Temporal and Spatial Analysis of Groundwater Level Variations in Agra District using GIS Techniques

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ABSTRACT

Background: The Geographic Information System (GIS) technique plays an important role in groundwater estimation. Hence, this study employs GIS techniques within ArcGIS 9.3 Software to investigate the Spatio-temporal variations in groundwater levels across the Agra district of Uttar Pradesh, India.

Methods: Utilizing data from 129 piezometer wells obtained from the National Institute of Hydrology at Roorkee, the research covers pre-monsoon and post-monsoon seasons spanning the years 2017 to 2020. Multiple topographic and spatial maps were generated to illustrate the groundwater level variations in different subdivisions of the Agra district.

Result: The results reveal significant fluctuations in subsurface water levels among various sections of the district, with a noticeable but not alarming overall decline. The pre-monsoon groundwater levels show a consistent decrease, from 16.98 meters below ground level (mbgl) in 2017 to 26.27 mbgl in 2020, growing at a mean annual rate of 3.58%. Similarly, the post-monsoon groundwater levels declined from 15.23 mbgl in 2017 to 25.84 mbgl in 2020, with a mean annual growth rate of 3.34%. A comparative analysis indicates higher pre-monsoon groundwater levels from 2017 to 2020 than their post-monsoon counterparts. These findings raise concerns regarding the availability of groundwater resources in the Agra district.

Key words: Geographic information system, Groundwater, Piezometer, Pre-monsoon, Post-monsoon seasons, Spatial maps, Topographic maps.

INTRODUCTION

India is endowed with several natural resources, especially water (Ibrahim *et al*., 2020). Water is regarded as the element most crucial to the continuation of life (Xiao *et al*., 2015). The aquifer is a term for a fragment of rock or an amorphous deposition that may hold plenty of water. The aquifer is a term for a fragment of rock or an amorphous deposition that may hold plenty of water. The water table is the level at which most of the cavities, rock fractures and voids in the soil are completely saturated with water (Eldrandaly, 2013). Natural discharge occurs when groundwater is replenished below and eventually runs to the surface. It typically takes place at springs and leaks and may produce oasis or wetland environments (Xia and Dong, 2016).

Groundwater is expressed and stored in an aquifer, a layer of transparent substrate. When water may flow freely under the surface and the saturation zone, the aquifer is unconstrained. Interiors of unconfined aquifers are typically more saturated because gravity causes water to flow downhill as shown in Fig 1 (Balasubramani *et al*., 2019). The water table, or phreatic surface, is the top layer of this saturated layer in an unconfined aquifer. The phreatic zone is located below the water table, where the bulk of the pore spaces are saturated with water (Shrivastava, 2022 and Jaiswal *et al.,* 2019). The groundwater's pace of movement is controlled by the hydraulic gradient. The majority of the groundwater comes from precipitation that infiltrates downward from the land surface (Singh and Kasana, 2017).

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Water travels downhill from water on the surface to the subsurface by hydrologic processes such as groundwater recharge, subsurface drainage, or persistent percolation. The primary way rainwater into an aquifer is via recharge (Arya *et al*., 2018). This process frequently manifests as a flux to the water table slope in the vadose region, which is found underneath root systems as shown in Fig 2. Whenever precipitation and/or reclaimed water are applied to the earth, both naturally occurring recharge are referred to as artificial groundwater recharge (Samanta *et al*., 2011). GIS methods are frequently employed currently for assessing

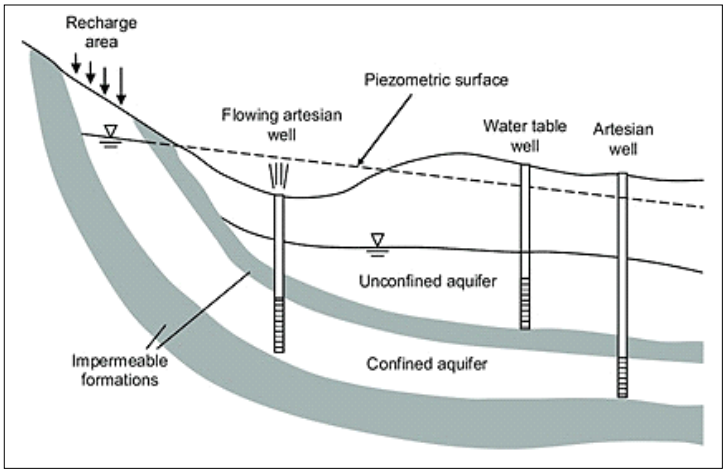


Fig 1: Groundwater aquifers visualization below the ground level (France, 1981).

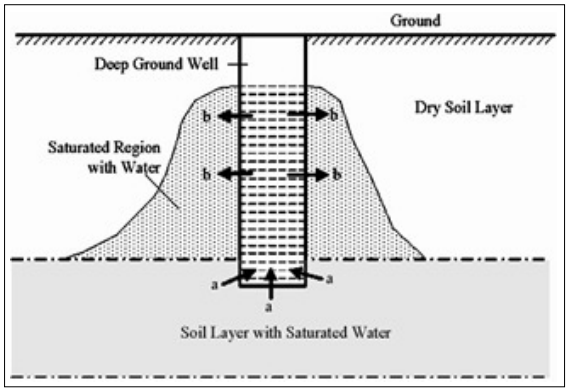


Fig 2: Groundwater movement sketch diagram (He *et al.*, 2005).

groundwater resources (Magesh and Chandrasekar, 2013).

GIS is an instance of software that collects, controls, stores, manipulates and exposes geographical or geographic data. GIS technology is a field of study that provides geographic concepts, applications and systems (Thakur *et al.,* 2021). By employing location as the primary key variable, GIS may link disparate data sets together. Dates and times that include the longitude, latitude and elevation's x, y and z coordinates can be used to record locations (Al Kuisi and El-Naqa, 2013; Zhu *et al*., 2018).

