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Temporal changes in groundwater quality under artificial recharge systems in the Bundelkhand region of Uttar Pradesh

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ABSTRACT

Groundwater scarcity and poor water quality are major constraints in the Bundelkhand region of Uttar Pradesh due to low rainfall retention, hard rock geology, and poor natural recharge capacity. The present study evaluated the effect of an artificial groundwater recharge system on groundwater quality and shallow aquifer replenishment at Banda University of Agriculture & Technology, Banda, Uttar Pradesh in the year of 2025. The recharge system included an artificial recharge pit, observation well, farm pond, and sub-surface barrier covering 28.5 ha watershed area. Groundwater samples collected from 15 locations were analyzed before and after recharge intervention for pH, Electrical Conductivity (EC), carbonates and bicarbonate, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), and chloride concentration. After recharge, EC decreased from 0.77–4.80 to 0.276–1.30 dS m^{-1}, while significant reductions in bicarbonate, RSC, and chloride concentrations were observed. Approximately 60 to 70% reduction in salinity hazard and 75 to 92% improvement in RSC were recorded. Groundwater levels also improved significantly following rainfall events, indicating enhanced aquifer recharge. The study demonstrated that artificial groundwater recharge effectively improved groundwater quality and groundwater availability under semi-arid conditions of Bundelkhand and may serve as a sustainable strategy for groundwater rejuvenation in water-stressed regions.

Keywords: Aquifers, Salinity, Sodicity, Drought, Groundwater recharge

INTRODUCTION

In the Bundelkhand region of Uttar Pradesh, most households live below the poverty line. The most often mentioned factor is the extreme water scarcity in the region. The region is characterized by the omnipresence of shallow soil that rests directly on the bedrock. As a result, the region has poor groundwater potential (only 4% of the total rainfall can be stored). The region has on average 850 mm of rainfall per year (June to September) but number of rainy days is very less. Hydrogeological settings of Bundelkhand region are different as most of the rainfall goes out from the area very rapidly after the monsoon and creates water shortage for rest of the time. As a result, trees and vegetation that hold topsoil, sediments as well as water are losing continuously. All these combined with undulating topography, improper management of available surface water leads to poor groundwater recharge capacity and most of the aquifers are deteriorating through both quality and quantity of available groundwater for crop production (Todd and Mays, 2022).

The demand for irrigation water is increasing day by day due to more diversification in crops and the demand for agricultural products. The south-west monsoon is responsible for about 80% of the annual rainfall. The Banda district is characterized by alluvial, hard rock as well as marginal alluvium. The district can be broadly classified into three physiographic units of alluvial Plain, marginal alluvial and high land area. The loose sediments as well as black cotton soils are mostly found in Banda district. The black cotton soil is prominent in the central part. The unconfined aquifers are comparatively shallow, and the thickness varies from

40 to 200 meters below ground level (m bgl) in the district (Central Ground Water Board, 2023). In BUAT campus groundwater level varies from 20 to 40 m bgl.

There are some general traditional practices of in-situ soil moisture conservation structures for making availability of soil moisture for long time and controlling heavy soil erosion. The available seepage from these structures may be lost through the prominent drainage system. Therefore, the study was conducted to prepare for developing such kind of structure that not only reduces the seepage loss but also harvest the subsurface flow to recharge the shallow aquifers of the area. As most of the subsurface flow exposed over the ground due to less penetration and lost through evaporation or drained out from the area prior to utilization and recharging the groundwater. The developed artificial recharge model intercept large quantity of base flow and ultimately recharging the groundwater. It also helped to increase the availability of irrigation water as well as improving the quality of groundwater. The developed model should replicate on the farmer's field for strengthening the traditional in-situ soil moisture conservation system prevailing in the area. Therefore, the present study was undertaken to evaluate the temporal changes in groundwater quality under an artificial recharge system in the Bundelkhand region of Uttar Pradesh.

