area

The Yamuna Nagar district (YND) is an administrative entity situated in the north-eastern region of the state of Haryana.The geographic area is situated within the latitudinal range of 29° 55' to 30° 31' north and the longitudinal range of 77° 00' to 77° 35' east. 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).

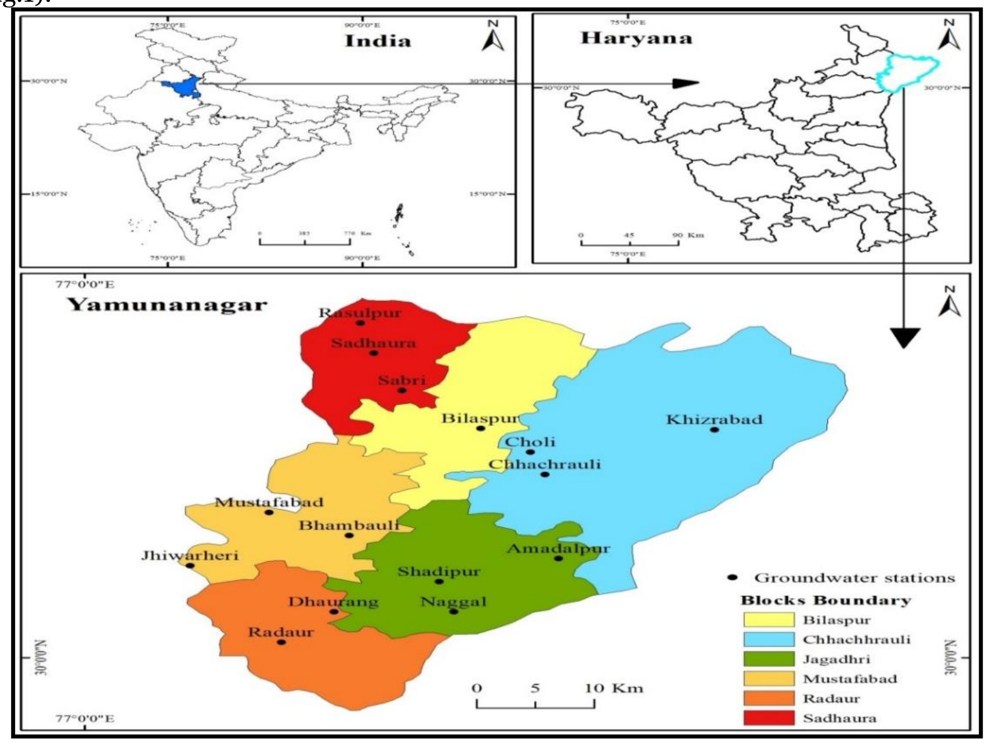


Fig. 1 Location map of the study area

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 YND district exhibits a high population density. According to the 2011 census, the population of the district is recorded as 12,14,205. 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 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. 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. The length of the unlined WJC (Waterway Junction Canal) measures 63.64 kilometres, while the

augmentation canal spans a distance of 22.54 kilometres. The net irrigated area measures 1130 square kilometres, whereas the total irrigated area spans 1860 square kilometres. The proportion of the total planted land that is irrigated is 91.6 percent.

3. Database and Methodology

The objective of this study is to comprehensively evaluate the susceptibility of groundwater to various causes. To achieve this, it is necessary to gather datasets related to hydroclimatic, physiographic, and socio-economic elements. Table 1 presents comprehensive information regarding the data types included in this study, as well as their respective sources. The dataset has been used to analyse the spatiotemporal variations in groundwater levels and their relationship with meteorological, physiographic, and sociological aspects over the Yamunanagar district from 2010 to 2020. The physiographic and climatic parameters were derived from satellite data obtained for the research area. The obtained features include topography, elevation, lithology, and rainfall variability. The elevation and slope maps of the entire district are obtained from the digital elevation model (DEM) of the study region. Further, DEM is used for the creation of district shapefiles, elevation maps, and slope map. In the context of hydrology and agriculture, factors such as the depth to groundwater level during a recent time, lithology, and LULC are taken into account. The LULC concerning water demand also takes into consideration socio-economic aspects. Various statistical methods and trends have been applied in this study to analyse the changing pattern of groundwater level, topography, elevation, Lithology, rainfall variability, LULC, and water demand. The detailed methodology is shown in Figure 2.

Table 1 Shows the different types of indicators, their type and sources used in this study

Sr. No.	Data Type	Source
1.	Rainfall (1901–2019)	India Meteorological Department (IMD) gridded (0.25° × 0.25°, daily) product. https:// www. imdpu ne. gov. in/ Clim_Pred_ LRF_ New/ Grided_ Data_ Download. html
2.	Groundwater data (2019))	Depth to groundwater level data all over India is available at Water Resources Information System (India-WRIS) Portal, Central Water Commission. https:// india wris. gov. in/
3.	Land use/land cover (2019)	Copernicus Global Land Service provides classified LULC maps at 100 m resolution all over the world since 2015–2019 (updated annually). https:// land. coper nicus. eu/ global/ produ cts/ lc
4.	Elevation	Aster digital elevation model (DEM) having 30 m spatial resolution. U.S Geological Survey and Distributed Active Archive Centre (DAAC).
5.	Lithology	Aster digital elevation model (DEM) having 30 m spatial resolution. U.S Geological Survey and Distributed Active Archive Centre (DAAC).
6.	Irrigated area	Irrigation Department Yamunanagar
7.	Water demand	Irrigation Department Yamunanagar

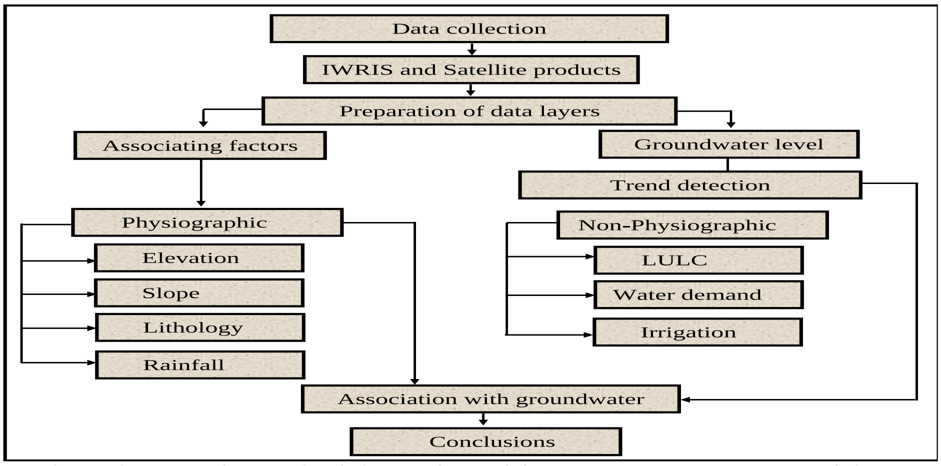


Fig. 2 Flow chart showing the methodology adopted for mapping (extraction) of the groundwater, physiographic and non-physiographic variables over Yamunanagar district, Haryana

