CASE STUDY

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Role of Geology in Groundwater Potential Zoning Using Remote Sensing and GIS: A Case Study of Neem Ka Thana, Rajasthan

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ABSTRACT

Geological and geomorphological factors significantly influence groundwater supply in semi-arid areas like Neem Ka Thana, Rajasthan (Wikipedia, 2025). This study highlights how geology, including lithology, soil properties, and structural aspects, helps define groundwater potential zones. The BhuKosh and WRIS databases are used to generate thematic layers for the study, which include geology, geomorphology, lithology, soil depth, and soil texture (Bhuvan, 2025; WRIS, 2024). To evaluate their impact on groundwater storage and transport, structural elements such faults, folds, and lineaments were mapped. These datasets first preprocessing offers information on subsurface flow behaviour, storage capacity, and recharge potential. The results demonstrate that in hard rock terrains, lithological variances, soil depth, and geomorphic units are important factors that influence groundwater availability (Strahler, 1957; Patel et al., 2012). This framework lays the foundation for subsequent multi-criteria groundwater potential mapping.

Introduction

In Rajasthan, where surface water supplies are still limited because of low rainfall and high evapotranspiration rates, groundwater serves as the principal supply of freshwater. The demand for groundwater is steadily rising in semi-arid areas like Neem Ka Thana, while recharge is still scarce. For sustainable water management, it is consequently crucial to comprehend how geology affects the occurrence of groundwater.

Aquifer parameters, infiltration capacity, and storage potential are directly influenced by lithology, geomorphology, structural features, and soil qualities. According to earlier research, hard rock terrains store groundwater through secondary porosity created by faults, weathering, and fractures (Strahler, 1957; Patel et al., 2012).

This study focusses on the geological drivers of groundwater availability, building on previous research in the Neem Ka Thana region, where watershed characterisation using parameters obtained from DEMs gave crucial insights into hydrological processes and recharge dynamics (Santosh Kumar et al). In this work, the thematic datasets from national repositories like BhuKosh and WRIS are integrated to show how geology-driven parameters, including soil depth, texture, lithology, and geomorphology, impact groundwater potential.

This paper establishes a geological baseline for groundwater studies in Neem Ka Thana, providing essential datasets for future integration into multi-criteria decision-making frameworks.

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Study Area

Neem Ka Thana, located in Sikar district, Rajasthan, lies between 27.759875°N, 75.770347°E (northwest) and 27.716509°N, 75.829854°E (southeast). The region is part of the Shekhawati tract, characterized by semi-arid climatic conditions, undulating topography, and an average elevation of ~446 m (Wikipedia, 2025). Annual rainfall ranges between 450–500 mm, with most precipitation received during the southwest monsoon (Wikipedia, 2025).

Geologically, Neem Ka Thana forms part of the Aravalli Craton, consisting of Precambrian metamorphic formations such as quartzites, schists, and gneisses, along with younger alluvial deposits (Heron, 1953). Structural features including faults, folds, dykes, and lineaments significantly influence groundwater occurrence by enhancing secondary porosity and recharge pathways.

Soil characteristics vary spatially, with sandy soils dominating the plains, while loamy and fine soils occur in isolated tracts. Soil depth ranges from shallow (<1 m) in hilly uplands to deep (>4 m) in Pedi plains, directly affecting infiltration capacity (WRIS, 2024). Geomorphic features such as dissected hills, pediments, and alluvial plains shape surface runoff and recharge dynamics (Bhuvan, 2025).

Ecologically, the watershed is influenced by surrounding Bansiyal-Khetdi Conservation Reserve (~70 km²) and Baleshwar Conservation Reserve (~221 km²), which highlight the interplay between land use, geology, and hydrology in this semi-arid ecosystem (Rajasthan Forest Department, 2024).

