

Indian Journal of Modern Research and Reviews

This Journal is a member of the '*Committee on Publication Ethics*'

Online ISSN:2584-184X



Research Article

Assessing Ecological Risk in Thar Desert: Indicators, Impacts, and Responses

Jainoo Singh Choudhary¹, Dr. Soyhunlo Sebu², Dr. Archana Sen^{3*}

¹ Research Scholar, Department of Regional Planning and Economic Growth, Barkatullah University, Bhopal, Madhya Pradesh, India

² Assistant Professor, Regional Institute of Education (RIE), Bhopal, Madhya Pradesh, India

³ Assistant Professor, Barkatullah University, Bhopal, Madhya Pradesh, India

Corresponding Author: *Dr. Archana Sen

DOI: <https://doi.org/10.5281/zenodo.19658373>

Abstract

Desert ecosystems are increasingly exposed to compounded ecological risks driven by climate variability and human pressures. This study assesses ecological risk in Indian hot deserts, with particular emphasis on western Rajasthan, by synthesizing multi-source evidence from remote sensing datasets, geospatial desertification assessments, land degradation vulnerability analyses, and regional climate risk studies. Key indicators including Normalized Difference Vegetation Index (NDVI) trends, land degradation status, dune dynamics, soil moisture stress, and anthropogenic land-use change reveal persistent negative impacts such as declining vegetation productivity, expansion of degraded and desertified land, increased wind erosion, and heightened sensitivity to extreme heat and rainfall variability. Canal irrigation expansion and infrastructure development have produced mixed outcomes, simultaneously supporting localized greening while accelerating secondary salinization and land instability in fragile zones.

Despite these risks, the assessment highlights the role of proactive government responses. National and state-led initiatives on desertification status mapping, land degradation neutrality, watershed development, afforestation, renewable energy deployment with environmental safeguards, and climate risk assessment frameworks have contributed to localized land restoration and improved monitoring capacity. Time-series satellite observations indicate stabilization or partial recovery in selected areas where integrated land and water management practices are implemented. Future resilience depends on scaling data-driven desert management, aligning renewable energy and irrigation planning with ecological thresholds, and strengthening adaptive governance under projected climate warming. The findings underscore that ecological risk in deserts is not static but policy-responsive, and that targeted, science-based interventions can mitigate degradation while supporting sustainable development.

Manuscript Information

- **ISSN No:** 2584-184X
- **Received:** 04-03-2026
- **Accepted:** 08-03-2026
- **Published:** 20-04-2026
- **MRR:4(SP1); 2026:** 81-87
- **©2026, All Rights Reserved**
- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Choudhary J S, Sebu S, Sen A. Assessing Ecological Risk in Thar Desert: Indicators, Impacts, and Responses. Indian J Mod Res Rev. 2026;4(SP1):81-87.

Access this Article Online



www.mrrjournal.in

KEYWORDS: Desertification; Ecological risk assessment; remote sensing; Land degradation vulnerability

1. INTRODUCTION

Arid and semi-arid ecosystems are among the most climate-sensitive landscapes globally due to limited moisture availability, sparse vegetation cover, and fragile soil systems. The Thar Desert of India, occupying large parts of western Rajasthan, represents a hot desert environment where climatic extremes interact strongly with anthropogenic pressures. Increasing frequency of heat waves, erratic monsoon rainfall, and prolonged droughts are superimposed on rapid land-use changes driven by irrigation expansion, infrastructure development, population growth, grazing, and renewable energy installations.

Ecological risk in desert systems arises from the interaction between exposure to climatic stressors, sensitivity of ecological components such as soils and vegetation, and the adaptive capacity governed by land management and policy

interventions. Unlike humid ecosystems, desert degradation can be rapid and recovery slow, often leading to irreversible changes once ecological thresholds are crossed. This study aims to systematically assess ecological risk in the Thar Desert by synthesizing evidence from remote sensing, geospatial assessments, and regional studies, with a particular focus on western Rajasthan and the Jaisalmer region.

