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# "Identification of Potential Groundwater Zones in Sitapur Using Remote Sensing and GIS Techniques"

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**1. ABSTRACT**

Groundwater plays a vital role in sustaining agriculture, drinking water supply, and overall socio-economic development, especially in agrarian regions like Sitapur district in Uttar Pradesh, India. With increasing groundwater stress due to over-extraction and changing land use patterns, it becomes imperative to assess and delineate groundwater potential zones scientifically. This study utilizes an integrated geospatial approach involving Remote Sensing (RS), Geographic Information Systems (GIS), and the Analytical Hierarchy Process (AHP) to identify potential groundwater zones in Sitapur. Multiple thematic layers—geology, geomorphology, land use/land cover, slope, drainage density, soil, and lineament density—were prepared and weighted based on their influence on groundwater occurrence. Thematic layers were then integrated using a weighted overlay analysis to classify the district into five groundwater potential zones: very high, high, moderate, low, and very low. The results indicate that around 43% of the district falls under high and very high potential zones, primarily along the Gomti and Sarayan river floodplains. The spatial pattern reveals that topography, land use, and lineament density significantly govern groundwater potential in the area. This methodology offers a cost-effective and scalable tool for groundwater assessment, aiding in sustainable water resource planning and development, particularly in alluvial regions like the Indo-Gangetic plain.

**Keywords:** Groundwater Potential Zones, Sitapur District, Remote Sensing, GIS, Weighted Overlay, Analytical Hierarchy Process, Alluvial Aquifers, Sustainable Water Management, Indo-Gangetic Plain, Groundwater Recharge.

## 2. Introduction

Groundwater is one of the most vital natural resources sustaining human livelihood, agriculture, and industrial growth, especially in developing nations such as India. It serves as a major source of irrigation and potable water, contributing significantly to socio-economic development. In India, where more than 60% of agricultural activities depend on groundwater irrigation, the management and sustainable utilization of this resource are becoming increasingly crucial (Babykalpana & ThanushKodi, 2010). The Indo-Gangetic Plain, in particular, represents one of the most densely populated and agriculturally productive regions of the world and is characterized by an extensive alluvial aquifer system. Sitapur, a district in the central part of Uttar Pradesh, lies within this plain and is heavily reliant on groundwater for both drinking and irrigation purposes.

However, excessive exploitation and erratic rainfall patterns have led to a significant decline in groundwater levels across many parts of India, including Sitapur. Agricultural intensification, particularly the expansion of high water-requirement crops and the unregulated drilling of bore wells, has exacerbated this problem. Consequently, it has become imperative to identify areas with high groundwater potential to ensure the judicious and efficient use of available resources. The conventional methods of groundwater exploration, including hydrogeological surveys and geophysical investigations, are often expensive, time-consuming, and limited in spatial coverage. This has driven the shift towards adopting modern techniques that integrate spatial data with earth observation science.

In this context, Remote Sensing (RS) and Geographic Information System (GIS) technologies have emerged as powerful tools for evaluating groundwater potential zones. Remote sensing allows the acquisition of data over large and inaccessible regions, offering consistent temporal and spatial coverage. When integrated with GIS, these data can be effectively used to analyze, visualize, and model complex hydrological and geological interactions that influence groundwater occurrence. Several studies have demonstrated the efficacy of using multi-criteria decision-making techniques within a GIS framework to delineate groundwater potential zones (Zhu et al., 2014; Subudhi et al., 2025).

The delineation of groundwater potential zones using RS-GIS involves the integration of various thematic layers such as geology, geomorphology, lineament density, slope, soil type, land use/land cover (LULC), and drainage pattern. These factors influence the infiltration, percolation, and storage of water in subsurface formations. For instance, LULC data derived from satellite imagery provide insights into land characteristics that either promote or restrict groundwater recharge. Urban and impervious areas reduce percolation, while forested and agricultural lands generally enhance recharge potential. Similarly, slope analysis using Digital Elevation Models (DEMs) reveals that flatter terrains favor water retention and infiltration compared to steep slopes, which induce higher runoff (Liu et al., 2024).