MATERIAL AND METHODS

Experimental Site Setup

The study was conducted in a 28.5 ha independent watershed area at Banda University of Agriculture & Technology, Banda, Uttar Pradesh. The artificial recharge system consisted of a recharge structure, observation well, farm pond, and sub-surface barrier. A recharge shaft was constructed upstream of the farm pond for direct injection of harvested rainwater into the shallow aquifer, while an observation well was installed downstream for monitoring groundwater level fluctuations and water quality changes. The design depth and dimensions of the recharge structure were finalized after detailed investigation of sub-surface strata and aquifer conditions.

The groundwater samples were collected from 15 sites from catchment area of study area and analyzed their quality parameters. The details of sampling sites are presented in Table 1 and Fig 1.

Table 1. Details of water sampling sites under study area

Samp_ID	Latitude	Longitude	Source
W01	25.51905659	80.34576652	Handpump
W02	25.51957172	80.34233875	Handpump
W03	25.52115801	80.34307509	Handpump
W04	25.52101804	80.34407705	Handpump
W05	25.533167	80.350803	Handpump
W06	25.532371	80.350204	Well
W07	25.532661	80.348991	Well
W08	25.531245	80.347275	Handpump
W09	25.531245	80.348175	Handpump
W10	25.53065	80.346519	Handpump
W11	25.52566	80.346913	Tube Well
W12	25.52571	80.346119	Tube Well
W13	25.52461	80.34607	Tube Well
W14	25.5245	80.34584	Pond
W15	25.52569	80.346268	Pond

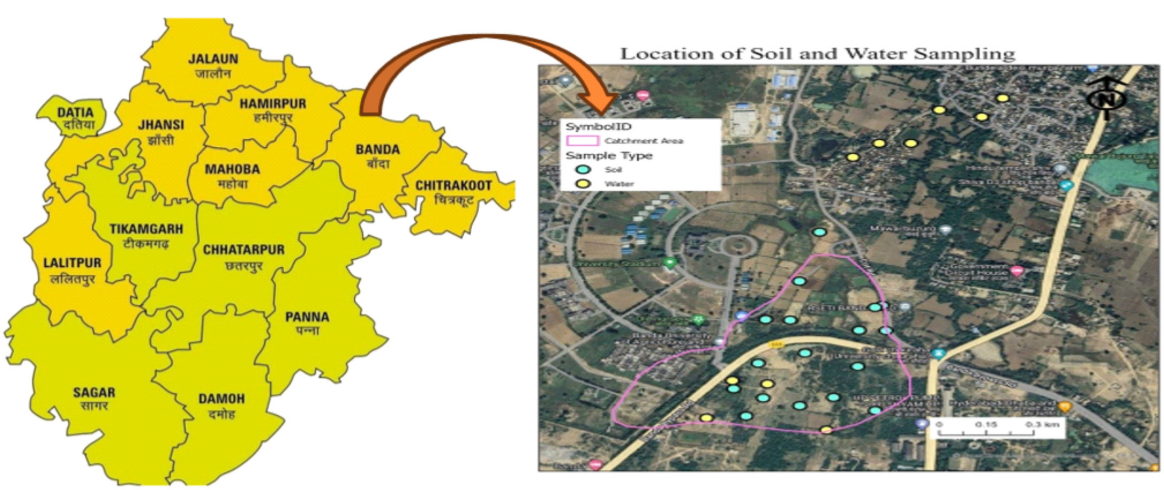

Fig. 1. Location of study site

Methods of Water Analysis

Groundwater samples were collected from different locations of the study area in clean plastic bottles and analyzed using standard analytical procedures (APHA, 2017). The pH and Electrical Conductivity (EC) of water samples were measured using digital pH and EC meters, respectively. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations were determined by acid titration using standard sulfuric acid. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were estimated through EDTA titration method, while sodium (Na^+) concentration was determined using a flame photometer. Chloride (Cl^-) content was analyzed by argentometric titration method. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were calculated using standard formulae. All analyses were carried out following standard procedures recommended for irrigation water quality assessment.

Collection of Baseline Information of Catchment Area

The catchment area was delineated using Digital Elevation Model (DEM) data and Google Earth imagery. Detailed field surveys were conducted to assess watershed characteristics such as slope, relief, drainage pattern, and drainage length for estimation of surface runoff and planning of the groundwater recharge system. The experimental site was selected within an agricultural watershed free from major point sources of pollution so that excess runoff water could be safely utilized for artificial recharge of shallow aquifers.