The existing literature underscores the considerable regional variability in groundwater, encompassing both shallow and deeper levels (El Mountassir *et al*., 2022) (Khan *et al*., 2015). This spatial heterogeneity, often denoted as "spatial variability" (Samanta *et al*., 2011), underscores the need for a nuanced understanding of groundwater dynamics (Shrivastava, 2022 and Jaiswal *et al.,* 2019). Moreover, groundwater levels exhibit temporal fluctuations, a phenomenon referred to as "temporal variability." Notably, the ground water variations in Agra district from 2007 to 2015 describes that the ground water level varies from 32.67 mgbl to 20.44 mgbl which is a declining trend due to the passage of Yamuna River basin and high recharge of surface water to groundwater in sandy soils across Agra district. From the year 2016 there was a rapid climate change occurred all over U.P state among all other districts Agra district becomes most densely populated district in the state due to urbanization. Moreover in 2016 Agra district was suffered for water crisis due to water pollution (Babiker *et al*., 2007; Biswas *et al*., 2018). In agricultural perspective the farmers vigorously shifted their cultivation towards water-intensive crops like rice and sugarcane (Montealegre *et al*., 2015). All these factors will directly affect the ground water level. For future reference, evaluate if the ground water level was alarming or adequate, in addition to find out how the aforementioned parameters influenced the ground water level. The present investigation evaluated by collecting of ground water data from years 2017 to 2020 in pre and post monsoon seasons for comprehensive assessment of magnitude of both spatial and temporal variations in groundwater levels specifically within the Agra district of Uttar Pradesh.

Addressing this gap, our study pioneers a novel approach by leveraging GIS technology to create extensive layers for groundwater level assessment (GWL). We establish robust databases for GWLs, meticulously capturing the pre- and post-monsoon fluctuations both spatially and temporally over a four-year period (2017-2020). The outcome is a series of spatial and temporal maps illustrating the nuanced variance in groundwater levels across the Agra district. The uniqueness of our contribution lies in the synthesis of spatial and temporal analyses, providing a holistic understanding of groundwater dynamics, a facet hitherto underexplored in the existing literature.

In essence, our research not only addresses a critical research gap but also introduces a novel methodology for the comprehensive assessment of groundwater dynamics. The comparison of spatial and temporal analyses derived from the piezometric wells data which is coupled with advanced GIS technology, positions our study at the forefront of ground-water research, offering valuable insights for groundwater levels management in the Agra district and beyond.

MATERIALS AND METHODS

Study area

The investigation into spatial groundwater level variance is centered in the Agra district in Uttar Pradesh, India. Geographically, the district extends between latitudes 27.17° north and longitudes 78.01° east (Fig 3). Agra is subdivided into 6 Tehsils and 15 administrative Blocks. The agrarian landscape supports the cultivation of major crops such as wheat, paddy, bajra, mustard and potato (Singh *et al*., 2015). This comprehensive depiction encapsulates the geographical and administrative nuances of the Agra district, forming the crux of our investigative purview. The study area, base map and georeferenced map of the selected area are shown in Fig 3, 4 and 5.

The piezometric readings from the selected locations of Agra district was used for the analysis of variation in groundwater levels in the particular study area. These obtained data were utilized for the derivation of spatial maps using the Arc GIS software and based on the maps the trend of groundwater levels was determined. The utilization of data from 129 piezometer wells, spanning the study duration, ensures a comprehensive and representative examination of groundwater levels. The integration of ArcGIS 9.3 software, housed at the Centre of Excellence for Advanced Groundwater Research (CEAGR), National Institute of Hydrology (NIH), Roorkee, further underscores the scientific rigor employed in this endeavor.

Yamuna river basin

The total length of the Yamuna River passing over the Agra district from Table 1, in ArcGIS is 242.48 km. Agra district the Yamuna River flows through through the blocks Achanera, Bichpuri, Khandauli, Shamshabad, Pinahat, Bah and Jaipur Kalan (Rathee and Mishra, 2023). The area of the blocks is given in Table 1.

There are three main components of ArcGIS 9.3 for desktops. ArcCatalog, ArcMap, Arc Toolbox (Xiao *et al*., 2015). The process flowchart of Spatiotemporal variation of groundwater levels in the Agra district by Arc GIS 9.3 software is shown in Fig 6.

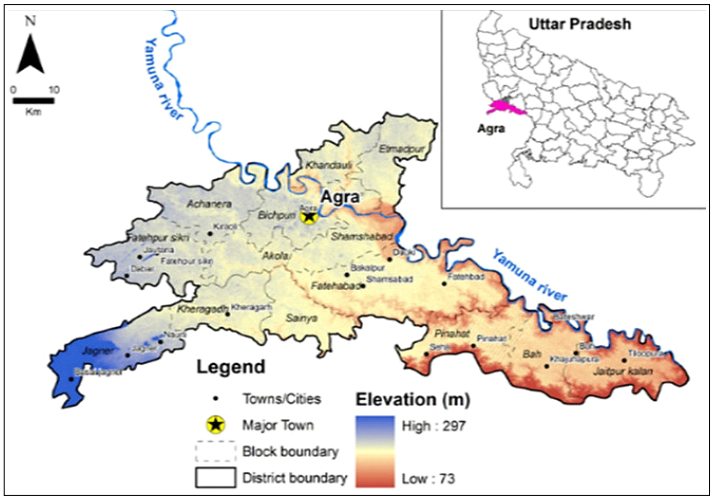


Fig 3: Study area map of Agra district showing Yamuna River and variation of ground elevation.

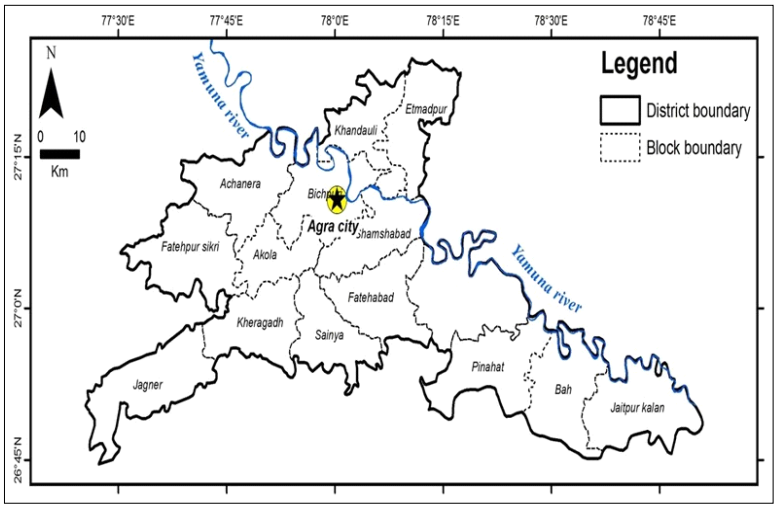


Fig 4: Base map of Agra district showing Yamuna River and various blocks.

