Sustainable Groundwater Management and Water Resource Availability in Western Uttar Pradesh: Challenges, Opportunities, and Policy Implications

Dr. Mohit Saharan

Professor, Dr. K.N. Modi Institute of Engineering & Technology, Modinagar, Uttar Pradesh, India

DOI: https://doi.org/10.51244/IJRSI.2026.1306000304

Received: 20 June 2026; Accepted: 25 June 2026; Published: 07 July 2026

ABSTRACT

Water is one of the most critical natural resources for sustaining agriculture, industry, and human life. Western Uttar Pradesh, situated in the fertile Indo-Gangetic Plain, is among the most agriculturally productive regions of India. The region depends heavily on groundwater resources for irrigation, domestic consumption, and industrial activities. The extensive cultivation of water-intensive crops such as sugarcane, wheat, and rice has significantly increased groundwater extraction over the past few decades. Simultaneously, rapid urbanization and industrial growth in districts such as Ghaziabad, Meerut, and Hapur have further intensified pressure on available water resources. This study examines groundwater availability, hydrogeological characteristics, challenges related to water management, and sustainable solutions for groundwater conservation in Western Uttar Pradesh. The paper emphasizes the need for integrated water resource management involving groundwater recharge, rainwater harvesting, efficient irrigation technologies, and community participation to ensure long-term water security and sustainable regional development.

Keywords: Groundwater Management, Water Resources, Western Uttar Pradesh, Sustainable Development, Rainwater Harvesting, Irrigation, Water Conservation

INTRODUCTION

Water plays a crucial role in socio-economic development and environmental sustainability. India possesses approximately 18% of the world's population but only about 4% of global freshwater resources. Consequently, effective water resource management has become essential for ensuring food security and economic growth.

Western Uttar Pradesh is one of India's most important agricultural regions. The area comprises districts such as Meerut, Ghaziabad, Hapur, Baghpat, Muzaffarnagar, Shamli, Saharanpur, Bulandshahr, Bijnor, and Gautam Buddha Nagar. The region lies within the Ganga-Yamuna Doab and benefits from fertile alluvial soils and extensive canal irrigation systems.

Despite these advantages, increasing dependence on groundwater has resulted in declining water tables in several districts. Rapid industrialization, population growth, and urban expansion have intensified pressure on water resources. Therefore, sustainable groundwater management has become a critical concern for policymakers, researchers, and stakeholders.

The nation's hydrogeological configuration

India is a large nation with a very diverse hydrogeologic system. Due to the presence of diverse geological formations with significant lithological and chronological changes, a complex tectonic framework, climatological differences, and a range of hadrochemical circumstances, the ground water behaviors on the Indian subcontinent are extremely complex. The age range of the rock formations is from the Quaternary-Recent to the Archaean. While recent sediments are limited to Indo-Gangetic alluvial plains, Archaean rocks can be found in southern states. The following are the main geological formations:

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

- Consolidated formations are made up of both igneous and metamorphic rocks, with the main types being granites, quartzites, quartzites and related phyllite, slate, etc., as well as basalts and related igneous rocks.

- The Mesozoic and Tertiary rocks that make up the semi-consolidated rock formations include limestone, sandstone, pebbles, and boulder conglomerates.

- Major rocks including boulders, pebbles, various grades of sand, and silt-clay are examples of the unconsolidated formations that date from the Pleistocene to the recent period. The main possible aquifer zones are formed by these rocks.

Hydrogeological Setting of Western Uttar Pradesh

Western Uttar Pradesh forms an integral part of the fertile **Indo-Gangetic Alluvial Plain** and possesses one of the most productive groundwater systems in India. The region comprises districts such as Meerut, Ghaziabad, Hapur, Baghpat, Muzaffarnagar, Shamli, Saharanpur, Bulandshahr, Bijnor, and Gautam Buddha Nagar. The hydrogeological characteristics of the region are primarily controlled by its alluvial geology, geomorphology, river systems, rainfall patterns, and land-use practices.