2. Study Area

The Thar Desert of Western Rajasthan

The Thar Desert extends over approximately 200,000 km² across India and Pakistan, with the Indian portion largely confined to Rajasthan. Western Rajasthan, including districts such as Jaisalmer, Barmer, Jodhpur and Bikaner, represents the hyper-arid core of the desert.

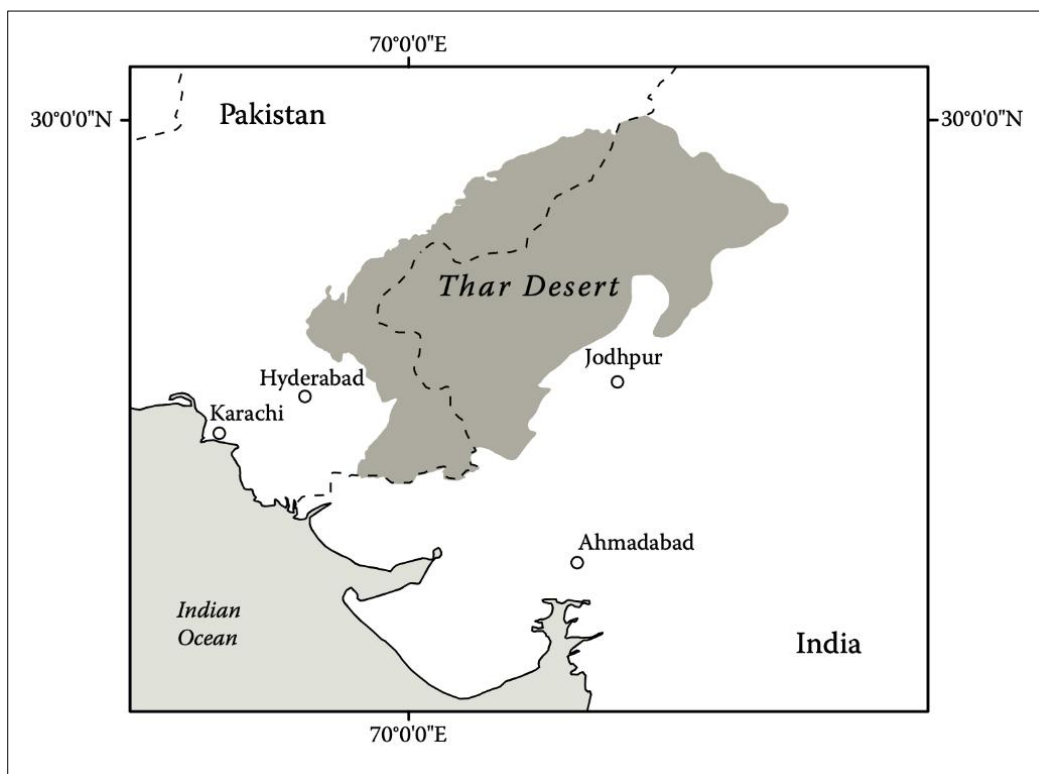


Fig 1: The Thar Desert

2.1 Climate

Annual rainfall ranges from less than 100 mm in western Jaisalmer to about 300–400 mm toward the eastern margins. Rainfall is highly variable both spatially and temporally, resulting in frequent droughts. Summer temperatures often exceed 48–50 °C, while high wind velocities during pre-monsoon months enhance aeolian activity.

2.2 Geomorphology and Soils

The region is dominated by sandy alluvial plains, longitudinal and transverse dunes, and distinctive zibar dune formations. Soils are coarse-textured, low in organic matter, and highly susceptible to wind erosion. These characteristics make vegetation cover a critical stabilizing component of the ecosystem.