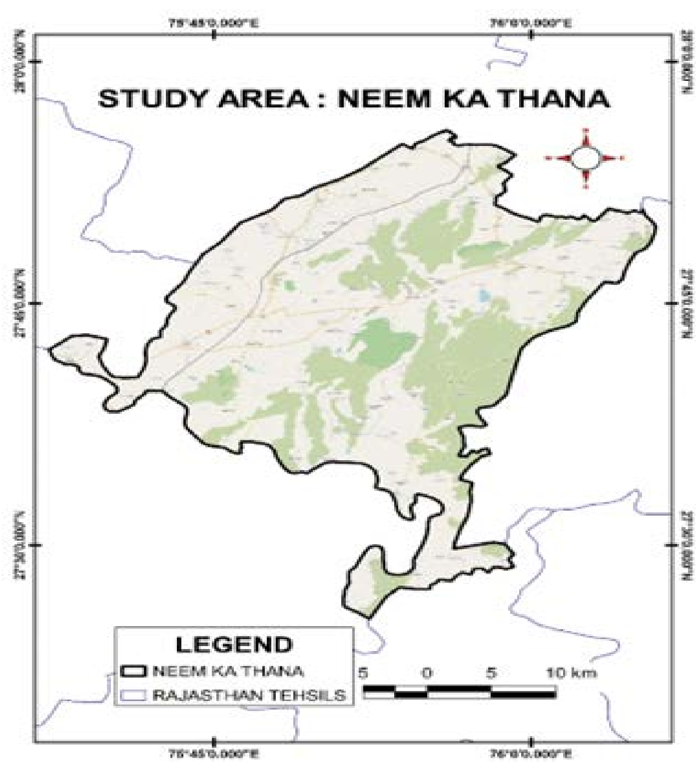

Figure 1 Neem Ka Thana Map

Data and Methodology

Data Sources

For this study, multiple thematic datasets were used to understand the geological and soil controls on groundwater potential in the Neem Ka Thana region. Geological, lithological, and geomorphological maps were obtained from the BhuKosh Geo-Platform of ISRO and the Geological Survey of India (GSI) databases (Bhuvan, 2025; Heron, 1953). Soil depth and soil texture layers were derived from the India Water Resources Information System (WRIS, 2024) and supplemented by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP, 2015) reports. Structural features such as faults, folds, and lineaments were interpreted from geological maps and validated using satellite imagery, following standard geological mapping practices (Wilson & Gallant, 2000).

Software and Tools

All spatial data processing was carried out in QGIS (version 3.28 and later) due to its open-source accessibility and wide range of hydrological and geological toolsets. DEM data used in the earlier watershed delineation study (Santosh Kumar, et al). served as a base reference for ensuring spatial consistency across datasets.

Preprocessing Steps

1. Data Import and Projection

All thematic layers were imported into QGIS and standardized to the WGS 84 / UTM Zone 43N projection to ensure compatibility during spatial analysis. Consistent projection systems are essential for overlaying multi-source datasets (Maidment, 2002).

2. Clipping to Study Area

Using the watershed boundary delineated in the earlier study (Santosh Kumar, et al), each dataset was clipped to match the exact extent of the Neem Ka Thana watershed. This step ensures that subsequent analyses are confined to the hydrologically relevant unit rather than administrative boundaries (Patel et al., 2012).

3. Attribute Cleaning and Standardization

The attribute tables of each layer were harmonized to maintain consistency. For instance, lithological units (e.g., quartzite, schist, gneiss) and soil textures (e.g., sandy, loamy, clayey) were standardized to avoid duplication and to simplify classification. This step enhances data quality and interoperability across thematic maps (Wilson & Gallant, 2000).

4. Raster Conversion

To maintain uniformity for later spatial modelling, polygon layers (such as soil and geology) were converted into raster format. Raster-based representation facilitates cell-by-cell analysis and supports integration with hydrological indices derived from DEMs (Patel et al., 2012).

Figure 2 Methodology Flowchart

Results and Discussion

Geology

According to the geology map, the hard rock formations that make up Neem Ka Thana's geology are primarily composed of gneiss, schist, and quartzite. Due to its extreme resistance and extremely low primary porosity, quartzite typically limits the amount of groundwater that may be stored. Despite being crystalline as well, schist formations have foliations and fractures that have the ability to locally retain water. Gneiss has a moderate capability for infiltration due to weathering and jointing. These differences demonstrate how geology acts as a first-order regulator of groundwater occurrence in hard rock, semi-arid environments (Heron, 1953).

Geomorphology

Valley fills, residual hills, and pediments are all identified on the geomorphological map. Pediments are gently sloping erosional surfaces that have poor infiltration and strong runoff. They are frequently just lightly covered in soil. Usually rocky and desolate, residual hills help with rapid runoff but have little storage capacity. Valley fills, on the other hand, are ideal areas for groundwater recharge because they are composed of colluvial and alluvium deposits, which represent depositional settings with higher infiltration potential. Thus, hydrological behaviour and resource potential are significantly influenced by these geomorphic environments.