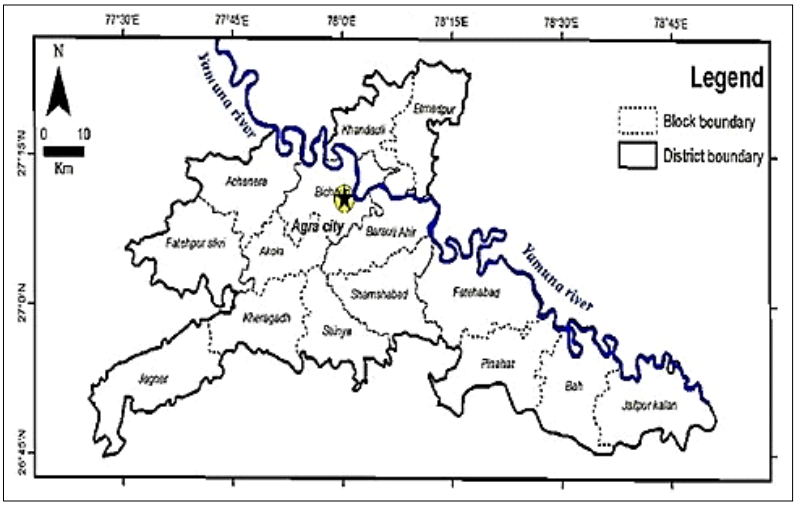


Fig 5: Georeferenced map of the Agra district showing Yamuna River and various blocks.

Table 1: Attribute table of Agra blocks.

Block name	Area (km^2)
Akola	171.25
Sainya	220.65
Kheragadh	247.5
Jagner	315.3
Fatehpur Sikri	315.44
Achanera	290.36
Bichpuri	282.11
Khandauli	211.22
Etmadpur	225.83
Barauli Ahir	231.9
Shamshabad	264.43
Fatehabad	360.74
Pinahat	289.6
Bah	277.47
Jaipur Kalan	301.62

ArcGIS 9.3.

Materials required for creating a DEM (Digital Elevation Model)

Raster map (paper), georeferencing, digitizing, ground survey (GPS data), points, lines (counters), interpolation, digital elevation model, counters from DEM, change projections, clip, merge, split features (Elkhrachy, 2018). This procedure and polygon shape files of the district and blocks boundary with the passage of the Yamuna River basin are shown in Fig 7(a, b, c and d).

The piezometer locations are given in Table 1 in the supplementary file. The piezometer data available was added to the boundary map of the Agra district as shown in Fig 7a, to get the locations of the piezometer and the point shape file. The various piezometer observation location points in the Agra district are shown in Fig 8.

Ground water level data

Groundwater level data as a part of the groundwater survey, the groundwater depths are recorded by using the piezometer. Two seasons (Pre- and post-monsoon) in a year are used to record the data on groundwater levels that are accessible. The amount of rainfall that season makes an impact on the groundwater depth. Groundwater level data for each piezometric location of the Agra district is available in NIH Roorkee and is used for the analysis. These data were available for the period of four years from 2017 to 2020 for both pre-monsoon and post-monsoon seasons as mentioned in Table 2 in the supplementary file.

Recording of the ground water levels

Groundwater levels are recorded in the observation wells. These observation wells give information on the water level in a formation. Varieties of equipment are available in the market for recording the groundwater levels. For table water indicator is a popular device for this purpose as shown in Fig 9. Groundwater levels are recorded in the observation wells. The water level meter was held in place precisely by the holding hook. After that, the observer was pass through the excavation with the vibrator attached to the measuring tape and at a specific depth, when the vibratory sensor contacts the water level, an alarm sounds on the water level indicator. The depth was recorded using the measuring tape and considered the presence of groundwater. The plastic tape provides an indication of the water level.

Digital elevation model

The pre-monsoon piezometer data from 2017 to 2020 was used to generate a raster map of the variability in water levels. The variation of the groundwater level in the Agra district from years 2017-2020 was plotted as shown in Fig 10 and 11 (a, b, c and d).

Statistical analysis

The statistical analysis for the average groundwater level was conducted using the R software. The correlation heatmaps was generated for the pre-monsoon and post-monsoon groundwater levels for the year 2017-2020 and were discussed elaborately.

RESULTS AND DISCUSSION

Spatial variation of the groundwater level of the Agra district

For the assessment of spatial variation of the groundwater level of the Agra district. Groundwater level data available at NIH Roorkee are used for the analysis. These data were available for the period of four years from 2017 to 2020 for both pre-monsoon and post-monsoon seasons as mentioned in Table 2 in the supplementary file. The prepared polygon shape file of the boundary of the Agra district, Yamuna River and block boundaries are shown in Fig 7 (a, b, c and d). The various observation points of piezometric locations in the Agra district shown in Fig 8. The variation of the groundwater level in the Agra district from the years 2017-2020 was plotted are shown in Fig 10 and 11 (a, b, c and d).

Pre-monsoon season

The average rainfall that occurred in the Agra district in the year 2016 was 770 mm (NASA Power Data accesses viewer 2023).