Fig 2: Lag gravels in the Thar Desert, India. Mohangarh (Jaisalmer) playa (exposed at center) is located in Jaisalmer district of Rajasthan and is the largest (about 501 ha) gypsum quarry in India. (Courtesy of Navin Juyal; from previously unpublished data. With permission)

3. METHODOLOGY

This research is based on a comprehensive synthesis of secondary data and published studies. The methodological framework integrates:

- 1. Remote sensing datasets:** Multi-temporal MODIS NDVI time-series to analyze vegetation dynamics from 2000 onwards.
- 2. Geospatial assessments:** Desertification Status Mapping (DSM) and Land Degradation Vulnerability Atlas (LDVA) prepared by SAC–ISRO to identify degradation processes and vulnerability classes.
- 3. Geomorphological studies:** Research on dune morphology, zibar dune dynamics, and aeolian processes in western Rajasthan.
- 4. Hydro-ecological studies:** Analyses of land-use change and ecological impacts associated with the Indira Gandhi Canal.
- 5. Climate risk assessments:** District-level climate vulnerability studies focusing on heat stress, rainfall variability, and extreme events. Indicators were evaluated qualitatively and quantitatively to identify spatial patterns, temporal trends, and dominant ecological risks.

4. Ecological Risk Indicators

4.1 Vegetation Dynamics (NDVI)

NDVI is widely used as a proxy for vegetation health and productivity in arid environments. Time-series analysis for western Rajasthan reveals pronounced interannual variability closely linked to monsoon rainfall. While short-term greening is observed during favorable rainfall years, long-term trends indicate stagnation or decline in core desert areas.

Localized increases in NDVI are evident in canal command areas and irrigated agricultural zones. However, these gains are

often unstable and dependent on continuous water input, making them vulnerable to management failures and climate variability.

4.2 Land Degradation and Desertification Status

DSM assessments identify wind erosion, vegetation degradation, and salinization as dominant degradation processes in the Thar Desert. LDVA results classify large portions of western Rajasthan under moderate to high vulnerability categories, indicating a high probability of further degradation under existing pressures.

4.3 Dune Dynamics and Aeolian Processes

Studies on zibar and transverse dunes indicate ongoing dune mobility in hyper-arid zones. Disturbance of surface crusts and vegetation removal due to grazing, road construction, and infrastructure development accelerate sand reactivation, increasing risks to settlements and transport corridors.

4.4 Soil Moisture Stress and Hydrological Alteration

Low soil moisture availability is a chronic constraint in the Thar Desert. Canal irrigation has altered local hydrological regimes, creating zones of increased moisture and vegetation growth. However, inadequate drainage and excessive irrigation have led to secondary salinization and waterlogging in several areas.

4.5 Anthropogenic Land-Use Change

Expansion of agriculture, settlements, renewable energy projects, and transportation infrastructure has fragmented desert landscapes. Such changes modify surface roughness, disrupt natural sand movement, and increase ecological sensitivity, particularly in fragile dune systems.