4. 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). The acquired water depth data are very limited to a greater degree, thus, the variability of the annual groundwater level has been interpolated with the Inverse Distance Weighted (IDW) technique using the annual groundwater level data of 15 wells. The IDW method shows the values of nearby places along with a measurement of how far they are from the study area (Goyal et al. 2010, Chen et al. 2007). 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. The neighbouring remote points and adjacent points (wells) have an impact on the surface's interpolation and assumption of insertion. It has been found as the best methodology for interpolation research based on the use of multiple inputs to observe groundwater level fluctuations over time and space. In this study, the 15 well-sampling point variables were employed to regulate the impact of adjoint point

5. Trend analysis

5.1. Mann-Kendall (MK) test

A well-known rank-based distribution-free test for looking at long-term data trends is the Mann-Kendall (MK) test. When using multitemporal data for climatological purposes, such as stream movement, water level, rainfall, and temperature, the standard MK test is used to assess the significance of cumulative variations (Mann 1945, Kendall 1975). The MK test proved particularly useful for discovering temporal input trends for the following reasons: (1) It is not necessary to distribute the data routinely (Tabari & Talaee 2011), (2) The information supports multiple explanations for each interval, (3) It enables skipped and changed integers in the sequential data series (Kundzewicz & Robson 2004), and (4) it features low sensitivity discontinuities, because of the heterogeneous time series. The MK test's main benefit is that it typically permits the 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 have been used to identify any downward or upward trends.

5.2. Sen's slope estimator test

Since Sen's slope estimator is dependable, it is utilised to handle the unbiased estimator of trends when the data are severely skewed (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 increasing trend whereas the negative Sen's slope component denotes a decreasing tendency. Over 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).

6. Results and Discussion

Groundwater variability and trend analysis
Spatial variability of groundwater level at different stations

A regional variation map of the average depth of groundwater level has been constructed using data from 15 observed stations (Fig. 3). The study conducted in the Yamunanagar district reveals that the average groundwater level has exhibited a range of 1.78 to 31.91 meters from 2010 to 2020 (Fig. 3).

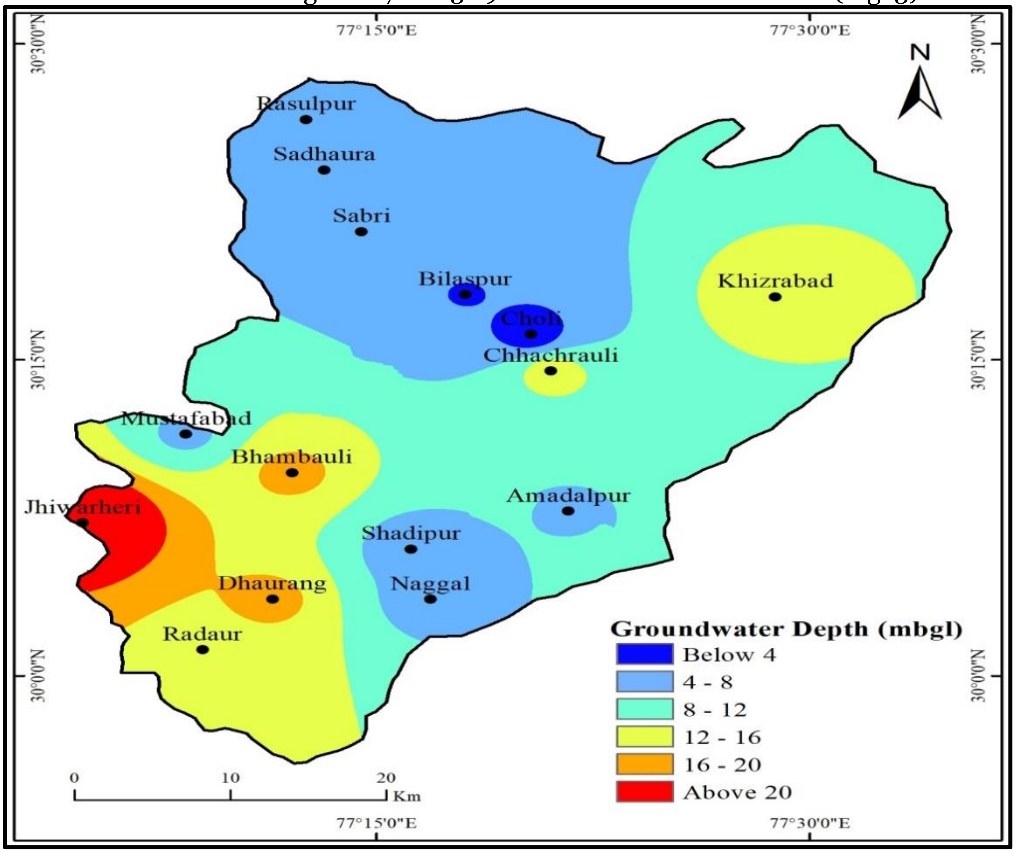


Fig. 3 Spatial distribution of depth to groundwater level over Yamunanagar district from 2001-2020

An analysis of groundwater data indicates that approximately 47% of wells in the Yamunanagar district exhibit groundwater levels over 8 meters, whereas approximately 53% of wells display groundwater levels below this threshold. During the designated period of investigation, the Jhiwarheri station exhibited the highest recorded water depth, while the Choli station experienced the lowest recorded water depth, as depicted in Figures 3. In the research region, the minimum area lies under the water level has been observed below 4 m and over 20 m, while the maximum area lies between 8 to 12 m. The spatial variability maps indicate that the highest groundwater levels, above 16 meters, are primarily observed in the southwestern portion of the research area, with smaller occurrences in the northeastern region. Nevertheless, the water level in the northern, northeastern, and southern sections of the area is below 8 meters. The studied area exhibits a moderate groundwater level depth ranging from 8 to 12 meters in its central and northeastern portions. The comprehensive examination of regional variability in groundwater reveals that the northern and centre regions of the district exhibit favourable groundwater conditions. Conversely, the southern area of the district has a higher degree of groundwater depletion, indicating its vulnerability. The analysis suggests that the southern section of the study area might benefit from the implementation of groundwater conservation measures. The observed fluctuations in groundwater levels in this area may be attributed to the excessive extraction of groundwater for agricultural and industrial purposes, as well as the unequal distribution of rainfall throughout the study period.

