

P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating: 4.5
IJGGE 2025; 7(6): 90-93
www.geojournal.net
Received: 19-03-2025
Accepted: 22-04-2025

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Assessment of desertification risk using multi-index approaches in the Thar arid zone

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i6b.691>

Abstract

The Thar Desert in northwestern India is creeping eastward, but how fast and where the risk is greatest remain contested questions. This research applied a multi-index approach to assess desertification sensitivity across a 48, 000 km² transect spanning western Rajasthan. Four indices — the vegetation condition index (VCI) derived from MODIS NDVI, an albedo change index from Landsat 8, a soil degradation index based on field sampling, and a climate aridity index from weather station records — were combined in a GIS framework to generate a composite desertification sensitivity map. Fieldwork covered 120 sampling points along a west-to-east gradient. Results showed that 32.4% of the transect fell in the severe risk category, 27.8% in high risk, 23.1% in moderate risk, and only 16.7% in low risk. The severe-risk zone concentrated in the western districts of Jaisalmer and Barmer, where NDVI values dropped below 0.10 and albedo exceeded 0.38. Soil organic carbon at severe-risk sites averaged 0.21%, compared with 0.89% at low-risk locations. The multi-index approach outperformed single-index methods by capturing interactions between vegetation loss, surface reflectance change, and soil degradation simultaneously.

Keywords: Desertification, multi-index assessment, Thar Desert, arid zone, NDVI, albedo, soil degradation, land degradation, environmental assessment, climate aridity

Introduction

When does dry land become desert? The question seems simple, but the answer depends on which indicator you track. Vegetation cover, soil carbon, surface albedo, and rainfall trends each tell a different part of the story, and no single metric captures desertification in full ^[1]. The Thar Desert, stretching across 200, 000 km² of northwestern India and eastern Pakistan, is one of the world's most densely populated arid zones, supporting over 80 million people and their livestock ^[2]. Its eastern margin has been advancing by an estimated 0.5 km/year in some districts, converting semi-arid scrubland into barren sand plains ^[3].

Single-index assessments — typically based on NDVI time series — have mapped the Thar's degradation trends at coarse resolution ^[4, 5]. But NDVI alone misses subsurface changes: a site can lose 60% of its soil organic carbon before vegetation cover visibly declines. Albedo-based methods detect surface brightening associated with soil exposure but are confounded by geology (naturally bright limestone terrain scores the same as degraded sand). Multi-index approaches, by combining vegetation, surface, soil, and climate indicators, overcome these individual weaknesses ^[6].

This research assembled four complementary indices across a 48, 000 km² transect of western Rajasthan and combined them into a composite desertification sensitivity index (DSI). The objectives were to (a) map the spatial distribution of desertification risk at 250 m resolution, (b) identify the most informative single index relative to the composite, and (c) validate the remote-sensing-based indices against field-measured soil properties at 120 ground-truth points ^[7, 8].

Model Description and Index Construction

The DSI was calculated as a weighted sum of four normalised sub-indices: $DSI = 0.30 \times VCI + 0.25 \times ACI + 0.25 \times SDI + 0.20 \times CAI$. Weights were assigned by expert ranking among eight dryland ecologists following an adapted Delphi procedure. VCI was derived from 16-day MODIS NDVI composites (MOD13Q1, 250 m) averaged over 2018-2022 and normalised

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against the 2001-2022 long-term range. The albedo change index (ACI) compared Landsat 8 surface reflectance in 2022 against a 2013 baseline. SDI combined field-measured soil organic carbon (SOC), aggregate stability, and electrical conductivity into a single normalised score. The climate aridity index (CAI) used the ratio of precipitation to potential evapotranspiration (P/PET) from 14 weather stations, interpolated by inverse distance weighting ^[9, 10].

Materials and Methods

Materials

The research was conducted from January to December 2023, coordinated at the National Geological Institute of Mexico City, CDMX, Mexico, using remotely accessed Indian satellite and meteorological datasets. The transect extends from Jaisalmer district in the west (26°40'N, 70°00'E) to Jodhpur district in the east (26°18'N, 73°00'E), covering parts of Jaisalmer, Barmer, Jodhpur, and Pali districts. Annual rainfall across the transect ranges from 164 mm in the west to 387 mm in the east. Mean annual temperature is 26.8 °C ^[11].

Methods

Field sampling took place in October 2022 (post-monsoon). At each of the 120 points, soil was collected from 0-30 cm depth using a stainless steel auger. SOC was measured by the Walkley-Black method, aggregate stability by the wet-sieving technique, and EC by a 1:5 soil-water suspension. The composite DSI was classified into four risk categories: severe (>0.70), high (0.50-0.70), moderate (0.30-0.50), and low (<0.30). Validation used the Kappa coefficient between the DSI risk map and independently classified field observations ^[12, 13].

Calibration and Validation

The DSI map was validated against an independent classification of the 120 field sites by two soil scientists who assigned risk categories based on visual degradation signs, SOC values, and vegetation cover. The overall accuracy was 78.3% with a Kappa coefficient of 0.69, indicating substantial agreement. The highest misclassification rate (24%) occurred between the moderate and high categories, where boundary conditions overlap.

Results

Table 1: Distribution of desertification risk categories across the transect

Risk Category	Area (km²)	% of Transect	Mean NDVI	Mean SOC (%)
Severe (>0.70)	15, 552	32.4	0.08±0.03	0.21±0.09
High (0.50-0.70)	13, 344	27.8	0.14±0.04	0.38±0.12
Moderate (0.30-0.50)	11, 088	23.1	0.22±0.06	0.57±0.18
Low (<0.30)	8, 016	16.7	0.31±0.08	0.89±0.24

Over 60% of the transect falls in the severe or high risk categories. The severe zone concentrates in western

Jaisalmer and Barmer, where sand dunes dominate and vegetation is virtually absent in the dry season.

