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Research Paper

Balancing Groundwater Irrigation and Geodiversity Conservation in the Thar Desert: A Geospatial Analysis of Jodhpur Region

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ABSTRACT

The Jodhpur district, located in the eastern fringe of the Thar Desert, presents a paradox of agricultural dependency on scarce groundwater and the presence of unique geodiversity that requires protection. In an environment with an average annual rainfall of less than 350 mm, farmers rely almost entirely on groundwater for irrigation. However, the expansion of irrigated agriculture is taking place alongside increasing recognition of the region's geoheritage, such as the Jodhpur Group sandstones, dune systems, and residual hills. This paper develops an integrated geospatial framework that assesses groundwater irrigation suitability and overlays it with a geodiversity index to highlight zones of potential conflict. Using datasets from the Central Ground Water Board (CGWB), soil maps from NBSS&LUP, and remote sensing products including Landsat-9, Sentinel-2, and SRTM DEM, irrigation suitability was classified based on hydrochemical and physical criteria (EC, SAR, Na%, soil pH, depth to water). Parallel to this, lithological and geomorphological parameters were used to derive geodiversity indices. Results indicate that approximately 23% of the study area falls under "highly suitable" irrigation zones, while around 19% of the district is classified as high in geodiversity value. Roughly 11% of land represents overlapping areas where both irrigation potential and geodiversity significance coincide, thereby requiring sensitive planning. The findings underline the urgent need to balance agricultural expansion with landscape conservation in the arid environment of Jodhpur.

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1. INTRODUCTION

Water scarcity and land degradation remain defining features of arid ecosystems worldwide. In western Rajasthan, the Thar Desert presents an acute case, where groundwater functions as the backbone of agricultural livelihoods but is simultaneously vulnerable to over-extraction and salinization. Jodhpur district, positioned at the transitional edge of the desert, exemplifies these challenges. Groundwater is the lifeline of farming communities here, supporting crops such as bajra, mustard, cumin, and guar. Yet, aquifer levels have been declining at an alarming rate, with Central Ground Water Board (CGWB) records showing average water table depths exceeding 50 meters in some blocks by 2023.

Parallel to this hydro-agricultural dependency, Jodhpur hosts landscapes of immense geoscientific and cultural value. The pink Jodhpur sandstone, quarried for centuries, defines the city's architectural identity. Dune corridors, residual hills, and escarpments represent evolutionary histories of desert processes and stratigraphy. These features together represent "geodiversity"—the natural range of geological, geomorphological, and soil features that underpin biodiversity and human culture.

The dilemma is clear: agricultural intensification, driven by groundwater extraction, often encroaches upon or modifies these landscapes, putting geodiversity at risk. Yet, conservation policies seldom integrate geodiversity considerations into water and land-use planning. This research builds on this gap, proposing a **dual-layer geospatial assessment** that simultaneously examines groundwater irrigation suitability and geodiversity indices, highlighting overlaps and opportunities for integrated management.

2. Study Area

Jodhpur district, situated between latitudes 26°00′–27°37′ N and longitudes 72°55′–73°52′ E, covers an area of about 22,850 km² in western Rajasthan. The district lies on the eastern margin of the Thar Desert and experiences a distinctly arid climate. Average annual rainfall is around 325 mm, with nearly 80% concentrated in the monsoon months of July to September. Rainfall is highly variable, often occurring in short and intense bursts that contribute little to groundwater recharge. Summers are extremely hot, with maximum temperatures frequently crossing 45°C, while winters are comparatively mild, though night temperatures can occasionally dip below 10°C.

The landscape of Jodhpur reflects the interplay of desert processes and geological history. Much of the district consists of flat to gently undulating alluvial plains, which are punctuated by stabilized and semi-stabilized dunes. Residual rocky hills and escarpments provide marked relief in an otherwise subdued terrain. The ephemeral Luni River, one of the few significant drainage systems of western Rajasthan, flows through the southern part of the district before dissipating in the desert plains.

Geologically, Jodhpur forms part of the Marwar Supergroup, with the Jodhpur Group sandstones being particularly prominent. These reddish-brown sandstones, along with associated limestones and shales, are overlain by Quaternary aeolian deposits that dominate much of the surface. These features not only shape the region's hydrogeology but also hold considerable geoheritage value.

Agriculture remains the dominant land use, accounting for nearly 55% of the district's area. However, productivity is restricted by coarse sandy soils, low organic content, and chronic water scarcity. Groundwater, stored in unconsolidated alluvial aquifers and fractured sandstone formations, is the principal source of irrigation. Yet, problems of high salinity and elevated fluoride levels limit its safe utilization in many parts of the district, posing challenges for both human health and sustainable farming.