7. Trend analysis of groundwater level at different stations

The statistical test results have been validated using the calculation of groundwater level trends in the Yamunanagar district. The Mann-Kendall test was utilised to analyse trends in groundwater level data spanning from 2010 to 2020, with a confidence level of 95% (Fig. 4).

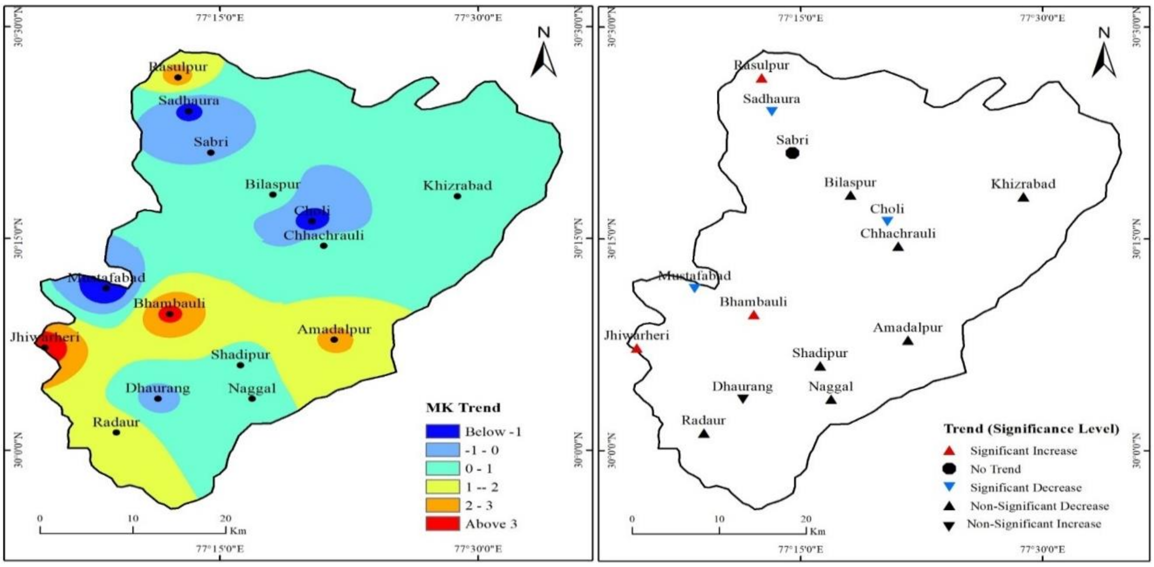


Fig. 4 Trend variation in the groundwater levels at various station during 2010 to 2020

Between the years 2010 and 2020, a notable decline in groundwater levels has been seen in three monitoring wells, namely Sadhaura, Choli, and Mustafabad. This observation serves as evidence that the vicinity surrounding these stations exhibits favourable groundwater levels, hence offering a promising outlook for subsequent periods. A statistically insignificant decline has been detected in Dhaurang. During the research period, a notable upward tendency has been seen in the localities of Jhiwarheri, Bhambauli, and Basulpur. The aforementioned stations exhibit the highest susceptibility within the district in terms of groundwater levels. An upward trend that lacks statistical significance has been noticed in the localities of Bilaspur, Khizrabad, Chhachrauli, Amadalpur, Shadipur, Naggal, and Rahaur. The susceptibility of these areas to fluctuations in groundwater levels within the Yamunanagar district is also evident. The examination of 11 years' worth of data pertaining to subsurface water levels in the Sabri region has revealed the absence of any discernible pattern. This suggests that there has been no significant alteration in the water level within this particular location. The investigation of groundwater trends in the study region, based on data from 15 wells, reveals that 4 of these wells exhibit a falling tendency. This accounts for approximately 26.6% of the total number of wells examined. The declining trend of underground water levels can be attributed mostly to canal irrigation, which involves the utilisation of river water and rainfall. However, a total of 10 wells have exhibited a rising trend, accounting for approximately 66.6% of the overall number of wells. The majority of the Yamunanagar district exhibits a state of vulnerability in relation to groundwater levels from 2010 to 2020. Groundwater plays a crucial role in agricultural practises within the research area and is one of the contributing factors to the observed upward trend. Out of the 15 wells examined, only one well exhibited no noticeable trend, as depicted in Figure 6.

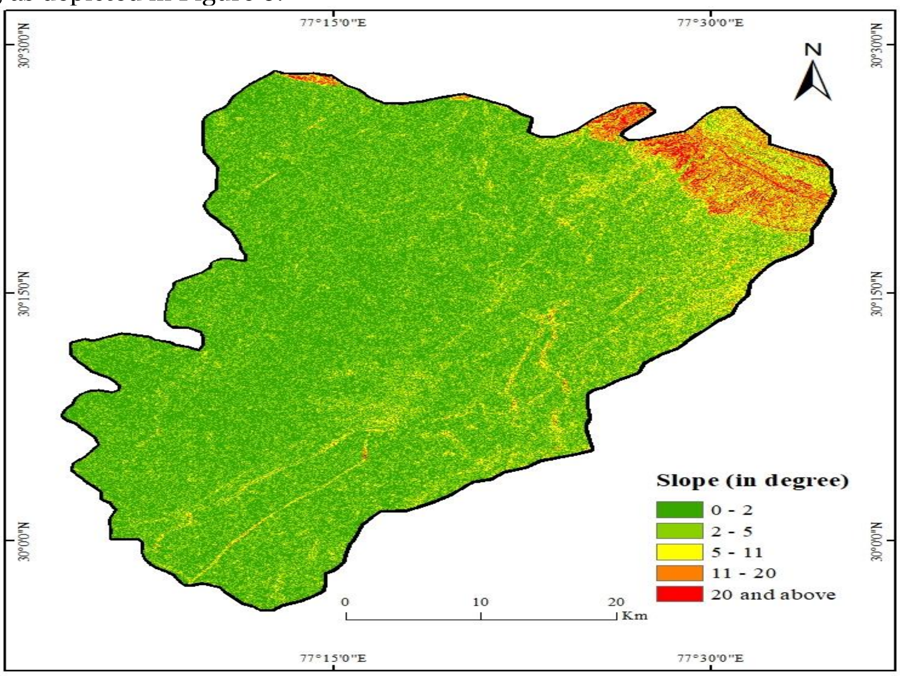


Fig. 6 Classified slope map of Yamunanagar District

A comprehensive examination indicates that the subsurface water level in the Yamunanagar district is currently in a vulnerable condition. Consequently, it is imperative to introduce groundwater conservation measures in the study area to safeguard both human well-being and the environment.