Soil Depth

The watershed's soil depth varies greatly, with deeper soils (>75 cm) found in valley and plain regions and shallow soils (<25 cm) concentrated on pediment and mountainous places. While deeper soils enhance storage and percolation ability, shallow soils decrease infiltration capacity and favour runoff. Particularly in the plains, this spatial variance identifies areas that are more suited for groundwater recharge and cultivation.

Soil Texture

The research area's sandy, loamy, and clayey classes are depicted on the soil texture map. Sandy soils have low water retention but higher porosity, which improves infiltration. Conversely, clayey soils limit percolation while retaining water. Loamy soils are ideal for recharging and agricultural productivity because they provide a balance between infiltration and retention. Therefore, the distribution of soil texture offers important information on trade-offs between recharge and storage.

Lithology

By displaying the spatial variance of quartzite, schist, and gneissic formations throughout the watershed, the lithological distribution helps to further refine the geological categorisation. Permeability and lithology are closely related: large quartzite outcrops limit recharging, while weathered schist zones and fractured quartzites provide more conducive conditions for infiltration. Accordingly, lithology offers vital information for locating possible groundwater-bearing areas (Patel et al., 2012).

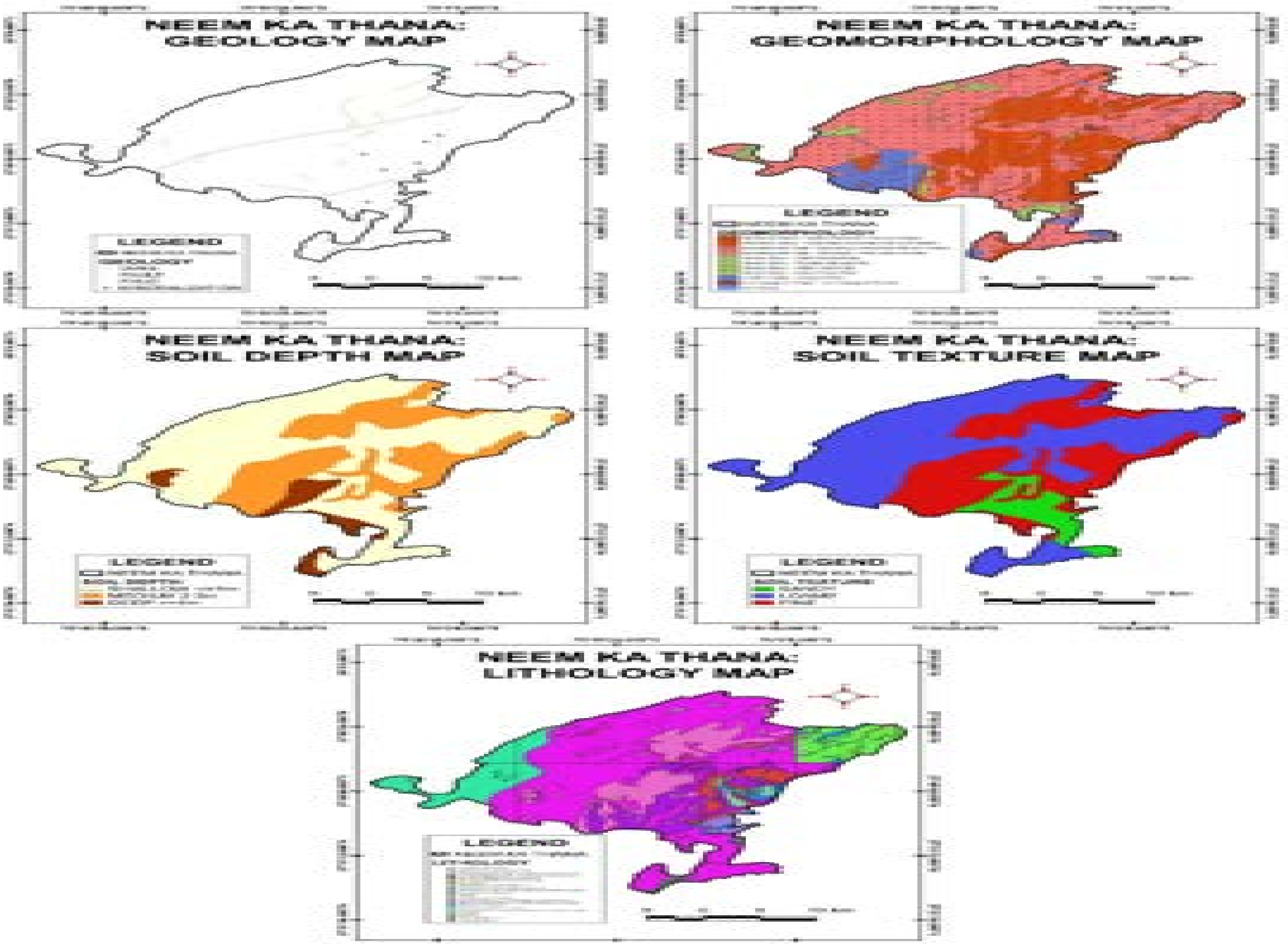

Figure 3 Geology Data Layers

Discussion

An examination of Neem Ka Thana's geology, lithology, geomorphology, soil depth, and soil texture offer vital information about the area's groundwater potential. Although each theme parameter has a distinct contribution to the occurrence and recharge of groundwater, the overall hydrogeological behaviour is determined by their combined influence.

The research region is dominated by schist and quartzite, according to the geology and lithology maps. Because quartzite is so hard and compact, it prevents infiltration, whereas schist and gneiss weather and fracture, forming secondary porosity that is good for storing groundwater. These observations are consistent with research from hard rock terrains in other parts of Rajasthan, where groundwater conduits are frequently primarily structural discontinuities (Patel et al., 2012; Wilson & Gallant, 2000).

Another important component was found to be geomorphology. Despite being widely distributed, sediment zones are typically unfavourable because of their surfaces that are prone to runoff. Limited recharging is also contributed by residual hills. On the other hand, because of their alluvial deposits, which serve as natural recharge basins, valley fills show a great deal of promise. This trend aligns with past research in India's semi-arid catchments, where depressions and valley fills are acknowledged as crucial recharging zones (Magesh et al., 2012).