From Fig 10(a), the groundwater levels in pre-monsoon season of the year 2017 are shown to be very shallow in Achanera (8.60 mbgl), Kheragadh (8.93 mbgl), Fatehpur Sikri (6.79 mbgl), Jagner (9.19 mbgl), Jaipur Kalan (14.70 mbgl) and Etmadpur (12.02 mbgl). While the groundwater is deeper in Fatehabad (27.66 mbgl), Barauli Ahir (24.05 mbgl), Bichpuri (21.94 mbgl), Shamshabad (28.09 mbgl) and Khandauli (22.84 mbgl). In Pinahat (17.07 mbgl), Sainya (18.14 mbgl) and Bah (19.93 mbgl) blocks the groundwater levels are found to be moderate.

The average rainfall that occurred in the Agra district in the year 2017 was 453 mm (NASA Power Data accesses

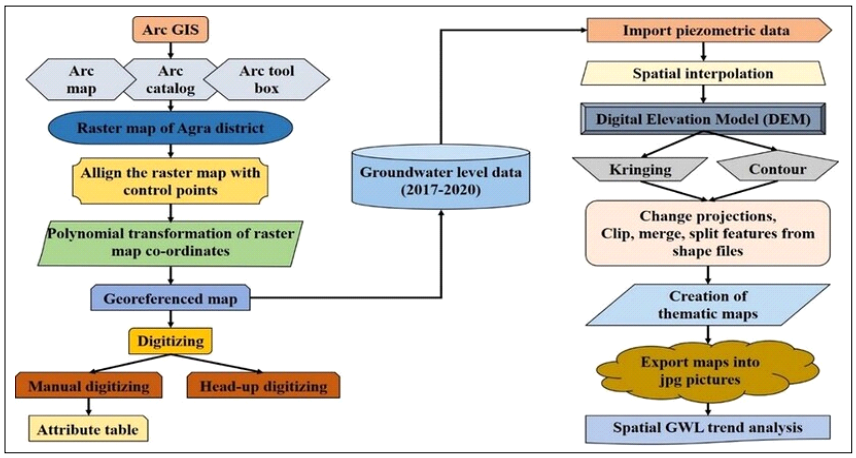


Fig 6: Process flowchart of spatial variation of groundwater levels in Arc GIS software.

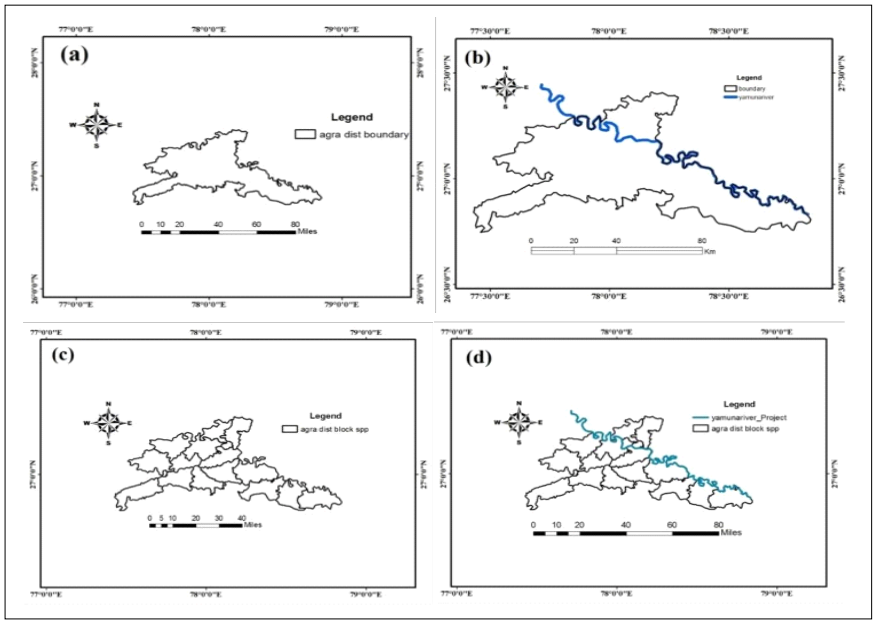


Fig 7: (a) Boundary map of the Agra district, (b) Boundary map of the Agra district with Yamuna River basin, (c) Blocks boundary map of the Agra district and (d) Blocks boundary map of the Agra district with Yamuna River basin.

viewer 2023). From Fig 10(b), the groundwater levels in the pre-monsoon season of the year 2018 are shown to be very shallow in Achanera (8.87 mbgl), Fatehpur Sikri (8.62 mbgl), Jagner (10.42 mbgl), Kheragadh (15.47 mbgl), Akola (16.33 mbgl) and Jaipur Kalan (19.91 mbgl) while the groundwater levels are shown deeper in Bichpuri (23.99 mbgl), Pinahat (24.14 mbgl), Fatehabad (29.11 mbgl), Shamshabad (29.88 mbgl) and Barauli Ahir (31.32 mbgl) blocks. In, Etmadpur (21.65 mbgl), Sainya (23.12 mbgl), Bah (23.73 mbgl) and Khandauli (21.82 mbgl) blocks, the status of groundwater levels are found to be moderate.

The average rainfall that occurred in the Agra district in the year 2018 was 858 mm (NASA Power Data accesses viewer 2023). From Fig 10(c), the groundwater levels in the pre-monsoon season of the year 2019 are shown to be very shallow in Achanera (9.0 mbgl), Jagner (10.7 mbgl) and Fatehpur Sikri (13.2 mbgl) while the groundwater levels are deeper in Jaipur Kalan (30.09 mbgl), Bah (31.1 mbgl), Fatehabad (36.4 mbgl), Shamshabad (34.8 mbgl) and Khandauli (29.8 mbgl). In Kheragadh (17.4 mbgl), Akola (18.0 mbgl), Bichpuri (20.4 mbgl), Barauli Ahir (27.20 mbgl), Etmadpur (23.50 mbgl), Pinahat (28.8 mbgl) and Sainya (28.46 mbgl) blocks, status of groundwater levels are found to be moderate.