Establishment of Groundwater Recharge System

The artificial recharge structure consisted of a recharge pit measuring 3.05 × 1.50 × 3.00 m with a shaft depth of 42.70 m and shaft diameter of 0.20 m. The structure was designed to facilitate direct recharge of harvested rainwater into the shallow aquifer system for improving groundwater quantity and quality.

Establishment of Observation Well

An observation well was established under the project for continuous monitoring of groundwater level fluctuations and water quality changes. The bore depth of the observation well was approximately 44.20 m with a bore diameter of 0.20 m. The observation well was used for periodic monitoring during pre-monsoon and post-monsoon periods.

Establishment of Surface Storage cum Sub-surface Barrier

An outlet cum sub-surface barrier was constructed to regulate excess runoff from the farm pond and enhance groundwater recharge. The waste weir cum sub-surface barrier had a crest length of 3.01 m, height of 0.80 m, and sub-surface barrier dimensions of 10.70 m × 3.01 m. The structure improved water retention and promoted infiltration into shallow aquifers.

Evaluation of Artificial Recharge System

Groundwater levels and water quality parameters were monitored periodically before and after monsoon seasons to evaluate the effectiveness of the recharge system. Soil moisture content at different locations within the catchment area was also monitored using standard procedures. Groundwater quality analysis included measurement of pH, Electrical Conductivity (EC), carbonate, bicarbonate, calcium, magnesium, sodium, Sodium Adsorption Ratio (SAR), and Residual Sodium Carbonate (RSC) to assess temporal changes in groundwater quality after artificial recharge intervention.

RESULT AND DISCUSSION

Groundwater quality analysis revealed significant improvement in *physico-chemical* properties after implementation of the artificial recharge system in the BUAT campus in Banda district of Uttar Pradesh. The initial soil and water samples parameters are depicted in Figure 2. The pH ranged from 7.21 to 8.94, while Electrical Conductivity (EC) varied from 0.77 to 4.80 dS m^{-1}, indicating medium to very high salinity conditions. Residual Sodium Carbonate (RSC) values ranged from 1.2 to 19.3 me L^{-1}, Sodium Adsorption Ratio (SAR) ranged from 0.99 to 18.82, and chloride concentration varied between 82.4 and 88.2 me L^{-1}, indicating poor groundwater quality for irrigation at several locations.

After establishment of the artificial recharge system, considerable improvement in groundwater quality was observed. The quality parameters of water sample collected in 2025 are presented in Figure 3.The pH remained within acceptable limits (7.11–8.55), while EC decreased significantly to 0.276–1.30 dS m^{-1}, showing approximately 60–70% reduction in salinity hazard compared to pre-recharge conditions. Carbonate ions were absent in