8. Physiographic factors and groundwater

8.1. Elevation zones and groundwater

The elevation zones are an important consideration, from the perspective of the effects of underground water. In general, there is a negative correlation between elevation and water availability, meaning that the higher the elevation, the less water is available. Water tends to flow from higher elevation locations with a high hydraulic head to lower elevation areas with a low hydraulic head because the water table often replicates the natural topography of a given surface. In contrast, low-elevation locations will stimulate water penetration into the subsurface and eventually promote groundwater recharge. High elevation and steep slopes will not encourage surface water infiltration from precipitation. Furthermore, first- or second-order streams predominate in these areas. On the other hand, because of their level topography, lower elevation zones have increased soil moisture retention. These regions are also frequently connected to streams of higher orders, as a result, year-round high flow is maintained. Even though the streams come from high-elevation zones, more areas at the lower elevations contribute to them, which improves their flow. In addition, baseflow in areas with high elevations is frequently lower than in lower levels. Therefore, it can be expected that low slopes and areas with lower elevations are less prone to subsurface water. Surface elevation in the current investigation has been observed from 228 to 642 m above mean sea level. The high-elevation region is mostly found in the form of Shiwalik hills in the N and NE. The study area's elevation generally declines, from the northeast to the southwest. As a result, the Yamunanagar district's elevation is split into 6 classes, each having a 40-meter class interval (Fig. 5).

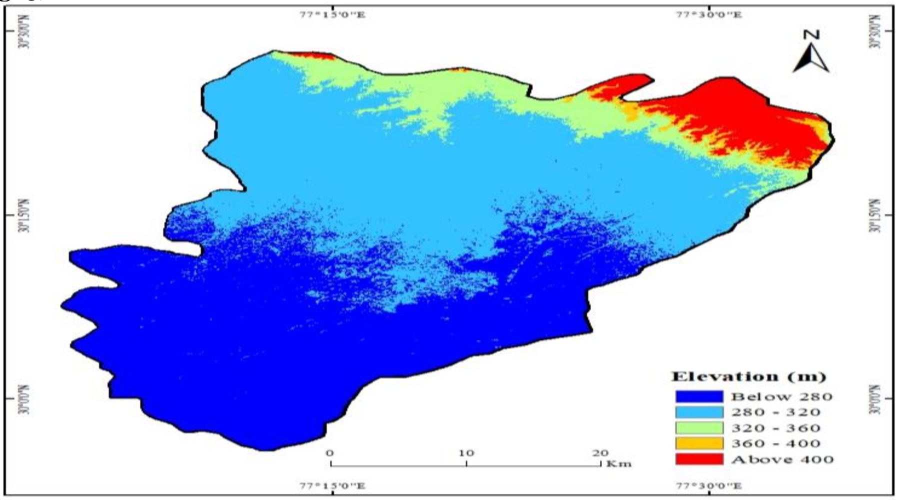


Fig. 5 Classified elevation map of Yamunanagar District

Figure 5 displays the spatial variance in elevation over the Yamunanagar district. In terms of subsurface water depth in the research region, the areas with elevations above 360 m are thought to be the most vulnerable, while those below 280 m are thought to be the least vulnerable. The basin is primarily associated with plain surface (gentle slopes), despite some areas having steep slopes caused by hilly topography.

8.2. Slope and Groundwater

The amount of water that percolates into the ground is greatly influenced by slopes. Therefore, steep slopes are an expression of significant surface run-off, and gentle slopes are an expression of significant percolation of water. The slope map of the study region is displayed in Figure 6. On the map, study regions with steep slopes are denoted by 11 to 20 degrees, which is shown in red colour. The observed landforms manifest as solitary elevations and crests, signifying locations with the highest levels of increased surface water drainage within the selected research region. These features align with a predominant northeast-to-southwest (NE-SW) trend. The potential for groundwater recharge would be notably diminished due to the decreased opportunity for surface water derived from precipitation in these regions to sufficiently infiltrate and permeate into the underlying subsurface. The minimum distribution of the regions with moderate slopes is represented by 5 to 11 degrees (yellow colour). The entire area is covered by regions with gentle slopes, which are indicated by 0 to 5 degrees (green colour). Moderate to gentle slopes will increase groundwater recharge by allowing precipitation-generated surface water to sufficiently penetrate the subsurface. This suggests that there is a much greater likelihood of good groundwater supply on low-lying slopes or gentle slopes. Similar to this, there are five alternative classifications for the slope over the study region: 0 to 2, 2 to 5, 5 to 11, 11 to 20, and over 20 degrees, in increasing order of vulnerability to subterranean water.

8.3. Lithology and Groundwater

Lithology is taken into consideration when determining how vulnerable subsurface water is to contamination because it has the potential to hold onto water. The water retention ability fluctuates with the type of lithology, specifically about the texture of the components. Clay has finer particles than other materials, which allows it to hold more water. The Yamunanagar district classified lithology map is displayed in Figure 7. There are four lithology groups over the study region, viz. (Conglomerate, sand, silt, clay), (Conglomerate, sandstone, silt, clay), (Grey, sand, silt, clay), (Silt, Clay and Micaceous Sand). Clay, Micaceous Sand, Silt, and Conglomerate are the main geological components of the area (Fig. 7).