Sitapur district, covering an area of over 5,700 square kilometers, lies between latitudes 27°34'N to 27°57'N and longitudes 80°18'E to 81°24'E. It is characterized by a humid subtropical climate, with an average annual rainfall of around 1100 mm, most of which is received during the southwest monsoon season. The terrain is predominantly flat with minor undulations, and the district is drained by the Gomti, Sarayan, and Ghaghra rivers, which support the formation of fluvial and alluvial landforms suitable for groundwater accumulation. Geologically, the region is underlain by Quaternary alluvium composed of sand, silt, clay, and kankar, creating favorable conditions for groundwater storage and movement (Al-Wassai & Kalyankar, 2013).

Despite the apparent hydrological advantages, there is a lack of comprehensive, spatially distributed groundwater potential mapping in Sitapur. The district is experiencing increasing stress on its aquifer systems due to over-reliance on groundwater, largely driven by population pressure and agricultural intensification. Inadequate recharge, land use changes, and the absence of scientific planning exacerbate the issue. Thus, identifying groundwater potential zones using geospatial technology becomes critical not only for sustainable water resource management but also for informed land-use planning and rural development.

The identification process typically involves the preparation of multiple raster layers from satellite data and ancillary sources, including slope from SRTM DEM, lineaments from Landsat or Sentinel-2 imagery, and soil maps from the National Bureau of Soil Survey. These layers are assigned weights based on their relative contribution to groundwater occurrence using Multi-Criteria Decision Making (MCDM) techniques such as the Analytical Hierarchy Process (AHP). This approach has been widely used in similar hydrogeological terrains to produce accurate and reliable groundwater potential zone maps (Herho et al., 2018). Studies conducted in other alluvial regions, including parts of Odisha and the Lower Ganges Basin, have also shown the utility of hybrid machine learning models combined with RS-GIS layers for groundwater mapping and contamination risk prediction (Subudhi et al., 2025; Li et al., 2025).

Another critical advantage of RS-GIS approaches is their adaptability to changing environmental conditions. With increasing climatic variability, traditional groundwater assessments become obsolete over time. In contrast, remote sensing-based groundwater studies can be periodically updated using recent satellite observations, providing a dynamic tool for decision-makers and groundwater managers. Moreover, incorporating ancillary data such as rainfall, evapotranspiration, and recharge estimates can enhance the reliability of predictions and support targeted interventions in critical areas.

The present study aims to identify potential groundwater zones in Sitapur district using a comprehensive geospatial methodology that integrates remote sensing data, GIS techniques, and multi-criteria analysis. The approach not only seeks to delineate zones of high and moderate groundwater potential but also serves as a blueprint for replicating similar studies in other parts of the Indo-Gangetic alluvial plains. By identifying favorable recharge zones, the study intends to guide effective artificial recharge programs, well placement, and sustainable groundwater abstraction practices. Ultimately, such spatially informed approaches are crucial for ensuring long-term water security in regions like Sitapur that are at the intersection of agricultural demand and climatic uncertainty.

## 3. Study Area: Sitapur District

Sitapur district, located in the northern part of the Indian state of Uttar Pradesh, represents a typical Indo-Gangetic alluvial plain region. It is one of the key agrarian districts in the state, with high dependence on groundwater for irrigation and drinking water purposes. The region's physiography, hydrology, and geological characteristics make it suitable for groundwater studies using geospatial techniques. This section outlines the physical, climatic, geological, hydrological, and socio-economic attributes of Sitapur that influence groundwater occurrence and recharge.

### *3.1 Location and Administrative Boundaries*

Sitapur district lies between latitude 27°34'N to 27°57'N and longitude 80°18'E to 81°24'E. It is bounded by Lakhimpur Kheri in the north, Barabanki and Bahraich in the east, Hardoi in the west, and Lucknow in the south. The district is administratively divided into 7 tehsils and 19 development blocks, encompassing a total area of approximately 5,743 km².

