Assessment of Groundwater behavior in Kulpahar Watershed, District Mahoba, Uttar Pradesh, India

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Abstract. In hard rock terrain, the groundwater occurs in two zones viz. shallow zone (in overburden) and deeper fractured zones mainly through secondary porosity. The groundwater level through 23 observation wells (fifteen dug wells and eight piezometers) has been monitored during pre and post-monsoon periods. An attempt has been made to evaluate the impact of rainfall on the groundwater level in the hard rock area of Mahoba district in the Bundelkhand region. The study depicts the impact of rainfall over the long-term groundwater level trend and establishes a conceptual structure to understand the hydrological stress conditions. Due to overexploitation, the groundwater condition has reached the category of a critical stage. The severity and duration of water-level responses to hydrologic stresses have been analyzed statistically as well as graphically. The groundwater level is spatially and temporally variable in hard rock areas and essentially depends upon the amount of rainfall, geological condition, and topographic slope. The analyzed rainfall data have been graded as a good year and a bad year based on the amount of precipitation. The long-term groundwater level trend (2006-2016) indicates a sharp decline in groundwater level trend in the western part due to higher base flow and poor recharge. On the other hand, due to the presence of thicker overburden and runoff accumulation therein, the groundwater level is rising in the northern part of the study area. It also validates that there is very fair control of slope and thickness of overburden on the groundwater regime apart from the rainfall.

Keywords: Groundwater, Kulpahar watershed, watershed development, and management

1. Introduction

Groundwater refers to the water that exists underneath the surface of the earth. It starts with precipitation and snowmelt that trickles down or infiltrates into the ground. The amount of water that enters the ground varies widely from place to place due to different lithology types, topography, and
natural precipitation variation. Groundwater is a dynamic natural resource that can be recharged most of the time during the rainy season by infiltration and percolation. It always runs through the fractures of rock and pore spaces over a long distance in the aquifers, which is easily accessible and cater to many people's needs.

Groundwater in hard rock terrains is usually restricted to fractured (ranges between 15m to 70m) and weathered zones. Groundwater availability in the terrain is dependent on the presence of secondary porosity or permeability in the forms of fracture, weathered horizons, and degree of connectivity of weak planes like joints and lineaments [1]. The groundwater resource of a region is one of the essential components for the area's balanced economic development [2]. Water resources are extremely limited but renewable, exhibiting diversity in their quality and quantity [3]. The timing and quantity of recharge achieving the aquifer have significant implications for groundwater resources [4]. Groundwater is affected by climate change through a variety of hydrological processes. The trends in climate variations have a direct impact on groundwater level trends [5]. Rainwater gained its significance with the emerging need and demands of water resources. Overexploitation of groundwater resources collectively results in declining water tables in most of the country [6]. The water table represents the groundwater reservoir and changes in its level account for the changes in groundwater storage [2]. The water table's rise suggests when the recharge exceeds discharge, while the fall in the water table reveals conditions when the discharge exceeds recharge [7]. One of the key solutions to encounter ever-increasing water needs would be the storage of the available rainwater through rainwater harvesting techniques [8]. The seasonal groundwater table fluctuation studies play a significant role in understanding the existing sub-watershed network's development and management. Variations in rainfall and groundwater table are closely related as precipitation is the prime source of aquifer recharge. Direct surface recharging is essential for efficacious water resource management in recent decades [9]. However, the correlation may sometimes be inadequate due to differences in rainfall intensity and distribution, which produce different amounts of recharge for the same amount of rainfall [10]. Therefore, investigating and finding out the relationship between the hydrogeological setup and recharge through rainfall in hard rock terrain is of great significance. An attempt has been made to address groundwater issues on the watershed in the Bundelkhand region's hard rock area.