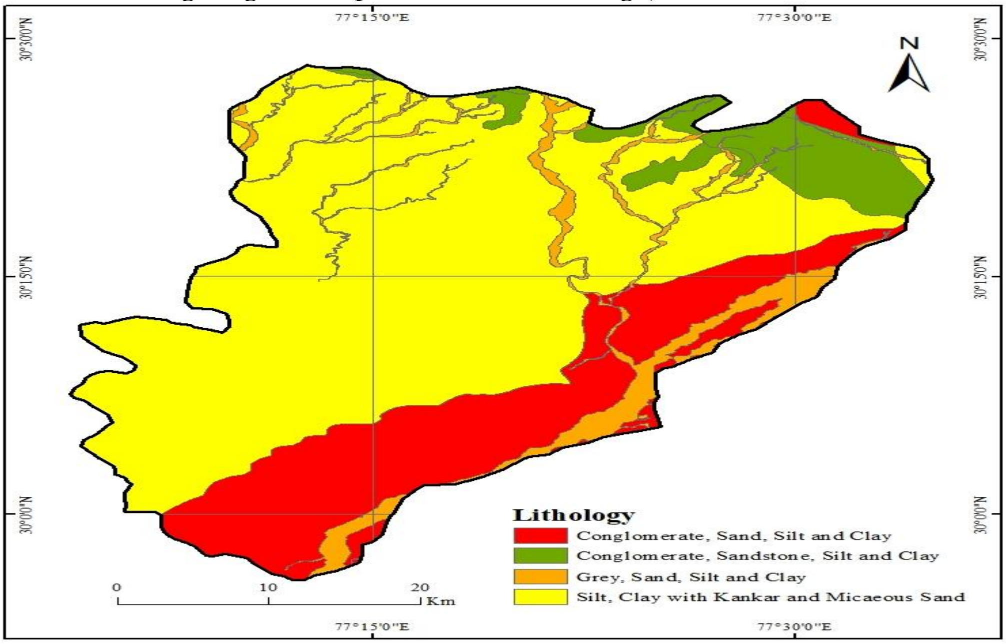


Fig. 7 Classified lithology map of Yamunanagar District

The most prevalent substance and one that has been extensively uncovered in the research region is clay. Clayey soil is most successful at managing subsurface water because of its ability to retain moisture for a prolonged period, which is crucial for providing water to plants and crops in times of water scarcity. Because most of the land has the least vulnerability to underground water, Yamunanagar district is in a suitable state from the perspective of lithology types.

8.4. Rainfall variability and groundwater

Rainfall is known to have a substantial impact on whether the circumstances for subsurface water are worse or better. Figure 3 and 4 shows the spatial variation maps of average groundwater depth and groundwater trend analysis map, whereas Figure 8, 9 and Table 2 shows the spatial variation maps of average rainfall and rainfall trend analysis map, respectively. The total area experienced rainfall ranging from 602 to 1029 mm, with an average of 813 mm.

Table 2 Shows the MK trend and rate of change of groundwater level among different stations during 2010 to 2020

Stations	z value	Sen's slope
Amadalpur	-1.40	-36.59
Bhambauli	0.00	4.19
Bilaspur	0.31	11.69
Chhachrauli	-1.40	-36.59
Choli	0.31	11.69
Dhaurang	0.00	4.19
Jhiwarheri	0.00	4.19
Khizrabad	0.31	11.69
Mustafabad	0.00	4.19
Naggal	-1.40	-36.59
Radaur	0.00	4.19
Rasulpur	-1.40	-18.86
Sabri	-1.40	-18.86
Sadhaura	-1.40	-18.86
Shadipur	-1.40	-36.59

According to the study of rainfall variability, the north-eastern region experiences average rainfall above 900 mm, whereas the north-western and south-eastern regions experience average rainfall below 750 mm (Figure 8).

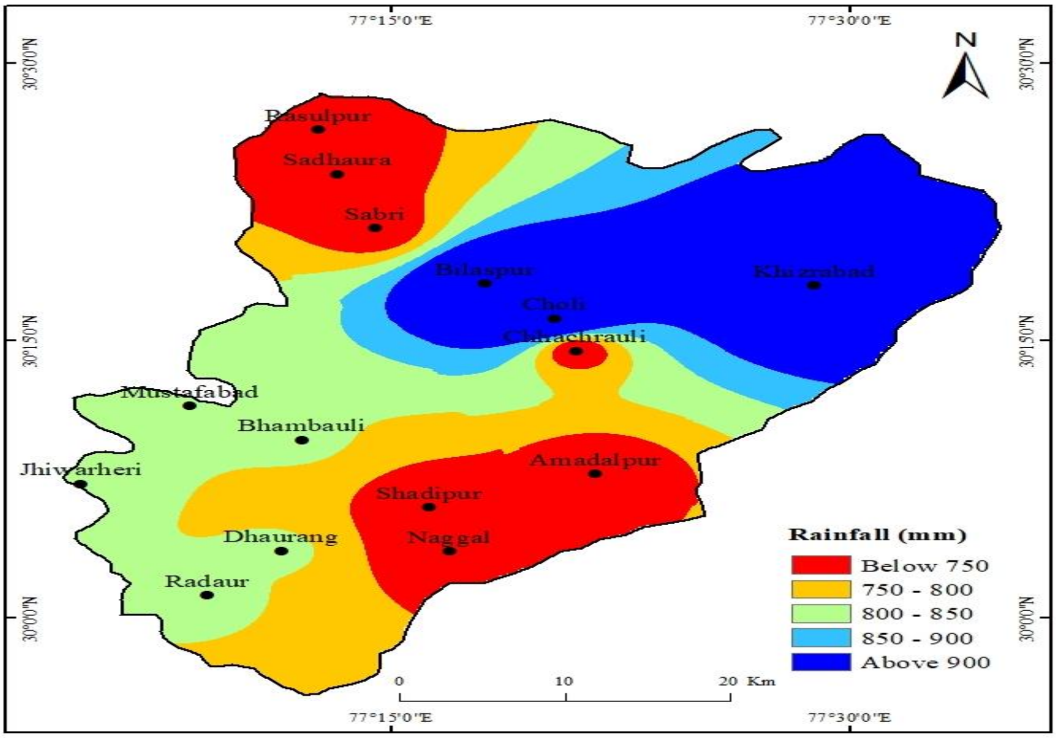


Fig. 8 Spatial distribution of rainfall over Yamunanagar district from 2001-2020

The north-eastern part of the study region (Choli and Khizrabad) shows an increase in trend rainfall over the study period, in contrast to the south-east and north-west parts of the district (Rasulpur, Sadhaura, Sabri, Chhachrauli, Amadalpur, Shadipur, and Naggal), which found a decreasing trend (Fig. 9). During the study period, low-rainfall years occur more frequently. Additionally, the -9.79-slope score indicates a decreasing pattern in rainfall as indicated by the Sen slope analysis.

Throughout the research period, rainfall is gradually increasing in the northeastern regions. Contrarily, the region still has average depths of water that are very deep, and researchers have discovered an increasing trend in groundwater depth, despite an increase in rainfall over time (Fig. 9).