The average rainfall that occurred in the Agra district in the year 2019 was 697 mm (NASA Power Data accesses viewer 2023). From Fig 10(d), the groundwater levels in the pre-monsoon season of the year 2020 are shown to be very shallow in Achanera (9.0 mbgl), Jagner (12.0 mbgl) and Fatehpur Sikri (15.2 mbgl) while the groundwater levels are deeper in Shamshabad (40.02 mbgl), Fatehabad (37.8 mbgl), Sainya (35.9 mbgl) Bah (32.3 mbgl), Jaipur Kalan (33.6 mbgl), Khandauli (33.1 mbgl) and Pinahat (31.40 mbgl). In Akola (18.40 mbgl), Bichpuri (19.10 mbgl), Kheragadh (21.90 mbgl), Etmadpur (26.40 mbgl) and Barauli Ahir (27.80 mbgl) blocks, the status of groundwater levels are found to be moderate. Due to the increase in population, urbanization, cultivation of water-intensive crops like rice and sugarcane and over-exploitation of ground-water for irrigation purpose and household purposes results in the decline of groundwater levels (Kaledhonkar *et al*., 2019 and Singh and Ahmad, 2011) in pre-monsoon season over the post-monsoon season from 2017-2020 years despite having the passage of Yamuna River basin over the Agra district.

Table 2: Procedure for digital elevation model (DEM) to show groundwater level.

DME	Description
Contour line	A contour line joins a collection of equal-elevation locations and is used to depict topography on a map's surface.
Inverse distance weighted (IDW)	When the set of points is dense enough to adequately capture the level of local surface variation required for analysis, this method should be utilized. By averaging the values of sample data points near each processing cell, it calculates cell values.
Kriging	Using this sophisticated geostatistical technique, an estimated surface is produced from a collection of points with z-values (or elevations).
Spline	The "spatial analyst tools" of ArcGIS include the "interpolation" section be assessed. This interpolation method predicts values using a mathematical function that reduces overall surface curvature, resulting in a flat surface that precisely passes through the input points.

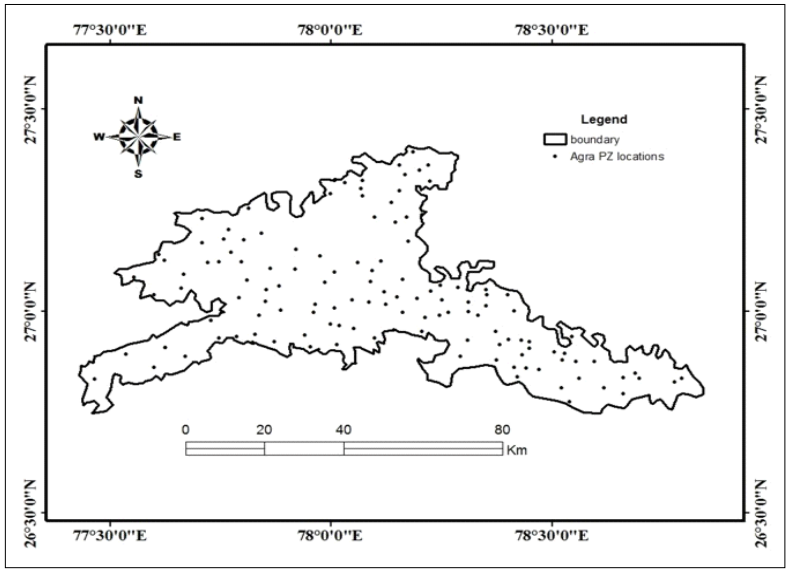


Fig 8: Piezometer locations in the Agra district.

Post monsoon season

The average rainfall that occurred in the Agra district in the year 2017 was 453mm (NASA Power Data accesses viewer 2023).

From Fig 11(a), the groundwater levels in the post-monsoon season of the year 2017 are shown to be very shallow in Fatehpur Sikri (6.64 mbgl), Achanera (7.95 mbgl), Jagner (7.45 mbgl), Kheragadh (8.13 mbgl) and Etmadpur (10.31 mbgl). While the groundwater is deeper in Shamshabad (23.67 mbgl), Fatehabad (25.17 mbgl), Barauli Ahir (22.42 mbgl) and Bichpuri (20.03 mbgl). In Akola (14.03 mbgl), Jaipur Kalan (12.82 mbgl), Pinahat (13.39 mbgl), Sainya (16.77 mbgl) and Bah (18.76 mbgl) blocks, the status of groundwater levels are found to be moderate.

The average rainfall that occurred in the Agra district in the year 2018 was 858 mm (NASA Power Data accesses viewer 2023). From Fig 11(b), the groundwater levels in post-monsoon season of the year 2018 are shown to be very shallow in Achanera (8.05 mbgl), Fatehpur Sikri (7.76 mbgl), Jagner (9.77 mbgl), Kheragadh (12.23 mbgl), Jaipur Kalan (19.60 mbgl) and Akola (15.68 mbgl). The groundwater levels are deeper in Barauli Ahir (30.09 mbgl), Fatehabad (27.26 mbgl) and Shamshabad (26.96 mbgl) blocks. In Etmadpur (20.08 mbgl), Khandauli (20.35 mbgl), Bichpuri (21.81 mbgl) and Sainya (21.06 mbgl) Bah (22.38 mbgl) and Pinahat (22.10 mbgl) blocks, status of groundwater levels is found to be moderate.

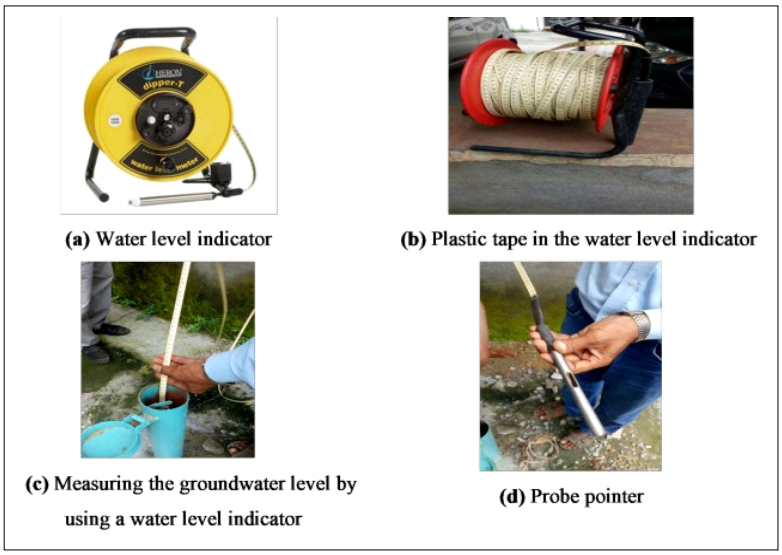


Fig 9: Measurement of the ground water levels by piezometer.