2. Study area
The study area, Kulpahar tehsil of district Mahoba comprising two blocks namely Jaitpur and Panwari (Figure 1). It extends from longitude 79°10'E to 79°40'E to latitude 24°50'N to 25°30'N with a total area of 1240 km². The study region mainly consists of the hard rock formation of Bundelkhand massif. Jaitpur block is characterized by rugged topography and very thin soil cover as overburden while Panwari Block is characterized by thick overburden consisting of clay, silt, and fine-grained sand. The dominant rock formations are highly jointed and fractured, responsible for groundwater in the weathered zone and under secondary porosity in a deeper fractured zone. The rainfall does not percolate subsurface since the rocks are massive and compact in nature. However, secondary porosity in the form of joints and fissures allow some water to percolate. The study area's climate is typical subtropical, punctuated by long and intense summer, with distinct seasons. The average annual precipitation is 864 mm, which is received mainly from the south-west monsoon. January is usually the coldest month with the temperature 8.3°C, and May is the hottest with the temperature shooting up to 47.5°C. Virma, Arjun, and Chandrawal River mainly drain the area under investigation. There is a huge reservoir known as Bela Tal near Jaitpur. Groundwater recharge is typically affected by climate change and human intervention, such as excessive or unsustainable groundwater abstraction. Evaporation and groundwater exploitation are significant factors responsible for groundwater stress in the study area.

3. Geological Set-up
The study area is characterized by leucogranite, older and younger Alluvium consisting of clay, silt, and sand. The most dominant lithology is leucogranite covering the mainly central and eastern part of
the study area while recent alluvium occurs in the northern part of the study area (Figure 2). A few patches of pink granite appear as enclosed in leucogranite or adjacent to the outcrop of leucogranite.

4. Material and Method
Secondary porosity caused by fractures mainly governs the occurrence and movement of groundwater in hard rock areas. Rainfall is the main source of recharge for groundwater. The infiltration and groundwater recharge are predominantly governed by land use practice, lithology, and elevation of the terrain. The groundwater level data from twenty-three hydrological stations collected from the Groundwater Department, Banda division, Uttar Pradesh, India from 2006 to 2016 were sorted, and statistical analysis was performed in Excel spreadsheets. Also, the rainfall data for the same years were collected from Additional District Magistrate (ADM) office Mahoba, Uttar Pradesh, India, and has been analyzed the same as above. Spatial maps have been generated with the help of ArcGIS 10.4, ERDAS IMAGINE 2013, and Global Mapper 18. Binary graphs have been prepared in Excel 2013 to analyze the factors influencing the infiltration rate and surface runoff known as Hydrograph. Rainfall data are one of the significant datasets in the spatial domain for controlling and monitoring the water resources budget. A good year and a bad year study have been performed to assess the impact of groundwater recharge and depletion. A good year and bad year were calculated based on the above and below values of average rainfall [11].

Figure 1. Geo-referenced map showing the Kulpahar watershed.
The procedure for discriminating between the good and bad years is demonstrated in equation 1 [12]. The formula for evaluation of a good year and a bad year is as follows:

\[
A = \frac{\text{Maximum Rainfall} - \text{Minimum Rainfall}}{2}
\]

(1)

If yearly average rainfall > A, the year is good year
If yearly average rainfall < A, the year is bad year

The adopted methodology to achieve the major objective of the present research is depicted below.
The characteristics of observation wells are given in Table 1. The data are processed to find out the seasonal fluctuations. To find this, the groundwater level of post-monsoon is deducted from the pre-monsoon groundwater level. The value of seasonal fluctuation reveals the change in the in-storage of groundwater regime under phreatic conditions.

Figure 3. Flowchart showing different components of methodology
To identify the controlling factors with respect to the water-level behavior, correlation analysis has been attempted with the seasonal changes in the rainfall. Correlation is the relation between the dependence of one variable with respect to another. The correlation value always lies between + 1 and -1, where +1 represents a strong positive correlation and -1 implies a weak negative correlation.
Zero value shows the non-dependence of the parameters, which means no correlation at all. Rainfall and water level correlations were analyzed to reveal the dependence of two parameters.

4. Result and Discussion
Detailed lithology/geology map has been prepared in ArcGIS 10.4, data acquired by Geological Survey of India (GSI) and field investigation. Groundwater in the region is mainly dependent on climate, stratigraphy, lithology, physiography, and drainage systems. The lithology encountered primarily in the study area comprising granite, alluvium, and sand-silt-clay, including schist, dolerite, and quartzofeldspathic veins as depicted in figure 2. As the area under investigation is mainly underlain by hard rock formation of Bundelkhand massif, the rainfall does not percolate and store underground since the rock is massive, compact, and relatively impervious. The granites are profusely and extensively jointed and fractured at certain locations allowing rainfall run-off to trickle down, acting as a good reservoir for groundwater in the study area. The granites are unconformably overlain by Quaternary alluvium consisting of gravel sand and clay. The thickness of these materials is known as overburden (weathered material), therein groundwater mainly occurs. The Bundelkhand granite is traversed by quartz veins and basic intrusive, mainly dolerite dike of pre and post-Cambrian age. These dykes have a limited longitudinal extent of a few meters, trending in NE-SW and NW-SE directions. Dykes usually play a key role in groundwater movement and storage. The upstream of the dyke is normally the storage of good volumes of water, while the downstream of the dykes is the poorer groundwater storage.