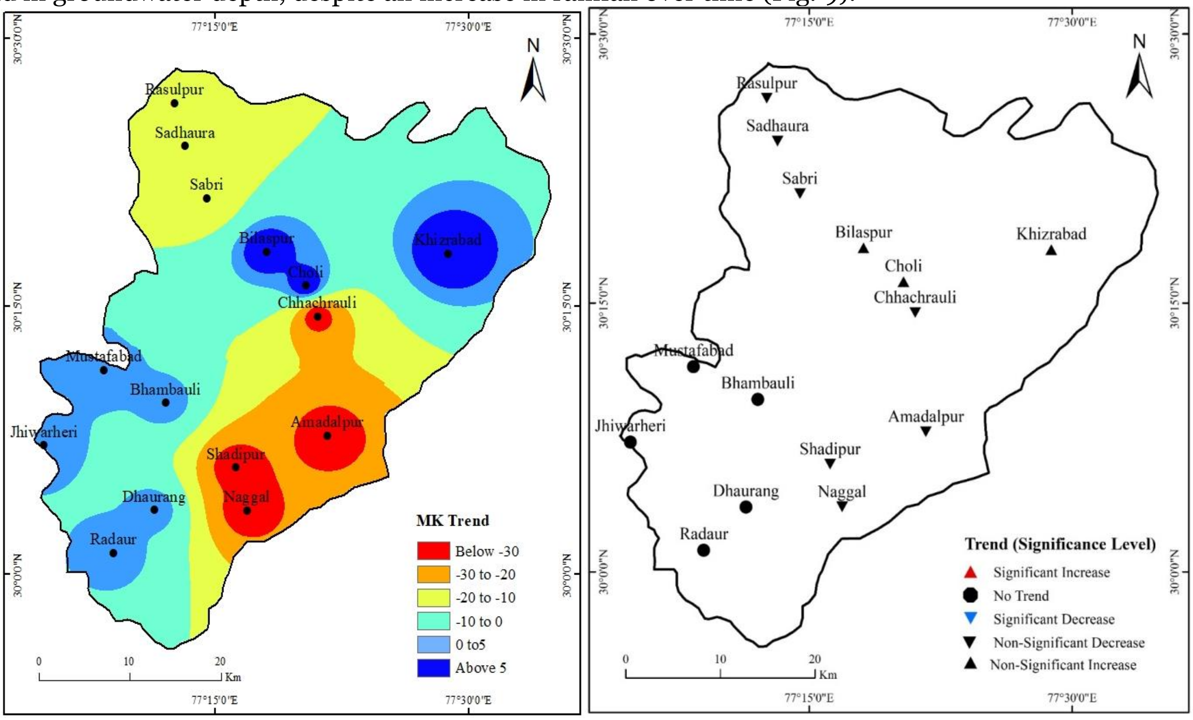


Fig. 9 Rainfall trend variation at various station during 2010 to 2020

This suggests that a significant amount of rainfall is lost as runoff due to the large intensity of rainfall with the effect of slope pattern due to the Himalayan foothill's region and pattern of hard terrain. A small amount of rain over a long period can cause more of a change in groundwater levels than a huge amount of rain over a short amount of time. As a result of the potential for heavy rainfall, this area needs to create big water collection systems. To meet water needs even during the hottest part of the summer, trapped runoff would help recharge groundwater.

In contrast, the north-western and south-western regions must install water harvesting structures to replenish the groundwater, which show a decreasing trend in rainfall and noticeably increasing depth of groundwater level. An increase in the likelihood of dry years or more opportunities to stress subsurface water can be inferred from a downward trend in yearly precipitation. Consequently, there may be a significant correlation between rainfall variability and the depth of subsurface water during the study period. Therefore, it appears that due to the trend of diminishing rainfall, these areas will be susceptible to subsurface water in the future. This indicates a rise in the water, which indicates that groundwater does get replenished following rains. This might be because the northern part of the research region has Himalayan foothills, which lack a gradual slope and prevent rainwater from recharging the deeper aquifer zones. The existence of steep to mild slope terrain in the area, which prevents water from penetrating the deeper aquifer zones, may be the cause of a pattern seen in the current study.

8.5. Non-physiographic Factors

Non-physiographic features have been generated using data from secondary sources from the research region. Water demand, irrigation, and LULC are among the parameters that have been included in this analysis.

8.6. Land use/Land cover and Groundwater

A crucial factor affecting the groundwater depth is land use and land cover (LULC). It is also regarded as a mark of a region's anthropogenic activities. Understanding the response of the study region to various hydroclimatic conditions requires an understanding of LULC. Additionally, it has a direct connection to the regional diversity in water demand. Regarding land use, it is anticipated that places with a high concentration of agriculture will experience the greatest groundwater stress, followed by residential and industrial sectors. Similarly, to this, places with vegetation cover and water bodies are better for groundwater levels due to maximal recharge rather than consumption of groundwater, from the perspective of land cover. Given that the vast majority of Indians rely on agriculture as their primary source of income. An important socioeconomic indicator for evaluating groundwater is LULC. The LULC classification of the Yamunanagar district is presented in Figure 10 and Table 3.

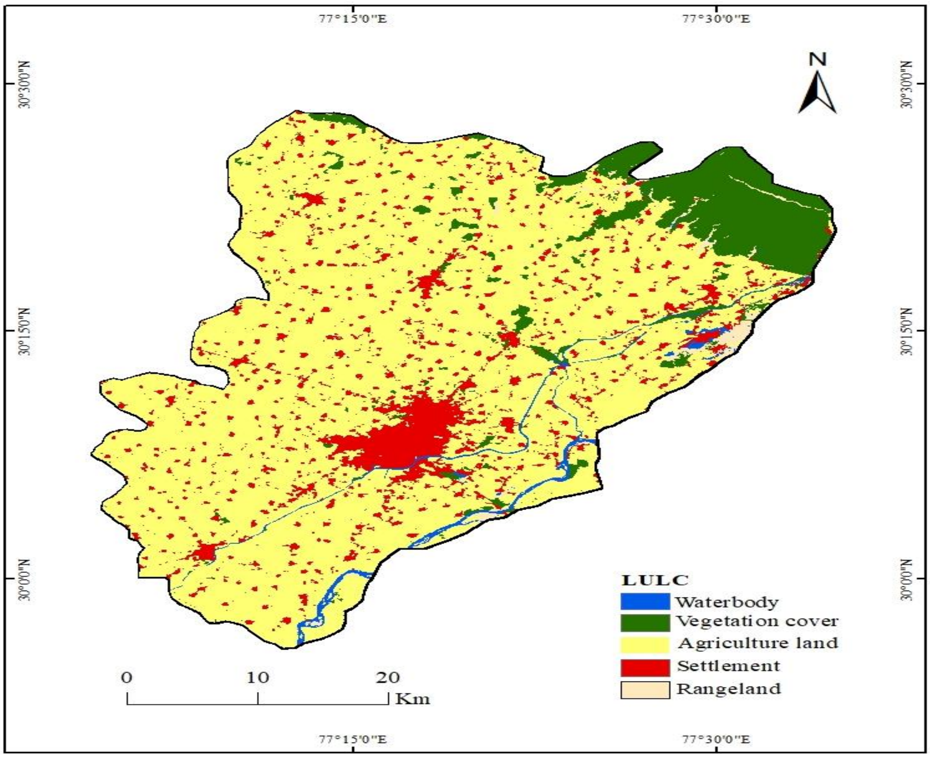


Fig. 10 Classified LULC map of Yamunanagar District

Table 3 Land use and land cover analysis of Yamunanagar district from 2010 to 2020