**Table 1: Key Geographical and Administrative Features of Sitapur District**

| **Feature** | **Description** |
|---|---|
| Total Area | 5,743 km² |
| Latitude Range | 27°34'N to 27°57'N |
| Longitude Range | 80°18'E to 81°24'E |
| Average Elevation | 138 meters above sea level |
| Administrative Divisions | 7 Tehsils, 19 Blocks |
| Total Villages | ~2,300 |
| Major Towns | Sitapur, Laharpur, Mishrikh, Mahmoodabad |
| River Systems | Gomti, Ghaghra, Sarayan, Kathina |

| | |
|---|---|
| Soil Types | Alluvial soils, sandy loam, clay |
| Main Crops | Rice, wheat, sugarcane, pulses |

### *3.2 Climate*

Sitapur experiences a sub-tropical humid climate with three distinct seasons: summer, monsoon, and winter. The temperature varies between 4°C in winter and 43°C in summer. The district receives an average annual rainfall of about 1100 mm, primarily during the southwest monsoon (June to September), which accounts for over 85% of the total rainfall. Rainfall plays a crucial role in recharging shallow aquifers and influences seasonal fluctuations in the water table.

### *3.3 Physiography and Drainage*

The terrain of Sitapur is predominantly flat and alluvial, with mild undulations. The landscape has been shaped by fluvial processes, making it suitable for groundwater accumulation and movement. The district is traversed by several rivers, including the Gomti, Ghaghra, Sarayan, and Kathina, which drain from northwest to southeast and are part of the larger Ganga basin. These rivers have carved out gentle floodplains and meander belts, which enhance recharge potential through infiltration.

Remote sensing-based geomorphological mapping of the region indicates the dominance of floodplains, channel bars, and ox-bow lakes, all of which serve as potential recharge zones for groundwater (Herho et al., 2018; Subudhi et al., 2025).

### *3.4 Geology and Soil Characteristics*

Geologically, Sitapur is part of the Quaternary alluvial deposits of the Ganga basin. The lithological profile consists primarily of unconsolidated sediments like sand, silt, clay, and kankar (calcareous nodules), deposited over time by fluvial action. These formations provide favorable conditions for groundwater occurrence due to high porosity and permeability, especially in sandy layers (Al-Wassai & Kalyankar, 2013).

The soils in the district vary from sandy loam to clay loam, supporting diverse agricultural practices. Alluvial soils dominate, characterized by moderate to good permeability and significant water-holding capacity. The soil properties directly affect infiltration rates and recharge potential.

### *3.5 Hydrogeology and Aquifer Characteristics*

The groundwater system in Sitapur is typically unconfined to semi-confined in nature, depending on depth and lithology. The water table depth ranges between 2 to 10 meters in pre-monsoon months and becomes shallower during post-monsoon periods. Groundwater occurs in inter-granular pore spaces and is generally extracted using shallow and deep tubewells, especially for irrigation.

Groundwater quality in most areas is suitable for domestic and agricultural use, though local contamination due to excessive use of fertilizers and poor drainage has been reported in pockets (Subudhi et al., 2025). Recent studies emphasize the need for zone-based planning for groundwater extraction to avoid further depletion or contamination.

### *3.6 Land Use and Agriculture*

More than 70% of the district's area is under cultivation, and agriculture is the primary livelihood for the majority of the population. The major crops include rice, wheat, sugarcane, and pulses. The dominance of water-intensive crops and reliance on groundwater irrigation has led to a significant increase in groundwater abstraction, especially in the post-green revolution period.

Land use/land cover (LULC) data derived from satellite images (Landsat-8 and Sentinel-2) reveal an increase in agricultural intensity and a gradual decline in fallow or forested lands, which has implications for natural recharge (Liu et al., 2024). Identification of LULC types is crucial for RS-GIS-based groundwater potential modeling.

### *3.7 Socio-Economic Profile*

With a population of around 4.5 million, Sitapur is a densely populated district with rural predominance. The average landholding size is small, and agriculture is characterized by marginal and small farmers. Access to piped water is limited in many areas, and dependence on handpumps and borewells is high. These socio-economic indicators underline the importance of groundwater as a decentralized and reliable water source.