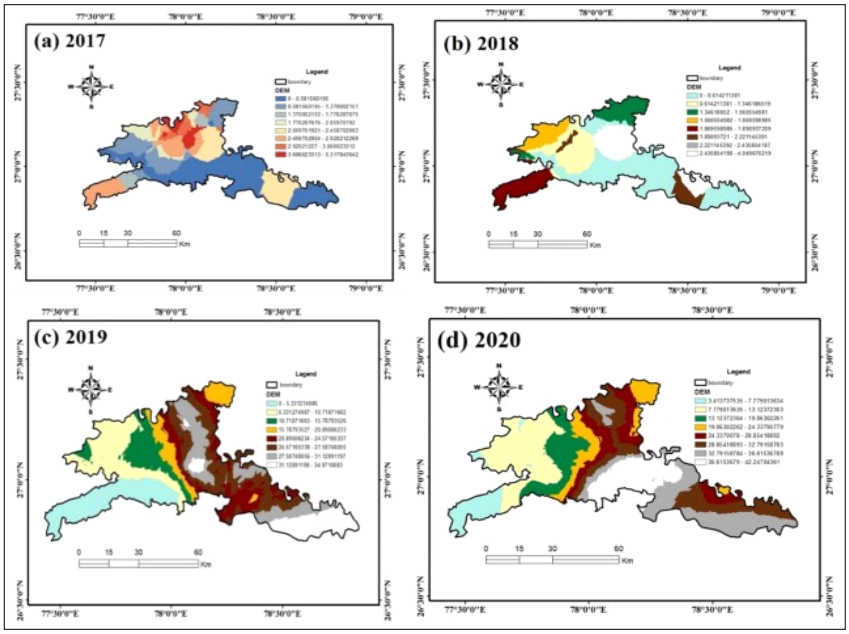


Fig 10: Variation of groundwater level in Agra district during pre-monsoon season from (a) 2017, (b) 2018, (c) 2019 and (d) 2020.

The average rainfall that occurred in the Agra district in the year 2019 was 697 mm (NASA Power Data accesses viewer 2023). From Fig 11(c), the groundwater levels in the post-monsoon season of the year 2019 are shown to be very shallow in Achanera (8.29 mbgl), Jagner (9.09 mbgl), Fatehpur Sikri (12.90 mbgl) and Bichpuri (14.64 mbgl) while the groundwater levels are deeper in Shamshabad (40.15 mbgl), Fatehabad (37.46 mbgl), Bah (32.07 mbgl), Sainya (35.61 mbgl) Khandauli (33.05 mbgl) and Jaipur Kalan (30.01 mbgl) blocks. In Akola (17.65 mbgl), Etmadpur (24.25 mbgl), Kheragadh (16.52 mbgl) Barauli Ahir (26.94 mbgl), Pinahat (27.70 mbgl) and Sainya (27.98 mbgl) blocks, status of groundwater levels is found to be moderate.

The average rainfall that occurred in the Agra district in the year 2020 was 507 mm (Anonymous, 2023). From Fig 11(d), the groundwater levels in the post-monsoon season of the year 2020 are shown to be very shallow in Achanera (8.46 mbgl), Jagner (10.90 mbgl), Fatehpur Sikri (14.26 mbgl) and Akola (18.27 mbgl) while the groundwater is deeper in Shamshabad (40.15 mbgl), Fatehabad (37.46 mbgl), Sainya (35.61 mbgl), Jaipur Kalan (33.35 mbgl), Khandauli (33.05 mbgl), Bah (32.07 mbgl) and Pinahat (31.29 mbgl). In Bichpuri (18.84 mbgl), Kheragadh (21.71 mbgl), Barauli Ahir (25.42 mbgl) and Etmadpur (26.73 mbgl) blocks, the status of groundwater levels is found to be moderate. Due to the adequate amount of rainfall and high recharge of surface water to groundwater in sandy soils in Agra district (Sahoo *et al*., 2021 and Kumar *et al*., 2017). There was a slight inclination in groundwater levels in post-monsoon seasons over the pre-monsoon season from 2017-2020 years.

Variation of groundwater level in blocks from 2017-2020

The groundwater variation with respect to different blocks of the selected location was shown in the Fig 12.

From Fig 12, the variation of groundwater levels was found to be shallow in Achanera (7.95 to 9.02 mbgl), Fatehpur Sikri (6.79 to 15.16 mbgl), Jagner (9.19 to 11.98 mbgl) Akola (14.69 to 18.27 mbgl) and Kheragadh (8.93 to 21.71 mbgl) Blocks. While the variation in groundwater levels was found to be deeper in Shamshabad (28.09 to 40.15 mbgl), Fatehabad (27.66 to 37.66 mbgl), Jaipur Kalan (14.70 to 33.35 mbgl), Sainya (16.77 to 35.91 mbgl) and Khandauli (20.35 to 33.13 mbgl). In, Bichpuri (18.83 to 21.97 mbgl), Etmadpur (10.31 to 26.73 mbgl) Pinahat (13.39 to 31.39 mbgl), Barauli Ahir (24.05 to 31.31 mbgl) and Bah (18.76 to 32.07 mbgl) blocks the variation in groundwater levels was found to be moderate in pre and post-monsoon seasons from years 2017-2020 with the effect of rainfall.

Statistical analysis results

The correlations between the pre-monsoon and post-monsoon groundwater levels were included in the Fig 13.

From the Fig 13, it is observed that all the considered years of groundwater levels were showing the positive correlation with the highest of 0.98 for the year of 2017, 2018 and 2020 followed by lowest of 0.87 in the year 2019. This is due to the extreme urbanization and the intensification of crop production techniques in the region of the Agra district has made the declination of groundwater in the year 2019. Later on, the groundwater levels were raised due to the unseasonal rainfalls in the parts of selected locations.