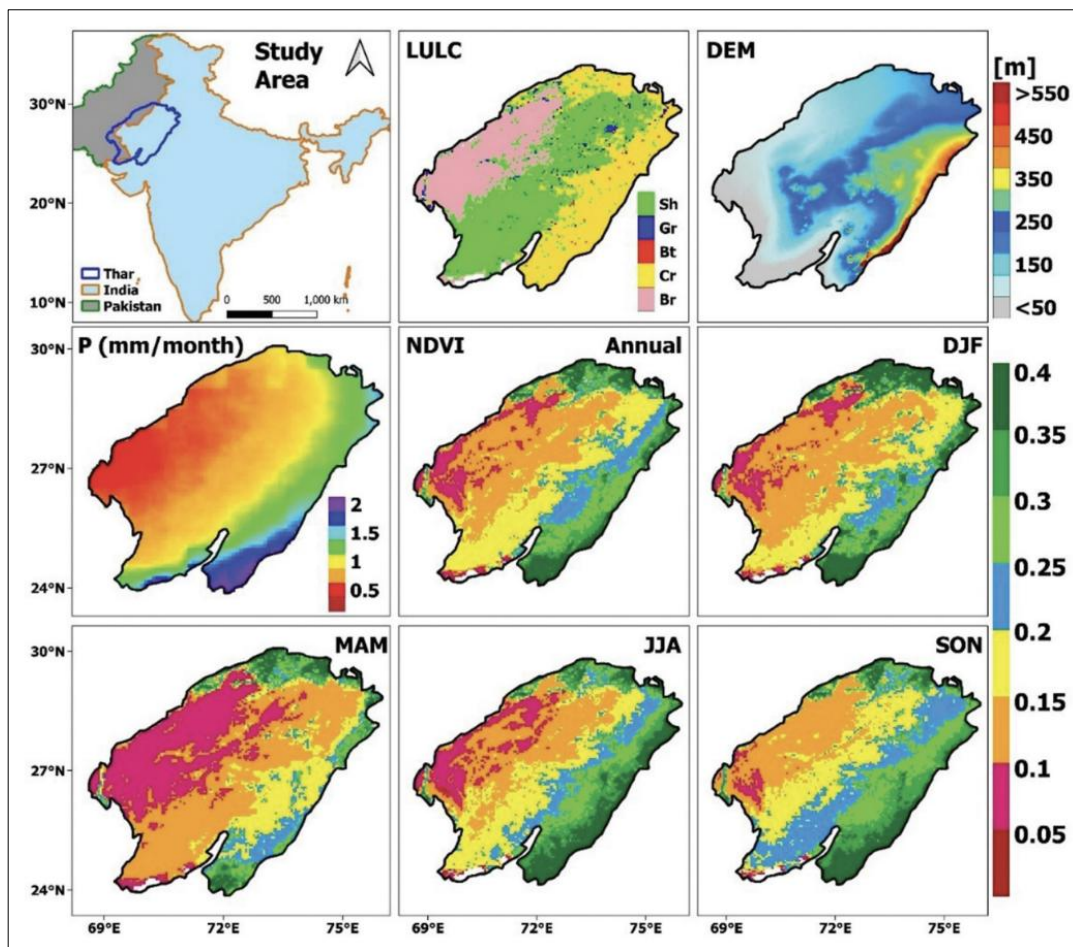


Fig 3: Study area of Thar desert; land use and land cover (LULC) with Sh – Shrublands, Gr – Grasslands, Bt – Built up, Ag – Agricultural or cropland, Br – Barren; The topography by digital elevation model (DEM); Precipitation (P, mm/month), surface greenness as Normalised Difference Vegetation Index (NDVI) for annual, and winter (DJF: December, January and February), pre- monsoon (MAM: March, April and May), monsoon (JJA: June, July and August), and post-monsoon (SON: September, October and November) seasons averaged for the period 2001–2020.

5. Ecological Impacts

The interaction of climatic stressors and human activities has resulted in multiple ecological impacts, including:

- Decline in native vegetation cover and productivity
- Expansion of degraded and desertified land patches
- Increased frequency and intensity of wind erosion events
- Soil salinization and reduced agricultural suitability in irrigated zones
- Heightened vulnerability to extreme heat and rainfall variability

These impacts reduce ecosystem services such as fodder availability, soil stability, and livelihood resilience for local communities.

6. Role of Irrigation and Infrastructure Development

The Indra Gandhi Canal represents one of the most significant anthropogenic interventions in the Thar Desert. Evidence indicates mixed ecological outcomes. Canal irrigation has supported localized greening, agricultural expansion, and reduced aeolian activity in command areas. Conversely, it has accelerated land degradation through salinization, groundwater quality deterioration, and destabilization of adjacent dune systems. Similarly, large-scale renewable energy development offers climate mitigation benefits but poses ecological risks if land clearance, surface modification, and habitat disturbance are not adequately managed.



Fig 4: Indira Gandhi Canal



Fig 5: Bhadla solar park (top), Jaisalmer Wind Park (bottom)

7. Government Responses and Policy Interventions

Multiple national and state-level initiatives aim to mitigate desertification and land degradation. These include desertification status mapping, land degradation neutrality targets under the UNCCD framework, watershed development programs, afforestation initiatives, and climate risk assessment frameworks. Remote sensing-based monitoring has improved the ability to detect changes over time, and evidence from satellite data suggests stabilization or partial recovery in areas where integrated land and water management practices are consistently applied.

8. DISCUSSION

The findings indicate that ecological risk in the Thar Desert is spatially heterogeneous and strongly influenced by management practices rather than climate forcing alone. Although rising temperatures, increased evapotranspiration, and growing rainfall variability intensify baseline ecological stress, the magnitude and direction of ecological change vary substantially across space depending on land-use decisions, water management, and institutional interventions.