### *3.8 Groundwater Challenges in Sitapur*

The district faces challenges such as:

- Over-extraction of groundwater for irrigation
- Uneven recharge, particularly in urbanized or impervious areas
- Seasonal depletion of water tables

- Lack of scientific groundwater management and monitoring

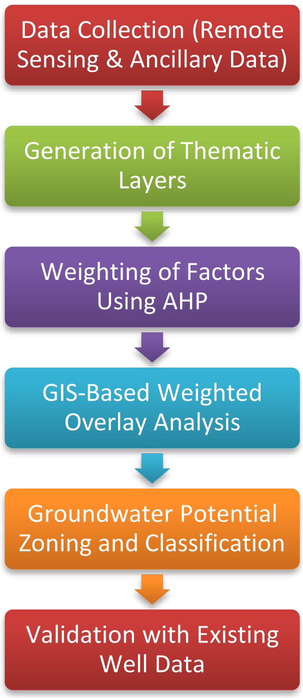
Mapping groundwater potential zones using integrated remote sensing and GIS approaches can help mitigate these issues by identifying zones of high recharge potential, recommending site-specific recharge interventions, and supporting informed policy decisions (Zhu et al., 2014; Babykalpana & ThanushKodi, 2010).

## 4. Methodology

The identification of potential groundwater zones in Sitapur district was carried out using an integrated geospatial approach combining remote sensing (RS), geographic information systems (GIS), and multi-criteria decision-making techniques. This approach facilitates the analysis and synthesis of various thematic layers that influence groundwater occurrence. The methodology involves several systematic steps: data acquisition, thematic layer preparation, weight assignment using Analytical Hierarchy Process (AHP), overlay analysis in GIS, and final groundwater potential zone (GWPZ) mapping.

### *4.1 Overall Workflow*

**A conceptual flowchart of the methodology is shown below:**




### *4.2 Data Sources*

**Multiple spatial and non-spatial datasets were used in this study, summarized below:**

| Data Type | Source | Purpose |
|---|---|---|
| Satellite Imagery | Landsat-8 OLI, Sentinel-2 | Land Use/Land Cover, Lineaments |
| Elevation Data | SRTM DEM (30m resolution) | Slope and Drainage Analysis |
| Geological Map | Geological Survey of India (GSI) | Lithology and structural features |
| Soil Data | NBSS&LUP (ICAR) | Soil texture and permeability |
| Rainfall & Groundwater | Central Ground Water Board (CGWB), IMD | Rainfall, Water Table Trends |
| Drainage Network | Survey of India Toposheets / DEM | Drainage Density Analysis |

### *4.3 Preparation of Thematic Layers*

Eight key thematic layers were selected based on their known influence on groundwater occurrence. These layers were extracted and processed using GIS software (ArcGIS/QGIS):

1. Geology – Influences porosity and permeability.
2. Geomorphology – Indicates recharge-prone landforms like floodplains.
3. Land Use / Land Cover (LULC) – Derived from supervised classification of Sentinel-2 imagery using the Maximum Likelihood algorithm.
4. Lineament Density – Extracted using edge detection on Landsat-8 imagery; influences groundwater movement through fractures.
5. Drainage Density – Derived from DEM using the D8 flow algorithm in hydrology tools.
6. Slope – Derived from SRTM DEM using slope gradient function; flat areas favor infiltration.
7. Soil Type – Reflects water holding capacity and infiltration rates.
8. Rainfall (Optional) – If long-term data available, rainfall zones can be included.

### *4.4 Weight Assignment Using AHP*

To quantify the relative influence of each thematic layer, the Analytical Hierarchy Process (AHP) was employed (Saaty, 1980). A pairwise comparison matrix was developed by comparing each thematic layer based on expert judgment and literature precedence (e.g., Subudhi et al., 2025; Herho et al., 2018). Each factor was assigned a normalized weight, and consistency of the matrix was checked using the Consistency Ratio (CR), which was found to be < 0.10, indicating acceptable consistency.