3. DATA AND METHODOLOGY

3.1 Data Sources

- **Groundwater**: CGWB monitoring wells (2000–2023), field samples (EC, pH, SAR, Na%).
- **Soils**: NBSS&LUP soil maps (scale 1:250,000) and district-level soil quality data.
- **Remote Sensing**: Sentinel-2 (10 m resolution) and Landsat-9 OLI (30 m) for LULC classification.
- **Topography**: Shuttle Radar Topography Mission (SRTM) DEM, 30 m.
- **Geology**: Geological Survey of India (1:50,000 lithological sheets).

3.2 Irrigation Suitability Mapping

Parameters and their weightings were determined using the Analytic Hierarchy Process (AHP):

- Depth to water table (30%).
- Electrical conductivity (25%).
- Sodium adsorption ratio (20%).
- Soil texture and pH (15%).
- Land use/cover (10%).

The layers were standardized into suitability classes (highly suitable, moderately suitable, marginally suitable, unsuitable).

3.3 Geodiversity Mapping

Following global approaches, geodiversity indices (GDI) were computed by combining:

- Lithological diversity (number and type of rock units).
- Relief heterogeneity (DEM-derived roughness).
- Slope diversity.
- Landform variety (dunes, escarpments, alluvial plains, residual hills).

Each parameter was normalized (0–1) and integrated into a composite GDI.

3.4 Overlay Analysis

The irrigation suitability map and geodiversity map were overlaid to identify zones of synergy and conflict. A matrix was developed:

- **High irrigation – Low geodiversity**: Priority zones for agriculture.
- **High irrigation – High geodiversity**: Sensitive zones needing regulated development.
- **Low irrigation – High geodiversity**: Conservation priority zones.
- **Low irrigation – Low geodiversity**: Marginal lands with limited potential.

4. RESULTS

4.1 Groundwater Irrigation Suitability

The groundwater suitability analysis illustrates the spatial variation in irrigation potential across Jodhpur district. Approximately **23% of the total area** falls under the "highly suitable" category. These zones are concentrated in the alluvial plains, particularly around Bilara block and the fringes of the

Luni basin. Here, aquifer yields are moderate, and groundwater quality parameters—such as electrical conductivity (EC) and sodium adsorption ratio (SAR)—remain within acceptable limits for most crops. Farmers in these tracts are already able to sustain relatively stable agricultural production compared to other parts of the district.

A larger portion, nearly 41% of the district, is classified as "moderately suitable." These areas, while capable of supporting irrigation, require more cautious management. The primary concern is salinity: EC values in these zones are elevated, and in certain pockets, sodicity hazards are also present. Continuous and intensive irrigation in these regions without adopting appropriate soil–water management strategies (e.g., gypsum application, crop rotation, or blending with better-quality water) could exacerbate soil degradation and reduce long-term productivity.

The remaining 36% of the land is categorized as "marginally suitable" or "unsuitable." These zones correspond largely with dune-dominated landscapes and the Osian block. Groundwater in these areas is often deep-seated, with EC values exceeding 3000 µS/cm. The high SAR levels observed in these aquifers indicate risks of sodicity, which can severely impact soil permeability and crop health. Irrigation development in such locations would not only be uneconomical but could also accelerate land degradation if pursued without safeguards.

4.2 Geodiversity Patterns

The geodiversity assessment revealed that about 19% of the Jodhpur district possesses high geodiversity values. These zones are distributed across several prominent landscape features:

- The **Mehrangarh–Soorsagar escarpment**, where massive sandstone cliffs dominate the skyline and form a distinct cultural and geological landmark.
- **Residual hills north of Mandore**, which preserve erosional remnants and provide important insights into the geomorphological evolution of the region.
- **Stabilized dune complexes northwest of Jodhpur city**, which represent characteristic desert landforms and host fragile ecosystems.
- **Drainage-incised tracts along ephemeral streams**, which capture the dynamic interaction between fluvial and aeolian processes.

In contrast, the alluvial plains and intensively farmed tracts exhibited relatively low geodiversity values. These areas are marked by uniform topography, limited lithological variation, and fewer distinct geomorphic features. While they are agriculturally productive, they contribute less to the region's geoheritage.

4.3 Overlay Analysis

The integration of irrigation suitability with geodiversity patterns offers critical insights for land-use planning. The overlay analysis revealed that about 11% of the district's land simultaneously exhibits both high irrigation potential and high geodiversity value. These "conflict zones" are of particular concern, as agricultural expansion here could compromise geoheritage features or destabilize sensitive landscapes such as dunes and escarpments. For these areas, strict regulatory measures and conservation-friendly irrigation practices are necessary.