![Figure 4. Land use land cover map.](image1)

![Figure 5. Digital Elevation Model Map.](image2)
Remote sensing and GIS technology provide an outstanding forum for evaluating and optimizing watershed management through prioritization studies [13]. Sentinel image, acquired on 6 June 2019, has been used to prepare land use land cover (LULC) map by unsupervised classification in ERDAS IMAGINE (Figure 4). The statistics on land use land cover classes are detailed in Table 3. The majority of the area is 837.24 km² of agriculture/fallow land and the least part is 13.29 km² of settlement. However, the surface water body covers an area of 25.24 km². Land use land cover diversity directly infuses the condition of recharging and processes of surface runoff. The land cover allows significantly higher infiltration to groundwater; on the other hand, land use limits groundwater infiltration to the subsurface. Cartosat DEM data are used for the analysis of terrain elevation (Figure 5).

| Class                      | Area (km²) | Area (%) |
|----------------------------|------------|----------|
| Waterbody                  | 25.24      | 2.04     |
| Settlement                 | 13.29      | 1.07     |
| Agriculture/Fallow Land    | 837.24     | 67.52    |
| Vegetation/Tree Cover      | 282.91     | 22.82    |
| Open Land/Bare Land        | 81.33      | 6.56     |

The elevation of the watershed ranges between 137 m to 342 m above the mean sea level. The water level follows the elevation trend/topography of the terrain. The lower elevation is towards the northern part of Kulpahar, which serves as a catchment zone, while the higher elevation is towards the southern side of the study area, which acts as a runoff zone. The rainfall data have been statistically analyzed to understand the seasonal variation in rainfall. Based on precipitation, a good year or a bad year classification has been carried out [14], [11]. Hydro-geologically, higher infiltration rates due to higher amounts of rainfall are expected in the good year, while these conditions do not prevail during the bad year causing poor infiltration. During the good year, as the amount of rainfall is higher, the groundwater table shows shallow depth. However, a deeper groundwater table has been observed during bad years due to poor rainfall. The water-level monitoring data is coherent with the period wise average rainfall results for both good and bad years (Table 4 and Figure 6). The lowest average rainfall recorded was 36.91 cm in the year 2007, and the highest average of rainfall recorded was 111.49 cm in the year 2016. The yearly average rainfall is observed to be 74.20 cm per year. If the annual average rainfall value is more than average, the year has been considered a good year, and those of below-average has been considered a bad year. The analysis revealed that the years 2006, 2007, 2008, 2009, 2010, 2012, 2014, and 2015 with less rainfall were considered bad years. There was a crisis of water resources and faced severe drought during those years. The remaining years (2011,
2013, and 2016) were good years and had a rainfall greater than the mean value throughout the assessment period.

4.1 Rainfall-Groundwater level Correlation Analysis

The monthly rainfall and water table data were scaled down to seasonal datasets and correlated to each other to find out the relationship between the parameters like groundwater level and rainfall. The statistical analysis and graphical representation of seasonal rainfall and water level data are depicted in tables 5, 6, 7, 8, and figures 7, 8, 9, 10, respectively.

The analysis indicates positive and negative correlations between rainfall and water level (Table 9). The highest positive correlation is 0.732, while the negative correlation is observed as − 0.945. Therefore, a negative correlation reveals a deeper water level with respect to higher rainfall amounts, and a positive correlation suggests a deeper water level with respect to lower rainfall amounts. Areas with higher negative correlations indicate stronger dependency and supportive relationships between the concerned parameters and hence are better in respect of water resources management. The study clearly shows that the higher positive and negative correlations are observed during the pre-monsoon and post-monsoon periods.

![Figure 6. Column graph depicting average rainfall from 2006 to 2016.](image)

Indeed rainfall plays a significant role in groundwater recharge. Higher positive correlation i.e., the deeper water level in pre-monsoon, implies less amount of rainfall, terrain characteristics as the area being granitic complex and, or overexploitation as well as more pumping of groundwater for irrigation and drinking purposes. On the other hand, observation explains the higher negative correlation i.e., shallower water level, i.e., favorable recharging conditions during the post-monsoon period. They may be due to a higher amount of rainfall, suitable lithological conditions, land use patterns, the existence of fractures, and abstraction. It reveals that appropriate planning for rainwater harvesting is the key remedy/solution to effectively managing water resources.