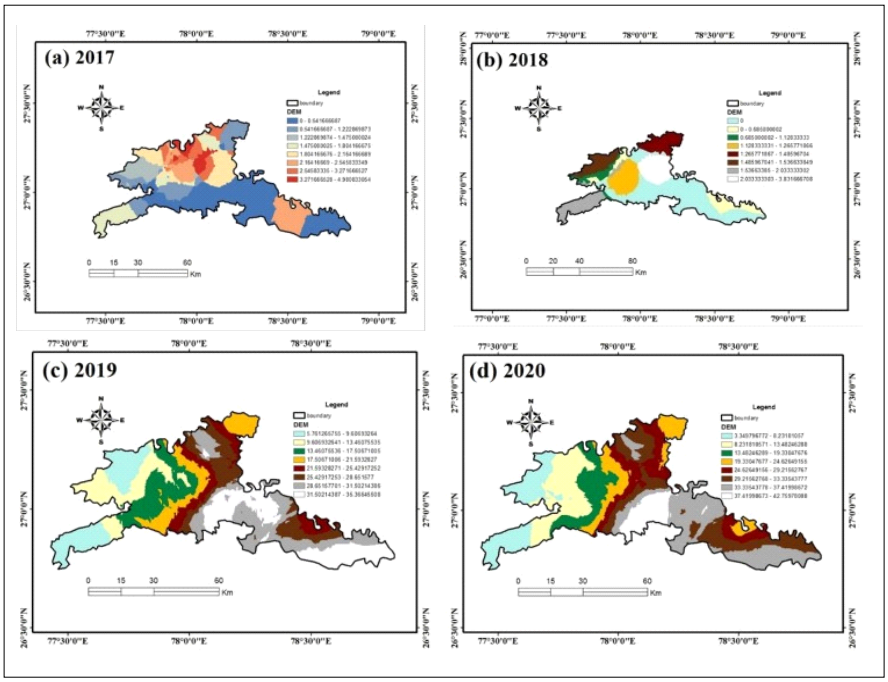


Fig 11: Variation of groundwater level in Agra district during the post-monsoon season from (a) 2017, (b) 2018, (c) 2019 and (d) 2020.