This knowledge is further enhanced by soil properties. Because shallow soils limit infiltration, rocky outcrops and upland pediments have a low capacity for recharge. On the other hand, deeper soils in valleys and plains improve infiltration and storage, promoting groundwater replenishment as well as cultivation. The trade-offs between recharge and storage are also influenced by soil texture: clayey soils hold moisture but limit downward flow, while sandy soils promote percolation but lack retention. By striking a balance between these two extremes, loamy soils offer the best circumstances for groundwater use that is sustainable.

The current findings show a high spatial link between drainage concentration zones and favourable recharge settings found in valley fills and deeper soils when compared to the watershed delineation results from (Santosh Kumar, et al). These studies collectively highlight the need to integrate geological, hydrological, and pedological viewpoints in order to completely understand groundwater dynamics in semi-arid environments.

Crucially, these findings demonstrate that groundwater occurrence in Neem Ka Thana is spatially heterogeneous rather than homogeneous, governed by the interaction of soil characteristics, lithology, and geomorphology. This implies that upland pediments should concentrate on soil conservation to reduce erosion and runoff losses, while interventions like check dams, percolation tanks, and recharge wells should be placed strategically in valley fills, loamy soils, and structurally weak zones for effective water resource management.

In order to create a groundwater potential zoning map, this research also prepares the ground for a multi-criteria decision analysis (MCDA), which will combine hydrological data with all thematic layers. In addition to validating the current findings, this technique will offer Rajasthani local authorities and water resource planners' practical suggestions.

Conclusion

This study shows how important geological, geomorphological, and soil characteristics are in determining the capacity for groundwater recharge in the semi-arid region of Neem Ka Thana, Rajasthan. The following important findings are obtained by methodically examining geology, lithology, geomorphology, soil depth, and soil texture:

1.Geological and Lithological Control: While schist and gneiss, with their structural characteristics like joints and cracks, increase the occurrence of groundwater, quartzite formations restrict infiltration because of their low porosity.

2.Geomorphological Influence: While pediments and residual hills are more prone to runoff and are less effective at storing groundwater, valley fills, with their depositional settings, are extremely favourable recharge zones.

3.Soil Properties: While shallow and clayey soils limit recharge, deep and loamy soils provide the ideal conditions for infiltration and storage.

4.Spatial Heterogeneity: Groundwater potential varies spatially throughout the watershed and is not uniform, requiring management measures tailored to specific locations.

In practice, this study can help Neem Ka Thana's planners and water managers prioritise groundwater recharge activities, optimise well siting, and lessen drought susceptibility. In a broader sense, the study supports the usefulness of geospatial analysis as an affordable and expandable method for evaluating groundwater in India's semi-arid areas.

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