On the other hand, approximately 14% of the district represents land that is highly suitable for irrigation but characterized by low geodiversity. These areas present opportunities for safe expansion of irrigation infrastructure without posing major risks to the geological or geomorphological heritage. Promoting agricultural development in such zones can help reduce pressure on ecologically and geologically sensitive areas.

Finally, around 8% of the land falls under the category of high geodiversity but poor irrigation potential. These zones, including dune fields and sandstone ridges, are unsuitable for conventional farming due to poor water quality and difficult terrain. However, they hold immense value for conservation, education, and geotourism. Protecting these landscapes from agricultural encroachment and groundwater exploitation should be a priority for sustainable regional planning.

5. DISCUSSION

The juxtaposition of irrigation suitability with geodiversity highlights a dilemma common to arid regions: maximizing food security while preserving fragile landscapes. For instance, the dune fringes north of Osian, while hydrologically promising, are geomorphologically sensitive. Large-scale irrigation here risks destabilizing dunes and causing secondary salinization. Similarly, the Soorsagar escarpment, apart from being a water-bearing sandstone aquifer, is also a geoheritage site central to Jodhpur's cultural identity.

This research shows that ignoring geodiversity in irrigation planning can result in irreversible degradation—flattening of dunes, erosion of escarpments, and groundwater salinization. Conversely, integrating geodiversity into water planning creates opportunities for multifunctional land use: areas unsuitable for irrigation can be developed as **geoheritage tourism zones**, supporting alternative livelihoods while conserving landscapes.

6. RECOMMENDATIONS

The results of this study highlight the urgent need to integrate sustainable groundwater use with geodiversity conservation in Jodhpur. Based on the spatial analysis, the following recommendations are proposed:

1. Targeted irrigation zoning

Agricultural expansion should focus on areas identified as having high irrigation potential but low geodiversity value. These regions, typically alluvial plains with moderate aquifer yields and suitable water quality, provide safe opportunities for crop intensification. Developing clear zoning maps can guide farmers and policymakers to prioritize such areas, reducing pressure on ecologically and geologically sensitive sites.

2. Conservation of sensitive landscapes

High geodiversity zones, such as the Mehrangarh–Soorsagar escarpments, residual hills near Mandore, and stabilized dune systems, require strict protection. Groundwater-intensive farming in these zones should be restricted to prevent land degradation and preserve geological heritage. Alternative livelihood strategies—such as eco-tourism, sustainable grazing, and agroforestry—can be promoted to balance conservation with community development.

3. Groundwater recharge interventions.

Moderately suitable irrigation areas require interventions to maintain long-term aquifer sustainability. Techniques such as percolation tanks, check dams, contour bunds, and small-scale recharge wells can help restore groundwater levels. In dune-dominated regions, coupling recharge measures with vegetation stabilization enhances both hydrological and ecological resilience.

4. Policy integration.

Geodiversity indices should be incorporated into water resource and agricultural planning frameworks. Current policies often consider only water availability and crop potential, overlooking the value of geological and geomorphological features. By integrating geodiversity, planners can ensure that irrigation development does not compromise landscape integrity.

5. Community engagement and awareness.

Sustainable management relies on local participation. Awareness campaigns and participatory water management programs can help communities understand the dual importance of groundwater and geodiversity. Traditional water harvesting methods, such as stepwells (baoris) and ponds (johads), can be revived and combined with modern management practices for long-term resilience.

7. CONCLUSION

Jodhpur, located at the edge of the Thar Desert, represents a region of both great opportunity and inherent vulnerability. Groundwater resources sustain agriculture in this harsh arid environment, yet excessive extraction and uncontrolled expansion of irrigation can lead to aquifer depletion and threaten the district's distinctive geological landscapes. This study highlights the value of a geospatial approach that assesses irrigation suitability alongside geodiversity. Findings indicate that roughly one-fifth of the district falls within zones where high irrigation potential coincides with high geodiversity, signaling areas of potential conflict. In these sensitive zones, careful planning and management are essential to protect sandstone formations, dune systems, and escarpments, while regions with high irrigation potential but low geodiversity offer safer options for agricultural development.

The results underscore that sustainable development in Jodhpur requires a balanced, integrated strategy. Effective groundwater management should be coupled with measures to conserve geodiversity, ensuring the long-term availability of water while safeguarding landscapes of ecological, cultural, and scientific importance. Involving local communities and reviving traditional water management practices, such as johads and baoris, can reinforce this balance and promote resilient agricultural systems. By combining careful planning, participatory management, and policy integration, Jodhpur can serve as a model for other arid regions, demonstrating that economic development and landscape conservation can coexist, securing livelihoods and preserving the unique geological heritage of the Thar Desert for future generations.

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