The geological formations of Western Uttar Pradesh consist predominantly of unconsolidated and semi-consolidated alluvial deposits of Quaternary age. These deposits are composed of sand, silt, clay, gravel, and kankar layers deposited by major river systems including the Ganga, Yamuna, Hindon, Kali, Krishni, and Ramganga rivers. Hydrogeologically, these formations can be classified as highly porous and permeable aquifers with substantial groundwater storage capacity.

The region is characterized by extensive multi-aquifer systems occurring at various depths. The shallow aquifers are generally unconfined and receive direct recharge from rainfall, canals, rivers, and irrigation return flows. The deeper aquifers are confined and possess significant groundwater reserves that support agricultural, domestic, and industrial water demands.

Physiography and Geomorphology

The physiography of Western Uttar Pradesh plays a significant role in groundwater occurrence and distribution. The region is broadly divided into the following geomorphic units:

1. Ganga-Yamuna Doab Region

The Ganga-Yamuna Doab constitutes the largest geographical area of Western Uttar Pradesh. It is bounded by the Ganga River in the east and the Yamuna River in the west. The area is characterized by fertile alluvial soils, gentle slopes, and extensive agricultural activities.

The alluvial deposits in this region often exceed several hundred meters in thickness and form highly productive aquifers. Groundwater occurs under both unconfined and confined conditions, making the area one of the most important groundwater reservoirs in India. Tube wells and bore wells in this region generally provide high yields suitable for irrigation and domestic supply.

2. Upper Ganga Floodplain

The floodplain areas along the Ganga River possess highly permeable sandy deposits that facilitate groundwater recharge. These zones serve as natural recharge areas and contribute significantly to maintaining groundwater levels in adjoining districts such as Bijnor, Meerut, Hapur, and Bulandshahr.

Groundwater quality in these areas is generally suitable for irrigation and drinking purposes, although localized contamination issues may occur due to anthropogenic activities.

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3. Yamuna Floodplain Region

The Yamuna floodplain extends across districts such as Baghpat, Ghaziabad, and Gautam Buddha Nagar. The aquifers in this region consist of coarse sand and gravel deposits with high transmissivity and storage characteristics.

These floodplains offer substantial opportunities for managed aquifer recharge and sustainable groundwater development. However, increasing urbanization and industrialization have created challenges related to groundwater contamination and declining recharge rates.

4. Hindon and Kali River Basin Areas

The Hindon and Kali river basins form important hydrogeological zones in Western Uttar Pradesh. Groundwater resources in these areas are influenced by river recharge and canal irrigation systems. However, industrial effluents and untreated wastewater have adversely affected groundwater quality in several locations, particularly around Ghaziabad and Meerut.

Groundwater Potential

Western Uttar Pradesh possesses excellent groundwater potential due to the presence of thick alluvial deposits and favorable recharge conditions. The aquifer systems exhibit high transmissivity and storage coefficients, enabling large-scale groundwater extraction.

The yield of tube wells generally ranges between **20 and 100 liters per second (lps)** depending upon aquifer thickness, depth, and local hydrogeological conditions. Groundwater is extensively utilized for:

- Agricultural irrigation
- Domestic water supply
- Industrial activities
- Commercial establishments

Agriculture remains the dominant consumer of groundwater, accounting for more than 80 percent of total groundwater extraction in the region.

Groundwater Recharge Sources

Groundwater recharge in Western Uttar Pradesh occurs through multiple sources:

- Monsoon rainfall
- Seepage from canals
- River infiltration
- Irrigation return flow
- Ponds and wetlands
- Artificial recharge structures

The extensive canal network, particularly the **Upper Ganga Canal System** and **Eastern Yamuna Canal System**, contributes significantly to groundwater recharge.