Based on a graphical analysis (Figure.7 -10) of groundwater level vis-à-vis rainfall, it is observed that there is a non-uniform impact of rainfall on the groundwater level in the entire area. It also reflects that the local topography, lithology, and overburden thickness effectively control parameters in the study area.
Table 5. Rainfall and groundwater water level during the pre-monsoon period.

| Year | RF_PRM | OW1  | OW2  | OW3  | OW4  | OW5  | OW6  | OW7  | OW8  | OW9  | OW10 | OW11 | OW12 | OW13 | OW14 | OW15 | OW16 | OW17 | OW18 | OW19 | OW20 | OW21 | OW22 | OW23 |
|------|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 2006 | 3.81   | 9.20 | 7.95 | 8.20 | 12.55| 5.50 | 11.70| 13.10| 15.20| 5.40 | 8.80  | 9.20 | 9.15 | 5.10 | 15.20| 5.40 | 8.80  | 9.15 | 9.20 | 8.45 | 7.35 | 9.00 |
| 2007 | 0.46   | 10.75| 9.38 | 19.00| 7.30 | 5.00 | 13.40| 13.10| 15.20| 7.15 | 11.80 | 13.00| 10.85| 9.20 | 10.85| 9.20 | 10.85| 9.20 | 10.85| 9.20 | 8.29 | 8.65 |
| 2008 | 0.35   | 13.55| 19.00| 7.30 | 13.40| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |
| 2009 | 0.35   | 13.55| 15.00| 0.30 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 |
| 2010 | 0.12   | 13.75| 11.35| 16.15| 7.50 | 1.70 | 13.40| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |
| 2011 | 1.73   | 7.00 | 10.30 | 2.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 |
| 2012 | 0.16   | 13.35| 10.30 | 8.85 | 16.90| 4.60 | 13.40| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |
| 2013 | 0.00   | 12.20| 8.75 | 3.35 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 |
| 2014 | 0.10   | 11.50| 10.30 | 8.85 | 15.95| 5.55 | 13.40| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |
| 2015 | 7.62   | 13.60| 10.30 | 7.80 | 15.95| 5.55 | 13.40| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |
| 2016 | 2.93   | 8.60 | 8.00 | 11.10| 19.00| 9.20 | 9.50 | 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10| 13.10 |

Figure 7. Line chart showing pre-monsoon rainfall vis-a-vis pre-monsoon groundwater level trends. [Abbreviations used in the table 5 and figure 7 are Rainfall (RF), Pre-monsoon (PRM), Observation Well (OW), Observation Piezometer (OP), centimeter (cm) and meter (m)].
Table 6. Rainfall and groundwater water level during the post-monsoon period.