Category	Area (%)
Waterbody	1.36
Vegetation Cover	9.30
Agriculture Land	77.86
Settlement	10.40
Rangeland	1.08
Total	100

Over the research region, there are five LULC classes: agricultural land (77.86%), settlement (10.40%), vegetation cover (9.30%), range land (1.08%), and water bodies (1.36%). Table 3 lists the percentage of each class's study region's area. A large portion of the research area (77.86%) is made up of agricultural fields, which are particularly vulnerable to changes in groundwater level. Because residential, industrial, and agricultural operations have all used groundwater to varying degrees. Therefore, we can conclude that the Yamunanagar district's groundwater stress is primarily caused by the agriculture sector. The northeastern part of the research area had the most vegetation cover, a rising tendency in rainfall, and a falling trend in the depth of the groundwater. In the northeastern part of the Yamunanagar district, the groundwater is in good condition mostly due to rainfall and tree cover.

8.7. Irrigated area and Groundwater

The Yamunanagar district has a gross irrigated area of approximately 2,48,570 hectares, or 130% of the total geographical area. In the study region, the blocks of Chhachhrauli (21.7%) and Jagadhri (20%) have been observed as having the most net irrigated area (Table 4).

Table 4 Irrigation based classification of Yamunanagar district

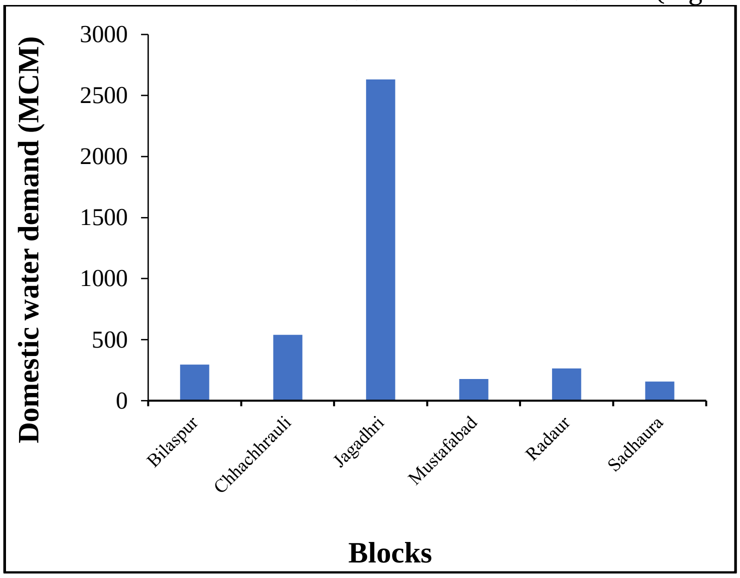
Block	Gross Irrigated Area (%)	Net Irrigated Area (%)
Amadalpur	-1.40	-36.59
Bilaspur	18.8	15.1
Chhachhrauli	19.7	21.7
Jagadhri	19.2	20.0
Saraswati Nagar	18.4	15.5
Radaur	17.5	19.3
Sadhaura	6.10	8.10
Total	100	100

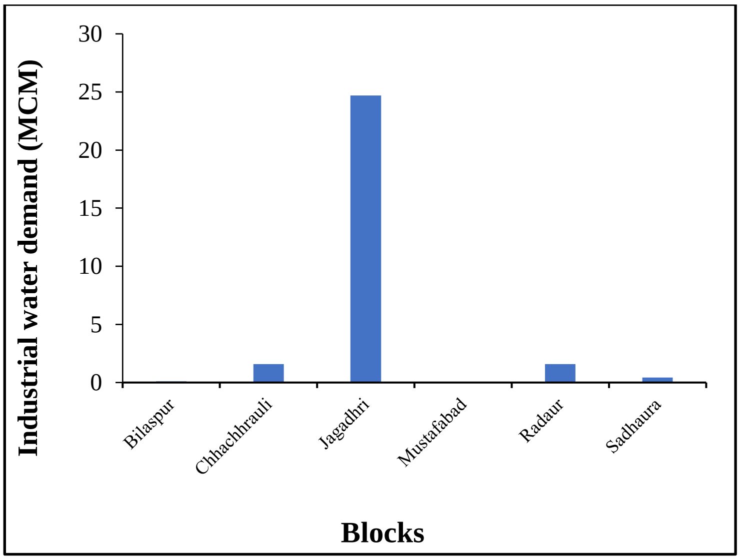
These blocks represent excess groundwater being used for irrigation purposes and are related to groundwater stress, which shows an increasing trend in groundwater depth throughout the study period (Fig. 4). The Sadhaura block (8.1%) has the lowest net irrigated area, indicating that there is very little groundwater stress in that area. This is also where the groundwater trend has been observed to be drastically dropping. In the research area, over time, there has been a direct correlation between groundwater variability and irrigated area. The groundwater depletion in the Yamunanagar district between 2010 and 2020 is attributable to the extreme use of groundwater for irrigation practices. However, the findings of this study will assist planners and policymakers in better managing water resources and LULC. Advanced irrigation techniques, as well as transitioning from the current cropping design that uses a lot of water to one that uses less, should be adopted.