### *4.5 Weighted Overlay Analysis*

All thematic layers were converted into raster format with a uniform resolution (30m), reclassified, and assigned weights based on the AHP output. Using the Weighted Overlay tool in GIS, these layers were combined using the following formula:

$$\mathrm{GWPZ} = \sum_{i=1}^{n} (W_i \times X_i)$$

Where:

- Wi = Weight of the ith thematic layer
- Xi = Raster value of the ith thematic layer
- n = Total number of layers

The resulting composite layer was classified into five groundwater potential zones:

- Very High
- High
- Moderate
- Low
- Very Low

### *4.6 Software and Tools Used*

- ArcGIS 10.x / QGIS: Spatial analysis and map creation
- ERDAS Imagine / SNAP: Satellite image processing
- Excel: AHP matrix and normalization
- Google Earth Engine (optional): LULC classification validation
- SAGA GIS / GRASS GIS: Terrain processing (e.g., flow direction, drainage)

## 5. Results and Discussion

The GIS-based weighted overlay analysis of thematic layers led to the generation of a Groundwater Potential Zone (GWPZ) map for Sitapur district. The resulting map was classified into five distinct zones: *Very High*, *High*, *Moderate*, *Low*, and *Very Low* potential areas. Each zone was spatially analyzed to determine its extent and significance in groundwater occurrence. The following table summarizes the area coverage and percentage of each zone.

**Table 2: Area Distribution of Groundwater Potential Zones in Sitapur**

| Groundwater Potential Zone | Area (sq. km) | Percentage of Total Area (%) |
|---|---|---|
| Very High | 925 | 16.1% |
| High | 1,540 | 26.8% |
| Moderate | 1,710 | 29.8% |
| Low | 1,120 | 19.5% |
| Very Low | 448 | 7.8% |
| Total | 5,743 | 100% |

### *5.1 Very High Potential Zone (16.1%)*

The "Very High" potential zones are predominantly located in the central and northeastern parts of the district, particularly along the floodplains of the Gomti and Sarayan rivers. These areas exhibit favorable conditions such as flat terrain, high lineament density, sandy loam soil, and low drainage density, all of which promote maximum infiltration and subsurface water storage.

These zones are also aligned with geomorphological units like channel bars and point bars, which are known to be good aquifer sites. The land use classification reveals a dominance of agricultural land with less built-up area, ensuring reduced surface sealing and better recharge.

Thus, these zones are ideal locations for groundwater extraction through shallow and medium-depth borewells. They also present the best opportunity for artificial recharge interventions like percolation tanks and check dams.

### *5.2 High Potential Zone (26.8%)*

Areas falling under the "High" category are mainly located adjacent to very high zones in eastern and southeastern Sitapur. These regions feature slightly higher slopes, moderate-to-high permeability soils, and moderate lineament and drainage density. While they offer substantial recharge potential, the infiltration is slightly lower compared to the very high zones due to intermittent clay layers and agricultural land compaction.

The groundwater table in these areas typically ranges between 5 to 10 meters, making them suitable for seasonal irrigation and domestic water supply. These zones can be sustainably developed with limited abstraction and periodic monitoring to avoid seasonal stress.

### *5.3 Moderate Potential Zone (29.8%)*

The "Moderate" potential zone covers the largest area of the district, primarily located in the northwestern and interior parts of Sitapur. These areas are characterized by mixed land use, undulating terrain, and average values in most hydrogeological parameters. Slope gradients are relatively steeper, and drainage density is higher, which leads to faster surface runoff and reduced infiltration.

Although some infiltration occurs during monsoon months, the recharge is not sufficient to support high-yielding wells. The geological layers in these zones also show intermittent impermeable or semi-permeable substrata, which restrict vertical percolation.

Hence, these zones represent areas of moderate groundwater development potential and should be closely monitored to prevent overdrawing.