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Groundwater Resources Availability in Western Uttar Pradesh

Groundwater is the most important source of water for irrigation, domestic consumption, and industrial development in Western Uttar Pradesh. The region receives average annual rainfall ranging from **700 mm to 1100 mm**, with nearly 80 percent occurring during the southwest monsoon season.

The alluvial aquifers of Western Uttar Pradesh possess substantial groundwater reserves due to favorable geological conditions and continuous recharge from rainfall and canal systems. However, rapid agricultural expansion, urbanization, and industrial growth have increased groundwater extraction considerably over the past few decades.

Groundwater withdrawal primarily takes place from shallow and intermediate aquifers through tube wells and submersible pumps. The irrigation sector remains the largest consumer of groundwater resources, particularly for the cultivation of sugarcane, wheat, and rice.

Several districts, including Meerut, Ghaziabad, Hapur, Baghpat, and Gautam Buddha Nagar, have experienced declining groundwater levels due to excessive extraction. In contrast, some floodplain regions continue to exhibit favorable recharge conditions and substantial groundwater availability.

The sustainable management of groundwater resources in Western Uttar Pradesh requires a balanced approach involving groundwater recharge, efficient irrigation technologies, rainwater harvesting, and scientific monitoring of aquifer systems. Such measures are essential to ensure long-term water security and support sustainable agricultural and economic development in the region.

REVIEW OF LITERATURE

Several researchers have highlighted the importance of groundwater management in India.

Jha (2007) emphasized that groundwater has become the backbone of Indian agriculture and contributes significantly to food security.

Shah (2009) observed that groundwater irrigation has transformed agricultural productivity but has also led to overexploitation in many regions.

Central Ground Water Board (CGWB, 2023) reported that several blocks in Western Uttar Pradesh are experiencing declining groundwater levels due to excessive extraction.

Kumar and Singh (2021) highlighted the importance of rainwater harvesting and artificial recharge techniques in maintaining groundwater sustainability.

National Water Policy (2012) advocates integrated management of surface and groundwater resources to achieve sustainable development.

The literature indicates that sustainable groundwater management requires a combination of technological, institutional, and policy interventions.

Objectives of the Study

The present study aims to:

1. Examine the hydrogeological characteristics of Western Uttar Pradesh.
2. Analyze groundwater availability and utilization patterns.
3. Identify major challenges affecting water resource sustainability.

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4. Evaluate existing water management practices.
5. Suggest policy measures for sustainable groundwater management.

RESEARCH METHODOLOGY

The study is primarily based on secondary data collected from:

- Central Ground Water Board (CGWB)
- Ministry of Jal Shakti
- Uttar Pradesh Groundwater Department
- Government reports
- Research journals
- Published books and articles

A descriptive and analytical research design has been adopted to examine groundwater availability and management practices in the region.

Hydrogeological Profile of Western Uttar Pradesh

Western Uttar Pradesh forms a part of the Indo-Gangetic Alluvial Plain. The region consists of thick deposits of:

- Sand
- Silt
- Clay
- Gravel

These deposits create highly productive aquifer systems capable of storing substantial quantities of groundwater.

Major rivers influencing groundwater recharge include:

- Ganga
- Yamuna
- Hindon
- Kali
- Ramganga
- Krishni

Groundwater occurs under both confined and unconfined conditions and is extensively extracted through tube wells, bore wells, and submersible pumps.

Water Resources Availability

Water resources in Western Uttar Pradesh originate from three major sources:

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Groundwater

Groundwater constitutes the primary source of irrigation and domestic water supply.

Major Uses:

- Agricultural irrigation
- Domestic consumption
- Industrial processes
- Commercial establishments

Surface Water

Surface water resources include:

- Upper Ganga Canal
- Eastern Yamuna Canal
- River systems
- Ponds and reservoirs

RAINFALL

Average annual rainfall ranges between 700 mm and 1100 mm.

Approximately 80% of annual rainfall occurs during the southwest monsoon season.