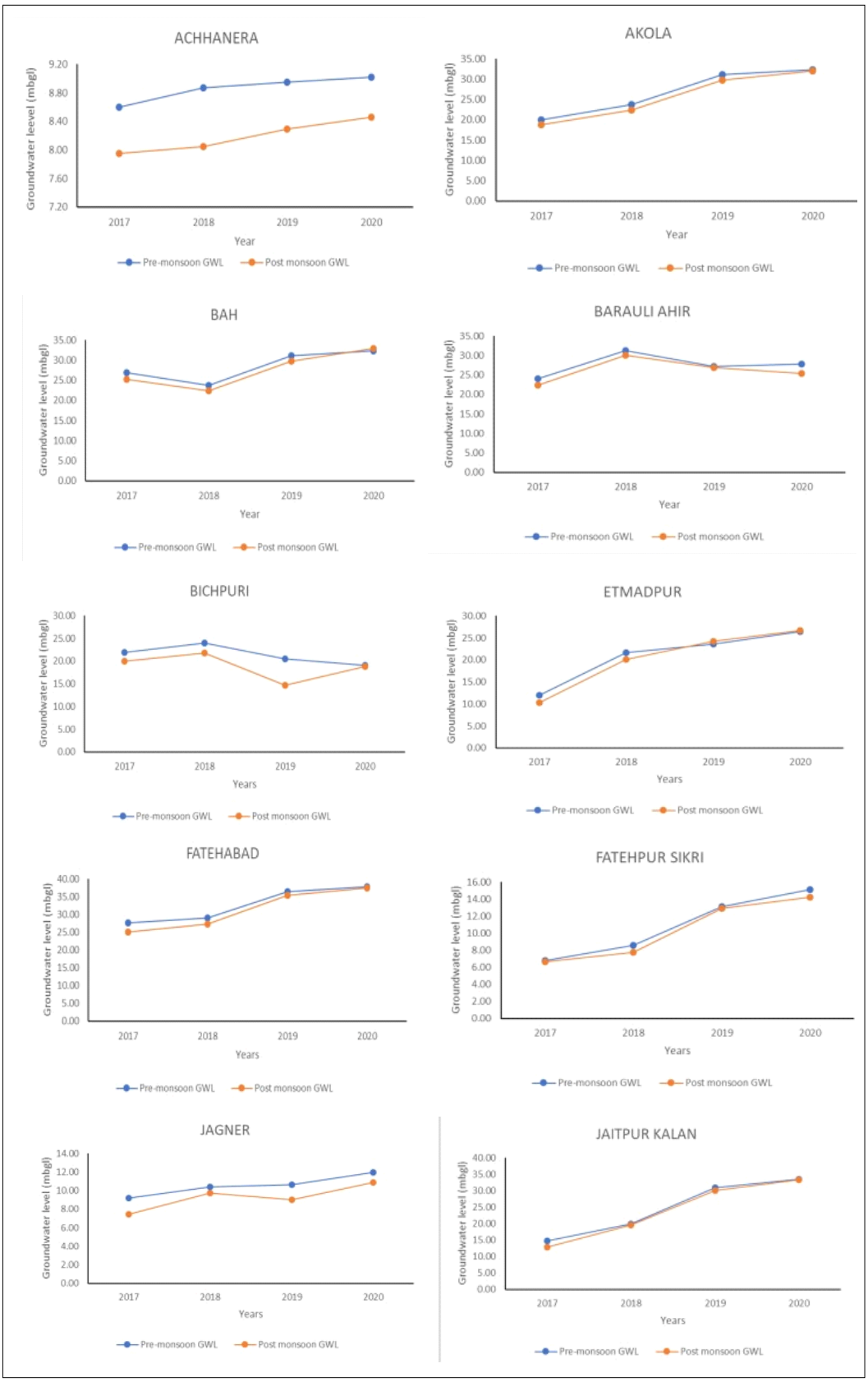


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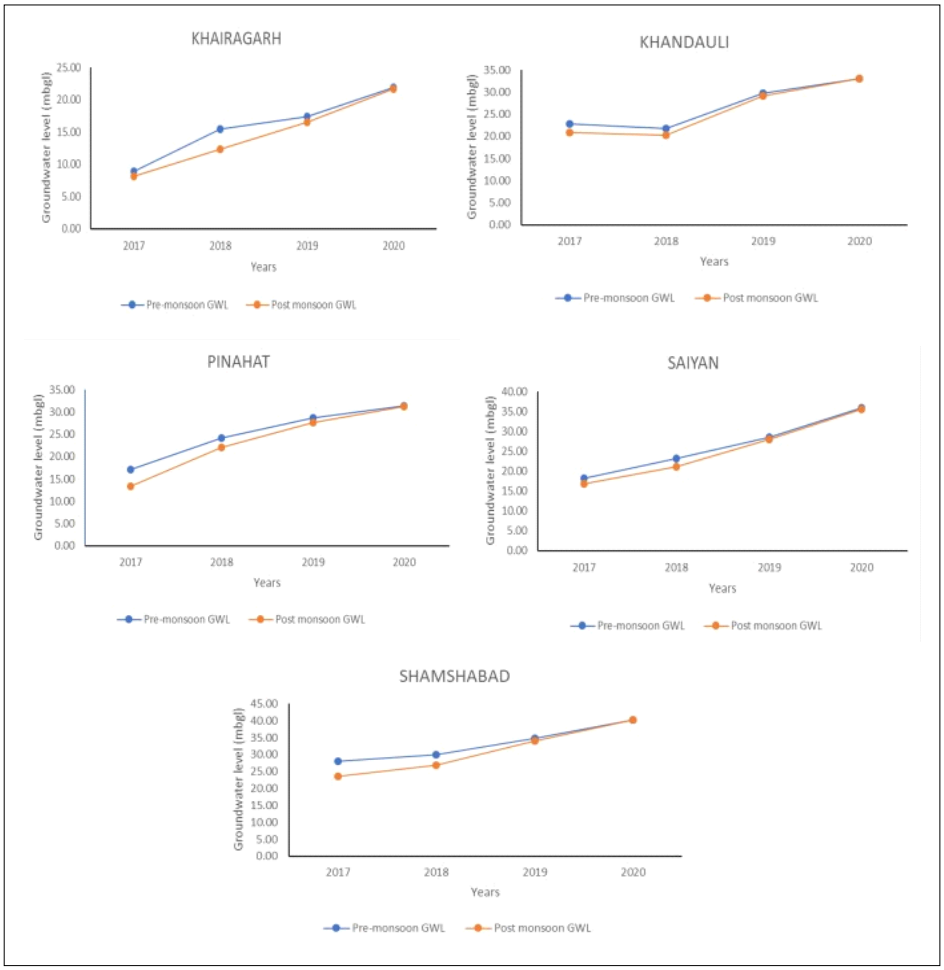


Fig 12: Average groundwater level in blocks of Agra district during pre and post-monsoon seasons from 2017-2020 years.

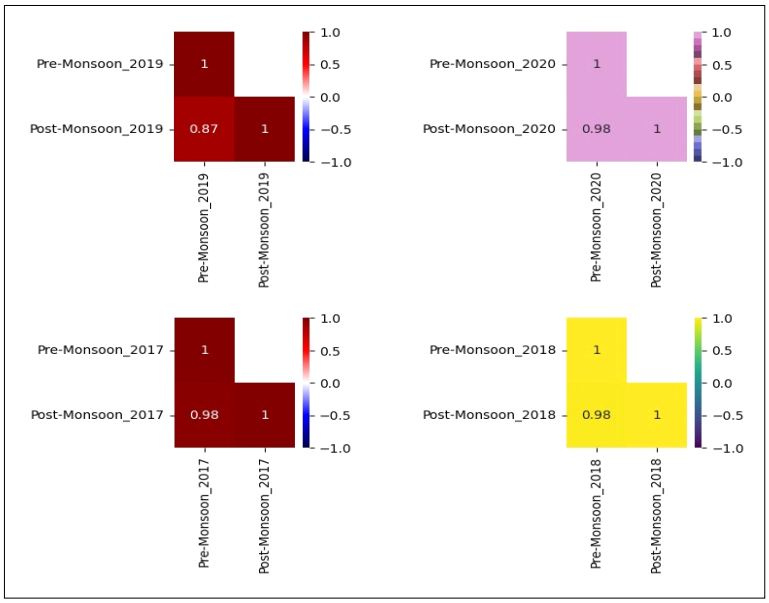


Fig 13: Correlation heat maps for the average groundwater for the year 2017-2020.

CONCLUSION

The comprehensive analysis of groundwater levels spanning the years 2017-2020 during both pre-monsoon and post-monsoon seasons provides insights into the hydrological dynamics of the Agra district. The study reveals a noteworthy variation in subsurface water levels across different sections of the region. Despite a consistent decline, the groundwater levels do not indicate an alarming condition. During the pre-monsoon period, the depths of groundwater levels increased from 16.98 mbgl in 2017 to 26.27 mbgl in 2020, exhibiting a mean annual growth rate of 3.58%. Similarly, in the post-monsoon season, the depths increased from 15.23 mbgl in 2017 to 25.84 mbgl in 2020, with a mean annual growth rate of 3.34%. The overall groundwater level depths in the Agra District witnessed an increase from 16.89 mbgl in 2017 to 27.07 mbgl in 2020, reflecting a mean yearly growth rate of 4.04%. To address this issue, interventions have been implemented to enhance groundwater recharge rates, coupled with effective utilization of this water during off-monsoon seasons. In areas where groundwater availability is limited, the implementation of rainwater harvesting structures is recommended to alleviate water scarcity in certain regions of Uttar Pradesh's Agra district. These findings contribute to a broader understanding of groundwater dynamics in the region and provide a basis for informed water resource management strategies.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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