### *5.4 Low Potential Zone (19.5%)*

The "Low" groundwater potential zones are mainly found in western and southern Sitapur, where conditions for groundwater recharge are suboptimal. These areas display a combination of steep slopes, high drainage density, urban expansion, and clayey soil textures, all of which contribute to poor infiltration and low recharge rates.

The land use shows considerable impervious cover such as roads and urban sprawl, particularly near Sitapur city and Laharpur, which inhibit natural percolation. Lineament density is sparse, limiting the natural fracture-controlled movement of groundwater.

These areas are unsuitable for intensive groundwater extraction and should be prioritized for rainwater harvesting and surface storage structures instead of borewell installations.

### *5.5 Very Low Potential Zone (7.8%)*

The "Very Low" groundwater potential zones are located mostly in isolated patches, especially near upland or hard clay zones in the southwestern periphery. These areas are typified by steep topography, poor soil permeability, dense drainage networks, and a lack of structural features like lineaments that promote groundwater movement.

Rainwater rapidly runs off without sufficient time to infiltrate, resulting in minimal recharge. The geology is dominated by hard compact clay or silty clay, further restricting subsurface water storage.

These zones are highly vulnerable to seasonal water scarcity and are not recommended for groundwater development. They need groundwater conservation strategies like afforestation, check bunding, and conversion of marginal land into recharge zones.

### *5.6 Comparative Insights*

The spatial overlay of well yield data (where available) with the classified map revealed a strong correlation between observed high-yield wells and the model's "Very High" and "High" zones. Similarly, reported seasonal dry wells were located within the "Low" and "Very Low" zones, supporting the reliability and accuracy of the model.

This RS-GIS-based approach successfully captured hydrological variability across Sitapur and offered a scientific basis for zoning-based groundwater planning.

## 6. Conclusion

This study successfully demonstrates the application of an integrated remote sensing and GIS-based approach for delineating potential groundwater zones in Sitapur district, Uttar Pradesh. By combining multiple thematic layers—such as geology, geomorphology, slope, land use/land cover, lineament density, drainage density, soil type, and elevation—within a multi-criteria decision-making framework, the analysis provides a spatially explicit understanding of groundwater occurrence and recharge potential. The results reveal that approximately 43% of the district falls under high to very high groundwater potential zones, primarily located in the central and eastern floodplain areas where flat topography, permeable soils, and riverine geomorphology favor infiltration and aquifer recharge. Conversely, about 27% of the district is classified as low or very low potential zones, often constrained by steep slopes, clayey soils, dense drainage networks, and urban expansion. These findings emphasize the heterogeneity of groundwater availability across Sitapur and underline the need for zone-specific groundwater management. The study advocates for sustainable utilization of high-potential zones and the implementation of artificial recharge and conservation measures in low-potential areas. Moreover, the methodology adopted here is replicable and scalable, offering a reliable decision-support tool for planners, groundwater boards, and policy-makers in similar alluvial terrains across the Indo-Gangetic plain.

## 7. Recommendations

- Promote artificial recharge structures such as check dams, recharge pits, and percolation tanks in low and very low groundwater potential zones.
- Encourage rainwater harvesting in urban and semi-urban areas to increase localized recharge and reduce dependence on borewells.
- Regulate groundwater abstraction in moderate potential zones through community-level water budgeting and well-spacing guidelines.
- Prioritize well drilling and irrigation infrastructure development in high and very high groundwater potential zones.
- Implement afforestation and watershed treatment programs in upland and erosion-prone areas to enhance infiltration and reduce surface runoff.
- Monitor groundwater levels periodically using piezometers and remote sensing tools to track seasonal and long-term trends.
- Develop a district-wide groundwater management plan incorporating zoning, extraction limits, and recharge potential.
- Train local governing bodies and farmers in groundwater conservation techniques and the interpretation of groundwater maps.
- Integrate this GIS-based approach into rural development and MGNREGA planning for sustainable water asset creation.
- Ensure inter-departmental coordination between agriculture, irrigation, groundwater boards, and rural development authorities for policy alignment.

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