| Year | RF_PTM | OW1   | OW2   | OW3   | OW4   | OW5   | OW6   | OW7   | OP9   | OP10  | OP11  | OW12  | OW13  | OP14  | OP15  | OP16  | OW17  | OW18  | OW19  | OW20  | OW21  | OW22  | OP23  |
|------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 2006 | 0.92   | 7.10  | 8.35  | 9.00  | 15.50 | 3.20  | 2.10  | 11.55 | 9.00  | 4.83  | 0.00  | 12.50 | 7.85  | 8.00  | 8.25  | 5.80  | 0.00  | 3.20  | 2.10  | 11.55 | 9.00  | 4.83  | 0.00  | 12.50 | 7.85  | 8.00  | 8.25  |
| 2007 | 3.09   | 9.85  | 10.30 | 9.18  | 18.25 | 5.10  | 3.90  | 13.40 | 10.10 | 6.50  | 0.00  | 13.00 | 7.20  | 9.20  | 9.00  | 8.55  | 9.20  |      |      |      |      |      |      |      |      |
| 2008 | 2.18   | 5.80  | 6.00  | 5.00  | 10.30 | 7.50  | 1.00  | 11.40 | 9.60  | 4.40  | 0.00  | 10.55 | 7.40  | 5.30  | 5.35  | 6.10  | 5.28  | 0.00  | 3.20  | 2.10  | 11.55 | 9.00  | 4.83  | 0.00  | 12.50 | 7.85  | 8.00  | 8.25  |
| 2009 | 13.29  | 4.15  | 7.30  | 7.75  | 12.05 | 6.80  | 3.20  | 11.05 | 11.45 | 8.80  | 4.40  | 13.00 | 4.25  | 6.70  | 5.55  | 5.40  | 5.40  |      |      |      |      |      |      |      |      |
| 2010 | 3.78   | 11.90 | 7.65  | 8.50  | 15.75 | 5.35  | 2.80  | 11.40 | 13.10 | 0.00  | 0.00  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2011 | 0.00   | 9.65  | 4.55  | 4.45  | 9.25  | 2.05  | 3.05  | 11.00 | 11.25 | 5.85  | 0.00  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2012 | 0.62   | 5.00  | 5.40  | 3.75  | 9.65  | 1.65  | 2.80  | 9.95  | 8.00  | 5.65  | 4.15  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2013 | 21.30  | 10.80 | 4.60  | 9.10  | 7.65  | 2.25  | 2.75  | 7.90  | 4.25  | 4.65  | 3.20  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2014 | 4.25   | 9.10  | 1.70  | 11.00 | 14.70 | 7.55  | 5.20  | 10.90 | 13.00 | 23.50 | 6.15  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2015 | 6.14   | 7.40  | 6.60  | 8.50  | 19.00 | 5.10  | 7.40  | 13.40 | 13.10 | 23.50 | 9.50  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |
| 2016 | 1.05   | 3.45  | 7.40  | 12.00 | 19.00 | 9.20  | 9.35  | 1.40  | 2.63  | 7.75  | 9.50  | 3.20  | 13.00 | 7.35  | 8.40  | 6.15  | 5.00  | 7.50  |      |      |      |      |      |      |      |      |

Figure 8. Line chart showing post-monsoon rainfall vis-a-vis post-monsoon groundwater level trends. [Abbreviations used in the table 6 and figure 8 are Rainfall (RF), Post-monsoon (PTM), Observation Well (OW), Observation Piezometer (OP), centimeter (cm) and meter (m)].
### Table 7. Yearly average rainfall and pre-monsoon groundwater level.

| Year | RF_Yearly | OW1 | OW2 | OW3 | OW4 | OW5 | OW6 | OW7 | OW8 | OW9 | OW10 | OW11 | OW12 | OW13 | OW14 | OW15 | OW16 | OW17 | OW18 | OW19 | OW20 | OW21 | OW22 | OW23 |
|------|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2006 | 44.39     | 9.20| 7.95| 8.20| 12.55| 5.00| 11.70| 13.10| 0.00| 0.00| 8.80| 15.20| 5.40| 0.00| 11.75| 0.00| 9.15| 9.20| 8.45| 7.35| 0.00|
| 2007 | 36.91     | 10.75| 9.58| 19.00| 7.30| 5.00| 13.40| 13.10| 0.00| 0.00| 11.80| 12.50| 18.40| 7.15| 0.00| 6.70| 13.00| 7.70| 10.85| 9.20| 9.05| 8.29|
| 2008 | 67.73     | 13.55| 10.30| 10.37| 19.00| 7.00| 13.40| 13.10| 0.00| 0.00| 11.80| 4.50| 15.50| 1.95| 9.00| 6.90| 13.00| 8.60| 10.65| 9.20| 10.50| 8.90|
| 2009 | 50.80     | 11.95| 10.30| 8.75| 15.60| 9.00| 3.20| 13.40| 13.10| 0.00| 0.00| 3.33| 5.40| 17.00| 6.90| 7.65| 7.85| 13.00| 7.25| 10.00| 8.30| 8.10| 8.00|
| 2010 | 45.91     | 13.75| 10.30| 11.15| 16.15| 15.10| 13.40| 13.10| 0.00| 0.00| 8.58| 6.60| 15.85| 6.65| 7.25| 7.45| 13.00| 6.95| 9.00| 8.85| 7.80| 9.40|
| 2011 | 78.52     | 12.00| 10.30| 11.16| 19.00| 8.00| 4.00| 13.40| 13.10| 23.40| 0.00| 11.50| 8.00| 17.15| 7.50| 9.95| 6.75| 13.00| 9.25| 13.00| 9.20| 8.20| 9.60|
| 2012 | 67.45     | 13.35| 10.30| 8.65| 16.90| 4.60| 3.90| 13.40| 13.10| 8.50| 7.45| 8.33| 5.20| 17.40| 7.50| 7.00| 6.15| 13.00| 6.75| 9.10| 6.10| 7.70| 10.50|
| 2013 | 104.73    | 12.20| 8.75| 15.30| 17.45| 4.85| 3.55| 13.40| 13.10| 7.75| 6.90| 8.48| 5.25| 17.75| 5.13| 7.45| 4.85| 11.70| 7.65| 12.70| 7.40| 9.80| 8.70|
| 2014 | 37.09     | 11.50| 10.50| 18.40| 5.95| 5.35| 13.40| 13.10| 8.85| 7.95| 9.48| 6.20| 18.60| 4.50| 5.20| 4.95| 9.55| 5.20| 7.05| 4.85| 6.13| 6.20|
| 2015 | 40.09     | 13.60| 10.30| 8.70| 15.95| 5.00| 7.00| 13.40| 13.10| 23.50| 7.30| 6.23| 4.60| 27.00| 7.50| 6.75| 5.65| 13.00| 6.90| 9.20| 6.25| 8.80| 7.95|
| 2016 | 111.49    | 8.60| 8.00| 11.10| 19.00| 9.20| 9.50| 13.40| 13.10| 23.50| 8.55| 8.63| 9.80| 13.00| 7.50| 10.10| 7.90| 13.00| 8.80| 11.30| 9.20| 10.40| 10.50|