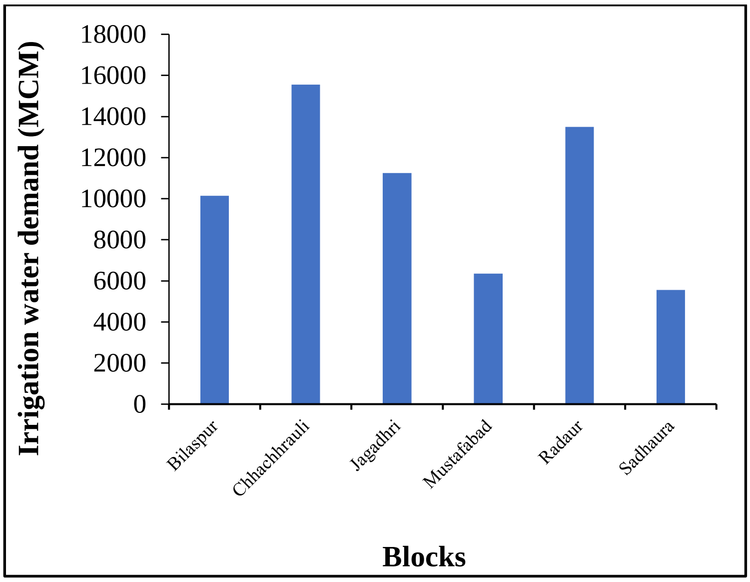
8.8. Water demand and Groundwater

The agricultural practices and industries of Yamunanagar are highly renowned. It has become a significant agricultural and industrial hub in the state. This has occurred, although it is quite remote from the rest of the state. The city manufactures equipment for petrochemical plants, sugar mills, paper mills, and highly effective equipment for sugar refineries, all of which are exported to various refineries across the nation. Due to the simple availability of the main raw material, poplar trees, the Yamunanagar district is also well known for its plywood manufacturing. It also contains one of the biggest repair shops for railway waggons and carriages in all of India. Due to expanding agriculture and industries, groundwater stress has increased due to the use of groundwater for industrial and domestic purposes, leading to an increasing number of immigrants and an increasing population. Block-wise water demand analysis reveals that the maximum water demand is found in the Jagadhri block, whereas the minimum water demand is found in Mustafabad, followed by Sadhaura (Fig. 11). The groundwater trend analysis observed an increasing trend in the water depth where the water demand is maximum and vice versa (Fig. 4). It indicates that the increasing trend of groundwater depth or groundwater stress in the Jagadhri block is due to the excess use of water in industrial and domestic practices during the study period.

The total water demand and irrigation water demand analysis has found maximum in the Chhachhrauli and Radaur blocks, whereas it is minimum in the Mustafabad and Sadhaura blocks (Fig. 11).







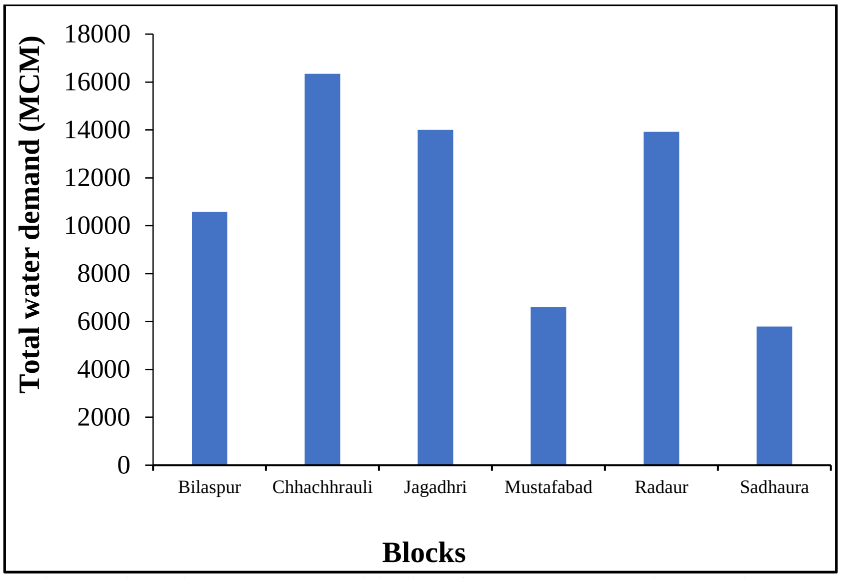


Fig. 11 Water demand analysis at various blocks of Yamunanagar district during 2001 to 2020

This study demonstrates that the variation in water demand in the study area has a considerable influence on groundwater depth fluctuations. Overall, the Mustafabad and Sadhaura blocks have a substantial declining trend in groundwater depth (Fig. 4), and they had the lowest water demand. Water demand and groundwater depth changes were shown to have a substantial linear connection. It seems that the Mustafabad and Sadhaura blocks have a bright future in the context of groundwater.

9. Conclusion

The results of the investigation of the physiographic and non-physiographic factors influencing groundwater levels in the Yamunanagar district demonstrated that both types of factors influenced changes in groundwater levels. Regarding individual factors, clay is the most common material that has been found in abundant amounts in the study region. Clayey soil exhibits a higher capacity for moisture retention over an extended period of time, making it particularly beneficial in managing subsurface water. Therefore, considering the lithology types, it can be concluded that Yamunanagar district is in a favourable state, as the majority of the area exhibits minimal susceptibility to groundwater. The Yamunanagar district is predominantly characterised by flat slopes, while certain areas exhibit steep slopes as a result of hilly topography. Conversely, the susceptibility of soil and slope to subsurface water is comparatively lower across the majority of the regions under investigation. The analysis revealed a notable linear relationship between rainfall variability and fluctuations in the groundwater table. The north-western and south-western regions, which exhibit a decreasing trend in rainfall and a significantly increasing depth of groundwater level, have to develop a water harvesting structure to recharge the groundwater. Land use and land cover analyses reveal that the majority of the study region is covered by agricultural lands (77.86%), which are most vulnerable to groundwater levels. Because maximum use of groundwater has been employed in agriculture activity, followed by industry and residential activities. The water demand and groundwater levels show a strong relationship because they are directly related to groundwater extraction. It indicates that the increasing trend of groundwater depth or groundwater stress in the southeastern part of the study region is due to the excess use of water in industrial and domestic practices during the study period. Hence, the western part of the study region experienced a significant decreasing trend in groundwater depth due to minimum water demand and sufficient rainfall. There is no denying that the extraction of groundwater has a substantial influence on the alteration of groundwater level distribution. The primary factor contributing to the depletion of groundwater in the Yamunanagar district between 2010 and 2020 is the excessive utilisation of groundwater for agricultural purposes.

Furthermore, it is important to conduct further research on the impact of local hydrogeology, topography, planning structure, and water intake priority on groundwater recharge. These aspects should not be overlooked, as they play a significant role in understanding this process. The findings underscore the necessity of promptly addressing the development of adaptation and mitigation methods within the study area. Additionally, there is a need for further standardisation of groundwater management regulations. To enhance the current fixed irrigation system, it is recommended to advocate for an alternative irrigation system. This involves minimising dependency on well irrigation during seasons of sufficient precipitation while increasing the diversion of water during dry periods. Additionally, it is essential to implement adequate supervision of individual well drilling practices to mitigate excessive extraction of groundwater. In addition, groundwater managers need to take into account the substantial effects of climate change on groundwater dynamics. These dynamics serve as crucial indicators that reveal alterations in groundwater levels.

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