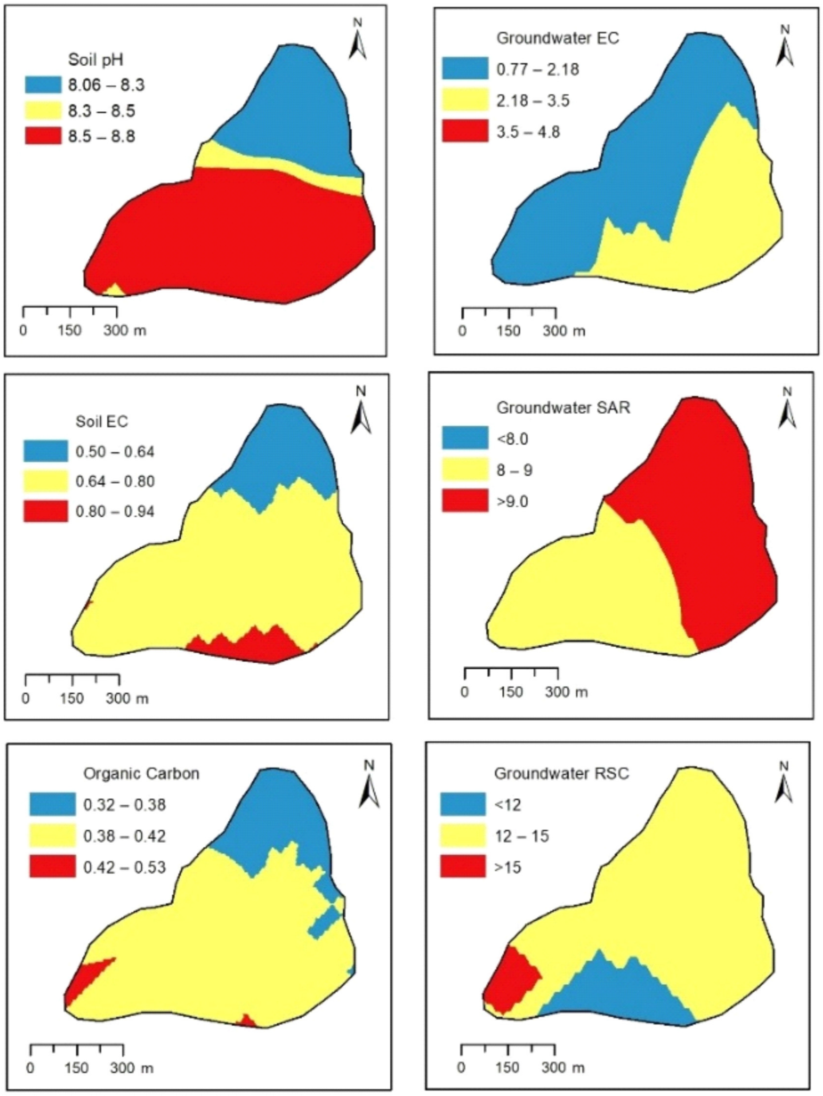

Fig. 2. Qualitative analysis of soil and water samples in 2023

all groundwater samples after recharge intervention, whereas bicarbonate concentration reduced from 8.7–24.0 me L^{-1} to 7.5–11.4 me L^{-1}, indicating nearly 50–60% reduction in alkalinity hazard.

Residual Sodium Carbonate (RSC) values decreased markedly from 1.2–19.3 me L^{-1} to 1.4–3.6 me L^{-1}, representing approximately 75–92% improvement in groundwater suitability for irrigation. Similarly, chloride concentration declined substantially from 82.4–88.2 me L^{-1} to 16.0–23.9 me L^{-1}, indicating about 70–80% reduction in chloride hazard after recharge intervention.

Although SAR values remained within moderate sodicity range after recharge (10.22–11.61), the variability and extremity of sodicity hazards reduced considerably compared to pre-recharge conditions, showing approximately 25–30% improvement in sodium hazard. The reduction in EC, RSC, bicarbonate concentration, and chloride content clearly indicated dilution of dissolved salts due to infiltration of harvested rainwater into shallow aquifers.

The observed temporal improvement in groundwater quality demonstrated the effectiveness of artificial recharge structures in mitigating salinity and alkalinity hazards under semi-arid conditions. The recharge system enhanced aquifer replenishment, improved groundwater circulation, and reduced accumulation of soluble salts in groundwater. Therefore, artificial groundwater recharge may serve as a sustainable strategy for improving groundwater quality and irrigation