Water Management Challenges in Western Uttar Pradesh

Overexploitation of Groundwater

Continuous extraction for irrigation has resulted in falling groundwater levels in many districts.

Particularly affected areas include:

- Ghaziabad
- Meerut
- Gautam Buddha Nagar
- Hapur
- Baghpat

Water-Intensive Agriculture

Sugarcane cultivation occupies a significant portion of agricultural land and requires large quantities of water.

Major water-intensive crops:

- Sugarcane

- Rice
- Wheat

Urbanization

Rapid urban growth has reduced natural recharge areas through:

- Concrete construction
- Road development
- Encroachment of ponds

Industrial Pollution

Industrial activities contribute to groundwater contamination through:

- Untreated effluents
- Heavy metals
- Chemical waste discharge

Climate Change

Climate variability affects:

- Rainfall distribution
- Groundwater recharge
- Water availability

Existing Water Management Practices

Canal Irrigation System

The Upper Ganga Canal network plays a significant role in reducing dependence on groundwater.

Rainwater Harvesting

Government agencies have promoted rainwater harvesting structures in:

- Educational institutions
- Residential colonies
- Industrial complexes

Artificial Recharge Structures

Common recharge techniques include:

- Recharge wells
- Check dams

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- Percolation tanks
- Recharge trenches

Watershed Development Programs

Several watershed management projects have improved groundwater recharge and soil conservation.

Sustainable Water Management Strategies

Promotion of Rainwater Harvesting

Mandatory rainwater harvesting should be implemented in:

- Government buildings
- Educational institutions
- Commercial complexes
- Residential societies

Efficient Irrigation Technologies

Farmers should adopt:

- Drip irrigation
- Sprinkler irrigation
- Precision farming techniques

Benefits include:

- Water conservation
- Increased productivity
- Reduced irrigation costs

Crop Diversification

Farmers should be encouraged to shift from water-intensive crops toward:

- Pulses
- Oilseeds
- Millets
- Vegetables

Restoration of Traditional Water Bodies

Revival of:

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- Ponds
- Wetlands
- Village tanks

can significantly enhance groundwater recharge.

Community Participation

Local communities should be actively involved in:

- Water conservation programs
- Monitoring groundwater extraction
- Maintenance of recharge structures

Smart Water Governance

Government agencies should utilize:

- GIS mapping
- Remote sensing
- Digital groundwater monitoring systems

for effective water resource management.

FINDINGS OF THE STUDY

The study reveals that:

1. Western Uttar Pradesh possesses significant groundwater resources due to its alluvial geology.
2. Agriculture accounts for the largest share of groundwater extraction.
3. Water-intensive crops contribute substantially to groundwater depletion.
4. Urbanization has reduced groundwater recharge potential.
5. Rainwater harvesting and artificial recharge can significantly improve groundwater sustainability.
6. Community participation is essential for effective water management.

Policy Recommendations

1. Strengthen groundwater regulation mechanisms.
2. Promote water-efficient agricultural practices.
3. Implement mandatory rainwater harvesting.
4. Encourage crop diversification.
5. Increase investment in recharge infrastructure.

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6. Enhance public awareness regarding water conservation.

7. Develop district-level water management plans.

8. Promote integrated surface and groundwater management.

CONCLUSION

Western Uttar Pradesh possesses abundant groundwater resources due to its favorable hydrogeological conditions and extensive alluvial aquifers. However, increasing agricultural demand, rapid urbanization, industrial growth, and climate variability have placed immense pressure on these resources. Sustainable water management is therefore essential for ensuring future water security.

An integrated approach combining groundwater recharge, rainwater harvesting, efficient irrigation technologies, crop diversification, regulatory measures, and community participation can significantly improve water resource sustainability. Effective implementation of these strategies will not only ensure long-term groundwater availability but also support agricultural productivity, economic growth, and environmental conservation in Western Uttar Pradesh.

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