**Figure 9.** Line chart showing the relationship between annual average rainfall and pre-monsoon groundwater level. [Abbreviations used in table 7 and figure 9 are Rainfall (RF), Pre-monsoon (PRM), Observation Well (OW), Observation Piezometer (OP), centimeter (cm), and meter (m)].
Table 8. Yearly average rainfall and post-monsoon groundwater level.

| Year | RF_Yearly | OW1 | OW2 | OW3 | OW4 | OP5 | OW6 | OW7 | OW8 | OP9 | OP10 | OW11 | OW12 | OP13 | OW14 | OP15 | OP16 | OW17 | OW18 | OW19 | OW20 | OW21 | OW22 | OP23 |
|------|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|-------|------|-------|------|------|------|------|------|------|------|------|------|
| 2006 | 44.39     | 7.10| 8.35| 9.00| 15.50| 3.20| 2.10| 11.55| 13.10| 0.00| 0.00| 7.63 | 6.86 | 9.00 | 4.83 | 0.00 | 0.00 | 12.50| 0.00 | 7.85 | 8.00 | 8.25 | 5.80 | 0.00 |
| 2007 | 36.91     | 9.85| 10.30| 9.18| 18.25| 8.90| 12.50| 10.10| 6.50 | 0.00| 5.40 | 13.00| 7.20 | 9.20 | 9.00 | 8.55 | 9.20 | 13.00| 7.20 | 9.20 | 9.00 | 8.55 | 9.20 |
| 2008 | 67.73     | 5.80| 6.00 | 5.00| 10.30| 6.80 | 1.00 | 11.40| 9.60 | 0.00| 4.40 | 2.15 | 4.00 | 5.68 | 10.55| 7.40 | 5.30 | 5.35 | 6.10 | 5.28 | 3.95 | 12.50|
| 2009 | 59.80     | 4.15| 7.30 | 7.75| 12.65| 6.80 | 1.20 | 11.05| 11.45| 0.00| 5.93 | 3.30 | 4.90 | 4.40 | 15.15| 3.45 | 2.50 | 3.60 | 6.70 | 5.55 | 5.40 | 5.40 |
| 2010 | 45.91     | 11.90| 7.65 | 8.50| 15.75| 5.35 | 2.80 | 13.40| 13.10| 0.00| 7.63 | 6.20 | 8.80 | 6.00 | 6.40 | 5.85 | 13.00| 3.45 | 7.35 | 8.40 | 6.15 | 5.00 | 7.50 |
| 2011 | 78.52     | 9.65 | 4.45 | 4.45| 9.25 | 2.05 | 3.05 | 11.00| 11.25| 5.85 | 0.00| 4.65 | 1.45 | 10.45| 6.10 | 3.65 | 3.35 | 4.05 | 4.25 | 4.35 | 4.40 | 8.05 | 4.65 |
| 2012 | 67.45     | 5.00 | 5.40 | 3.75| 9.65 | 1.65 | 2.00 | 9.95 | 8.00 | 5.65 | 4.15 | 2.58 | 1.25 | 9.90 | 3.70 | 4.09 | 1.80 | 4.70 | 2.80 | 4.30 | 4.75 | 4.25 | 5.80 |
| 2013 | 104.73    | 10.80| 4.60 | 9.10| 7.65 | 2.25 | 2.75 | 7.90 | 4.25 | 4.65 | 3.20 | 5.20 | 1.60 | 4.85 | 3.87 | 2.48 | 1.15 | 7.15 | 1.55 | 3.50 | 1.60 | 3.55 | 3.05 |
| 2014 | 37.09     | 9.10 | 3.70 | 11.00| 14.70| 5.75 | 5.20 | 10.90| 12.90| 23.50| 6.15 | 4.78 | 3.40 | 16.03| 4.10 | 4.17 | 3.20 | 7.10 | 4.60 | 6.30 | 3.10 | 6.00 | 5.70 |
| 2015 | 40.09     | 7.40 | 6.60 | 8.50 | 19.00| 5.10 | 7.40 | 13.40| 13.10| 23.50| 9.50 | 7.58 | 6.90 | 7.60 | 7.50 | 8.06 | 5.75 | 13.00| 7.02 | 9.67 | 7.00 | 9.05 | 8.95 |
| 2016 | 111.49    | 3.45 | 7.40 | 12.00| 19.00| 9.20 | 9.55 | 1.40 | 2.63 | 7.75 | 9.50 | 3.05 | 11.90| 12.70 | 3.95 | 11.50| 8.20 | 13.00| 12.50 | 2.95 | 6.70 | 2.70 | 10.50|