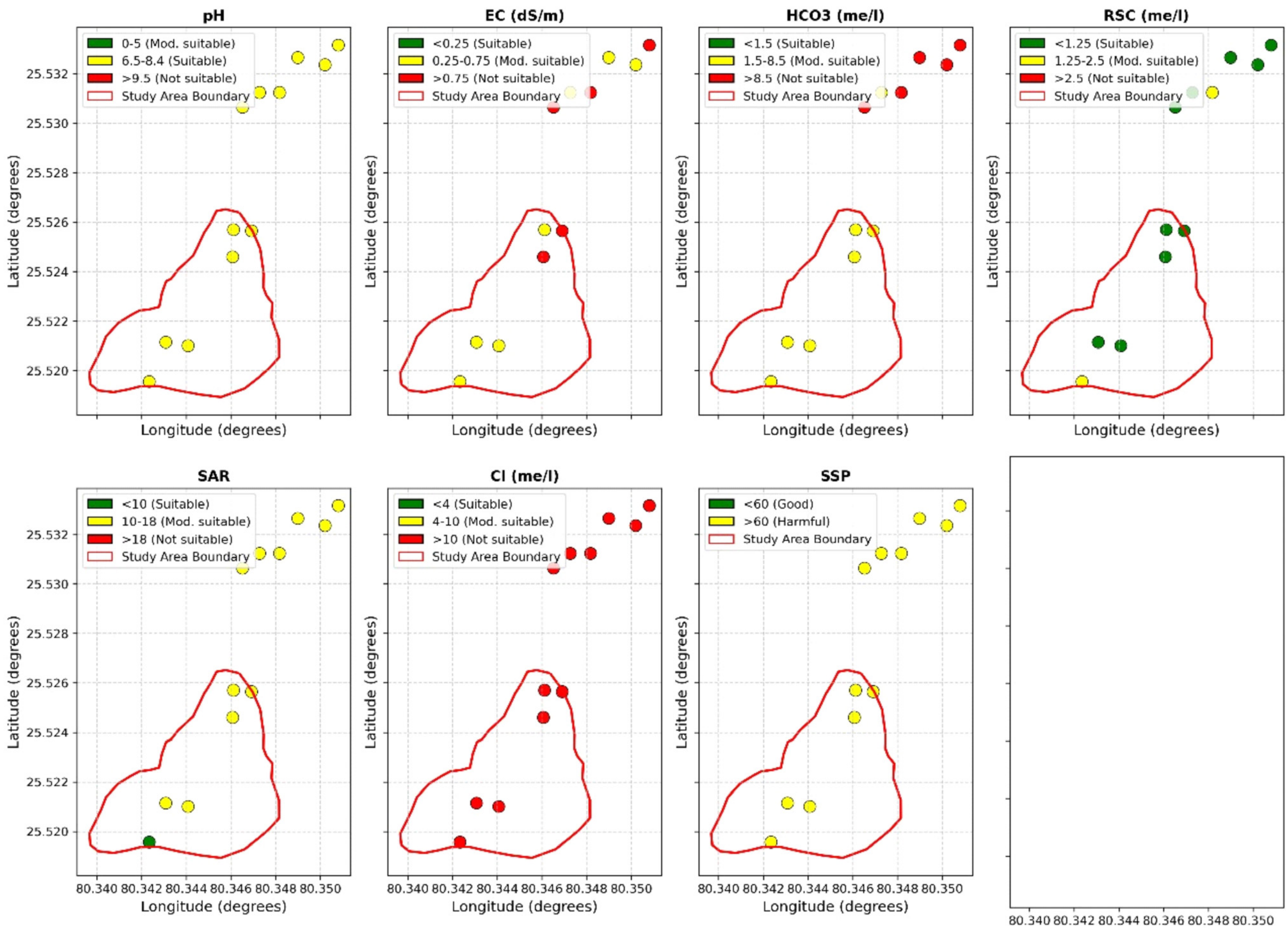

Fig. 3. Quality parameters of water samples collected from catchment area of study sites in 2025

suitability in salt-affected regions of Bundelkhand. Similar study was conducted by Ali and Ali (2018); Pandey *et al.* (2021); Singh *et al.* (2021).

Temporal Changes in Groundwater Level

The graph illustrates the temporal variation in groundwater level of the observation well and recharge well in relation to rainfall events (Figure 4). A significant decline in pressure head (water depth) was observed after rainfall occurrences, indicating rapid recharge of shallow aquifers through the artificial recharge system.

Initially, groundwater depth remained around 3.6–3.8 m, but after continuous rainfall events, the water level gradually rose and reached about 1.1–1.5 m, demonstrating effective recharge of groundwater. The recharge well responded more rapidly to rainfall compared to the observation well due to direct infiltration through the recharge structure.