8.1 Spatial Heterogeneity of Ecological Risk

Remote sensing-based assessments reveal that degradation is not uniformly distributed across western Rajasthan. Core hyper-arid zones, characterized by low rainfall, mobile dunes, and sparse vegetation, exhibit persistent negative NDVI trends and high land degradation vulnerability. In contrast, areas influenced by irrigation infrastructure, watershed interventions, or vegetation management display episodic stabilization or localized greening. This spatial heterogeneity highlights that ecological risk in deserts is governed by the interaction between natural sensitivity and anthropogenic modification, rather than by climate variability alone.

8.2 Climate Change as a Stress Multiplier

Climate change functions primarily as a stress multiplier in the Thar Desert. Rising mean temperatures, more frequent heat waves, and erratic monsoon patterns increase evapotranspiration demand and reduce effective soil moisture availability. These changes amplify wind erosion, vegetation stress, and land degradation processes, particularly in already vulnerable landscapes. However, climate signals alone do not fully explain observed degradation patterns. Comparable climatic exposure often results in contrasting ecological outcomes where land management differs, underscoring the importance of adaptive capacity.

8.3 Role of Land-Use Planning and Water Management

Land-use planning and water management emerge as critical determinants of ecological risk. Canal irrigation has produced mixed ecological outcomes: it has enhanced vegetation productivity and reduced aeolian activity within command areas, yet simultaneously triggered secondary salinization, waterlogging, and land instability in poorly drained zones. Similarly, expansion of agriculture and settlements in ecologically fragile dune landscapes has increased surface disturbance, accelerating sand reactivation and erosion. These findings suggest that ecological benefits from development interventions in deserts are conditional upon alignment with geomorphological and hydrological thresholds. Where irrigation intensity exceeds soil and drainage capacity, short-term greening may mask long-term degradation risks.

8.4 Policy Interventions and Ecological Responsiveness

The synthesis indicates that desert ecosystems in western Rajasthan are more policy-responsive than traditionally assumed. Areas subjected to integrated land and water management such as afforestation, controlled grazing, watershed development, and soil conservation measures—demonstrate signs of stabilization or partial recovery in vegetation indices and land degradation status. National initiatives on desertification status mapping and land degradation neutrality have improved the identification of high-risk zones and enabled targeted interventions. Importantly, the availability of long-term satellite data has enhanced monitoring capacity, allowing early detection of

degradation trends and evaluation of policy effectiveness. This evidence challenges the perception of deserts as ecologically static systems and instead positions them as dynamic landscapes capable of recovery under appropriate governance.

8.5 Infrastructure and Renewable Energy Development Trade-offs

The rapid expansion of renewable energy infrastructure in western Rajasthan introduces a new dimension of ecological risk. While solar and wind projects contribute to climate mitigation goals, land clearance, surface leveling, and access road construction can disrupt dune stability and vegetation cover if not carefully planned. The findings suggest that renewable energy deployment in desert environments must incorporate ecological sensitivity mapping and cumulative impact assessment to avoid transferring climate mitigation benefits into localized ecological degradation.

8.6 Implications for Adaptive Governance

The observed heterogeneity in ecological risk underscores the need for adaptive, spatially explicit governance frameworks. Uniform policy prescriptions are unlikely to be effective across the diverse ecological settings of the Thar Desert. Instead, risk-sensitive land-use zoning, integration of remote sensing indicators into planning, and alignment of irrigation and infrastructure development with ecological carrying capacity are essential.

Future resilience of the Thar Desert will depend on scaling data-driven desert management approaches that integrate climate projections, land degradation vulnerability, and socio-economic considerations. Strengthening institutional coordination and local participation will be critical to translating policy intent into sustained ecological outcomes.

9. CONCLUSIONS

The Thar Desert faces persistent ecological risks driven by climate variability and anthropogenic pressures. Remote sensing and geospatial evidence reveal widespread land degradation, vegetation stress, and geomorphic instability in western Rajasthan. However, targeted government interventions demonstrate potential for stabilization and partial restoration. Ecological risk in deserts is not static; it can be mitigated through science-based, adaptive management strategies aligned with ecological thresholds.

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