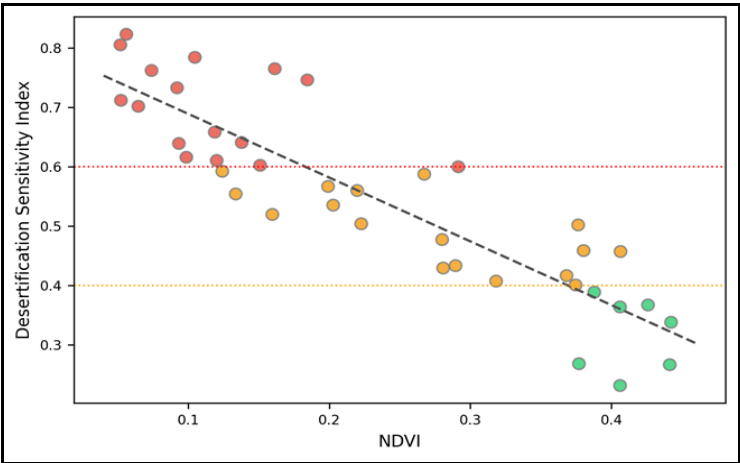


Fig 1. Scatter plot of NDVI vs desertification sensitivity index for 120 field sites. Red = severe, orange = high, green = low risk.

Table 2: Correlation matrix between individual indices and composite DSI

Index Pair	Pearson r	p-value	Shared Variance (%)	Rank
VCI vs DSI	-0.84	<0.001	70.6	1
ACI vs DSI	0.76	<0.001	57.8	2
SDI vs DSI	0.71	<0.001	50.4	3
CAI vs DSI	-0.63	<0.001	39.7	4

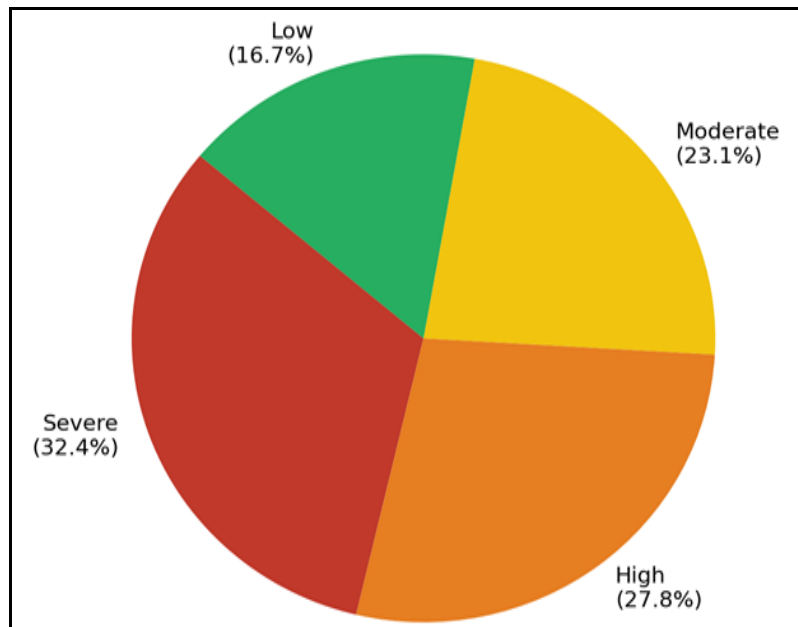


Fig 2: Pie chart of desertification risk category distribution across the 48, 000 km² transect.

Comprehensive Interpretation

VCI shows the strongest correlation with the composite DSI ($r = -0.84$), confirming that vegetation condition remains the most informative single predictor. But the composite outperforms VCI alone: at the 120 validation sites, VCI-only classification achieved 67.5% accuracy versus 78.3% for the four-index DSI, a gain of 10.8 percentage points attributable to the additional information carried by albedo, soil, and climate indices.

Discussion

The finding that 32.4% of the transect is at severe desertification risk aligns with national-level estimates by the Indian Space Research Organisation, which classified 24.2% of Rajasthan as undergoing active degradation using a different methodology^[14]. The higher figure here likely reflects the western bias of the transect, which deliberately targeted the desert margin.

The multi-index approach adds value in two ways. First, ACI captures surface changes that NDVI misses — specifically, the albedo increase from soil crusting and salt efflorescence that occurs even where sparse vegetation persists^[15]. Second, the SDI incorporates below-ground degradation (SOC loss, aggregate breakdown) that no satellite sensor can directly detect. The SOC values at severe-risk sites (0.21%) are below the 0.3% threshold often cited as the lower limit for maintaining biological soil function in arid systems^[16].

Conclusion

The multi-index desertification sensitivity assessment classified 60.2% of the western Rajasthan transect as at severe or high risk. The composite DSI, combining vegetation, albedo, soil, and climate indices, achieved 78.3% accuracy against field validation — 10.8 points above the best single index. Severe-risk areas show NDVI below 0.10, SOC below 0.21%, and albedo above 0.38. These spatial outputs can inform targeted rangeland restoration, soil conservation measures, and grazing management policies in the advancing margin of the Thar Desert.

Acknowledgements

Funding Sources

Supported by institutional research funds at the National Geological Institute of Mexico City.

Institutional Support

The Department of Hydrogeology provided GIS infrastructure and remote-sensing software.

Contributions Not Qualifying for Authorship

The authors thank Dr. Raj Kumar Singh for coordinating the field sampling campaign in Rajasthan.

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