Figure 10. Line chart showing relationship between annual average rainfall and post-monsoon groundwater level. [Abbreviations used in the table 8 and figure 10 are Rainfall (RF), Post-monsoon (PTM), Observation Well (OW), Observation Piezometer (OP), centimeter (cm) and meter (m)].
Table 9. Correlation between rainfall and water level records.

| Sample No | Location  | Easting (X) | Northing (Y) | Elevation | Hydrostation | DWT WTE |
|-----------|-----------|-------------|--------------|-----------|--------------|--------|
| OW1       | Alipur    | 348017.450  | 2813557.440  | 165.00    | Dug Well     | 11.86  |
| OW2       | Bauraha   | 339843.039  | 2815483.770  | 179.53    | Dug Well     | 9.74   |
| OW3       | Bharwara  | 354034.155  | 2806831.481  | 184.18    | Dug Well     | 9.63   |
| OW4       | Dharwar   | 355287.872  | 2806177.626  | 182.12    | Dug Well     | 17.18  |
| OP5       | Dharwar   | 333156.537  | 2807722.010  | 183.26    | Piezometer   | 6.55   |
| OW6       | Kankau    | 340074.299  | 2802047.931  | 197.97    | Dug Well     | 4.21   |
| OW7       | Kotra     | 336253.425  | 2811996.639  | 177.79    | Dug Well     | 13.25  |
| OW8       | Panwari   | 358067.482  | 2817806.018  | 170.42    | Dug Well     | 13.10  |
| OP9       | Benda     | 344471.455  | 2809031.374  | 185.78    | Piezometer   | 8.66   |
| OP10      | Parapatar | 347779.794  | 2803918.866  | 182.55    | Piezometer   | 3.47   |
| OW11      | Rari Kala | 349777.190  | 2813246.231  | 174.45    | Dug Well     | 9.31   |
| OW12      | Toyya     | 342667.580  | 2799553.515  | 191.38    | Dug Well     | 6.57   |
| OP13      | Bahadur Kala | 334454.577 | 2800473.924  | 194.95    | Piezometer   | 18.06  |
| OW14      | Mathua Itaura | 351111.553 | 2810397.124  | 174.65    | Dug Well     | 6.15   |
| OP15      | Kalpadh Swasthy Kendra | 363326.725 | 2801351.285  | 196.45    | Piezometer   | 6.31   |
| OP16      | Mahua Bandh | 357642.366  | 2784618.586  | 242.18    | Piezometer   | 5.85   |
| OW17      | Leta      | 357912.501  | 2809735.769  | 185.70    | Dug Well     | 12.45  |
| OP18      | Ladpur    | 349000.911  | 2794183.615  | 199.70    | Piezometer   | 6.82   |
| OW19      | Bajipur   | 351218.706  | 2787396.994  | 209.55    | Dug Well     | 9.91   |
| OW20      | Bajipur   | 344705.070  | 2797205.895  | 237.85    | Piezometer   | 8.12   |
| OW21      | Ragoliya Bajipur | 370004.229 | 2800369.578  | 195.76    | Dug Well     | 8.88   |
| OW22      | Kalpadh   | 364308.707  | 2789532.142  | 217.56    | Dug Well     | 8.43   |
| OP23      | Khadya    | 355018.614  | 2795561.828  | 195.14    | Piezometer   | 7.38   |