After the monsoon period, groundwater levels showed a gradual decline due to reduced rainfall and groundwater withdrawal. Overall, the results indicate that the artificial recharge system significantly improved groundwater recharge and enhanced shallow aquifer storage in the Bundelkhand region of Uttar Pradesh.

CONCLUSION

The artificial groundwater recharge significantly improved groundwater quality in the Bundelkhand region of Uttar Pradesh. The recharge interventions through recharge pit, observation wells, farm ponds, and sub-surface barriers enhanced infiltration of harvested rainwater into shallow aquifers, resulting in reduction of salinity and sodicity hazards.

A considerable decrease in Electrical Conductivity, Residual Sodium Carbonate, bicarbonate concentration, and chloride content was

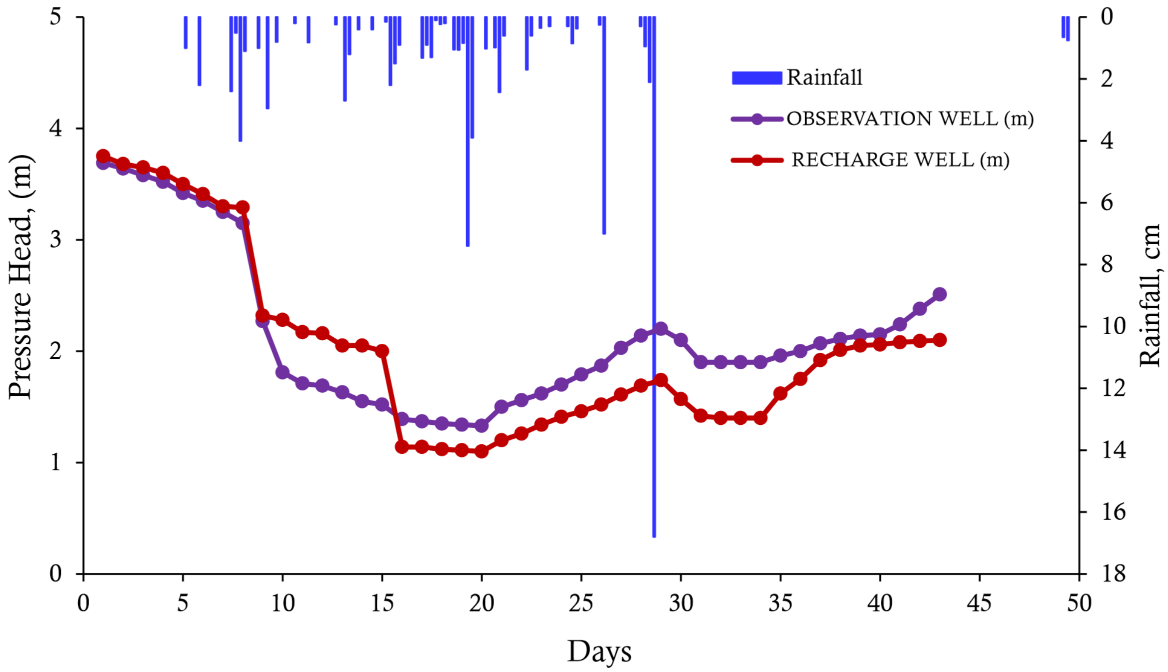

Fig. 4. Temporal changes of ground water level in observation well

observed after recharge intervention. Approximately 60–70% reduction in salinity hazard, 75–92% improvement in RSC, 50–60% reduction in alkalinity hazard, and 70–80% reduction in chloride concentration were recorded compared to pre-recharge conditions. The Sodium Adsorption Ratio also showed improvement, indicating better suitability of groundwater for irrigation purposes.

Temporal monitoring of groundwater quality confirmed that artificial recharge diluted dissolved salts and improved overall groundwater conditions in shallow aquifers. The study suggests that artificial groundwater recharge systems can serve as an effective and sustainable approach for rejuvenating degraded aquifers and improving irrigation water quality in semi-arid and salt-affected regions of Bundelkhand. Replication of such recharge models at village and watershed levels may substantially enhance groundwater sustainability and agricultural productivity in water-stressed regions of Uttar Pradesh.

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