[Abbreviations used in table 9 Rainfall (RF), Pre-monsoon (PRM), Post-monsoon (PTM), Observation Well (OW), and Observation Piezometer (OP)].

4.2. Groundwater Flow

To understand the groundwater flow condition (magnitude and direction), the water table elevation has been computed for all the 23 locations (Table 10), and the water table elevation maps for pre-monsoon and post-monsoon were prepared using Arc-GIS (10.4). The perusal of these maps (Figures 11 and 12) indicates that the groundwater flow gradient is steeper in the watershed's northern part than the central and southern parts. Groundwater flow has a sympathetic relationship with topographic slope, nature of sub-surface soil (overburden), and groundwater withdrawal. It is essential to mention that groundwater flow is from SW to NE during pre-monsoon and post-monsoon periods. It indicates that the groundwater recharge through precipitation in the area has no bearing on the groundwater movement.

Table 10. Water table elevation (WTE) during pre-monsoon and post-monsoon period in the study area. All values are in meter (m).

| Sample No | Location  | PRM Av. (2006-16) | PTM Av. (2006-16) |
|-----------|-----------|------------------|------------------|
| OW1       | Alipura   | 153.14           | 157.35           |
| OW2       | Bauraha   | 169.80           | 173.00           |
| OW3       | Bharwara  | 174.55           | 176.16           |
| OW4       | Dharwar   | 164.94           | 168.38           |
| OP5       | Dharwar   | 176.71           | 178.35           |
| OW6       | Kankau    | 193.76           | 194.19           |
| OW7       | Kotra     | 164.55           | 167.30           |
| OW8       | Panwari   | 157.32           | 160.16           |
| OP9       | Benda     | 177.09           | 179.33           |
| OP10      | Parapatar | 178.88           | 179.40           |
| OW11      | Rari Kala | 165.13           | 168.61           |
| OW12      | Toyya     | 184.81           | 186.15           |
| OP13      | Bahadur Kala | 176.89         | 185.01           |
| OW14      | Mathua Itaura | 168.50         | 169.78           |
| OP15      | Kalpadh Swasthy Kendra | 190.14         | 192.02           |
| OP16      | Mahua Bandh | 236.33           | 237.95           |
| OW17      | Leta      | 173.24           | 175.60           |
| OP18      | Ladpur    | 192.88           | 195.76           |
| OW19      | Bajipur   | 199.64           | 203.62           |
| OW20      | Bajipur   | 212.73           | 213.21           |
| OW21      | Ragoliya Bajipur | 186.88         | 189.52           |
| OW22      | Kalpadh   | 209.13           | 211.31           |
| OP23      | Khadya    | 187.76           | 190.38           |
Figure 11. Map showing groundwater flow during the pre-monsoon period (2006-2016).

Figure 12. Map showing groundwater flow direction during the post-monsoon period (2006-16).

5. Conclusion
The groundwater assessment in the Kulpahar watershed has been attempted considering the impact of precipitation on observed groundwater water levels for a long duration (2006-2016). The study reveals that the impact of precipitation is visible in unconsolidated overburden existing in the northern part of the watershed. The water table of a region is an essential available identity to evaluate changes in the nature of aquifers and groundwater. The declining water table in the western portion of the study area indicates discharge or more pumping from the aquifer for irrigation and drinking purposes. Rising the water table in the northern portion of the study area indicates the aquifer's optimum recharge. The declining and increasing trends during the pre-monsoon period reflect that the area under investigation is not dependent on rainfall rather than controlled by lithological characteristics, land-use practices, and proper aquifers management. To ameliorate the current groundwater condition scenario derived from the present study, the proper and effective artificial recharge structures and sustainable use of groundwater may be attempted in the southern part of Kulpahar Watershed on priority. So that the surface and sub-surface runoff is arrested at the required location.

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