Standard Operating Procedure (SOP) for Mapping Land Degradation due to Wind Erosion in India

Introduction and Background

In India, wind erosion affected areas are confined to its hot arid region (spread over about 31 million ha) and cold arid region (7 million ha). Most part of hot arid region is located in northwestern India, with Rajasthan sharing the maximum area (20.8, 61.9%), Gujarat (6.22 m ha, 19.6 %), Punjab and Haryana (2.75 m ha, 8.6 %). Besides, in the southern part of country arid areas also occur in the state of Karnataka (2.7 %), Maharashtra (0.4 %) and Andhra Pradesh (0.4 %) area. In the cold arid region of country, wind eroded features occur in Leh and Nubra valley. Wind erosion is the major process of land degradation in the arid region, as it affects about 70% area in the region and consequently influences land, people and their activities such as agriculture. The Thar desert in India is an integral part of the hot arid region of Rajasthan. Climatically, the region is characterized by an aridity index of -66.6 that passes roughly through the eastern margin of the desert along the NNE-trending Aravalli hill ranges. A variety of landforms have been identified in this region, which are result of interplay of climate, vast desert area and presence of Aravalli range, thus broadly, the landforms can be categorized as aeolian, fluvial, tectonic and lacustrine type.

Unlike other deserts of the world, in Thar desert, wind erosion activities are restricted to the summer months when strong winds associated with the south-west monsoon creates favourable conditions for sand and dust raising winds. The wind erosion sorted landforms manifest through sand dunes, sandy plains and other Aeolian landforms. Majority of landforms (> 80%) are of Aeolian origin. Sand dunes occur in about 48% area. Spatial variations in sand dunes (occurrence, morphology and topography) are visible in relation to rainfall and wind speed gradients from eastern part (along the Aravalli Mountain system) to the west (at Jaislamer district). The agricultural pattern and the farming system equally reflect the impacts of such climatic as well as landform system.

Recent changes in the climate, especially in the rainfall pattern, availability of irrigated water and research interventions has brought in significant stability to Aeolian landscape. For example, situations of dryland farming in the northern part of Rajasthan have changed to double cropping. The interdune plains in Sri Gangnaganagr and Hanumangarh districts which were moderate to very high wind erosivity zones with large scale sand mobility and also used to be kept fallow due to want of water, because of canal irrigation, are now regarded as double crop areas and the erosion by wind actions has reduced. Cultivation pressure has increased in both rainfed and irrigated areas. Mechanized farming using tractor ploughing of sand dunes has nullified stabilization effects of increasing rainfall. Sand control measures have been adopted mostly in drylands, sand dune stabilization work has been taken up restraining sad movement from croplands, wind breaks like shelter belts and vegetative barriers are now either used at community level or by state agencies. Such activities would suggest the actions taken for restricting the impacts of wind erosion.Wind erosion is also a major component of Desertification in western Rajasthan. The problem initiates as wind lifts sediments from the land surface, transports and deposits at another place. Many parts of western Rajasthan are conducive for such activity as majority of area have presence of loose, dry and finely granulated particles on the surface, amount and density of vegetation in the form of trees, shrubs and grasses are very less and strong –turbulent wind regime. A comprehensive summary on movement of sediment particles by wind erosion processes was reported by Bagnold (1943) for desert sands and by Chepil and Woodruff (1963) for agricultural lands.Transport of particles, is commonly described by three distinct modes: suspension, saltation, and surface creep. In the suspension mode, aggregates or particles that are removed from local source area is transported to high altitudes and over long distances, depending on their size, shape, and density. Chepil (1945) reported that 3 to 38% of total transport is occurred through suspension mode. Size of suspended aggregates/particles ranges from 2 to 100 μm with a mass median diameter of about 50 μm in an actively eroding field. Suspended particles generated through wind erosion process is generally considered as nutrient rich particles as plant nutrients and organic carbon are mostly associated with finer soil fractions. The enrichment ration even increases with the increase of coarse sand content in bulk soil. Consequently, suspension indirectly impacts soil productivity by removing nutrient rich fractions of soil or by leaving behind the less-fertile soil constituents. In the saltation mode, eroded particles are jumped or hopped from one place to another place. Saltating particles leave the surface with wind force but are generally large enough to be suspended and thus returned back to surface. On returning to surface, saltating particles initiate the movement of another particle. Size of saltating particles/aggregates ranges from 100 to 500 μm. The bulk of transport during wind erosion, roughly 50 to 80% occurs through saltation mode. Majority of saltating particles/aggregates rises up to a height of 30 cm and in some cases up to a height of 120 cm. In the surface creep mode, coarse sand sized mineral particles having diameter 500-1000 μm are pushed and rolled on soil surface. About 7-25% of total mass transport occurs through surface creep mode (Lyles et al., 1985).

Objective of wind erosion mapping

1. To identify and map the spatial distribution of wind erosion affected area using visual Interpretation of Multi-Seasonal Remote sensing data, Geospatial tools, and its validation.
2. Monitor temporal changes in land degraded area due to wind erosion across various agro-ecological regions of India

Datasets Required

Dataset	Description
Landsat 8 Operational Land Imager (OLI)	(**Jan-March**) To observe spatial pattern and morphological characteristics of field indicators of wind erosion under different Land Use Pattern
Landsat 8 Operational Land Imager (OLI)	(**May-June**) To observe the Sand drifting/reactivation during this period in the absence of minimal vegetation cover.
Field Observations	Ground-truthing through field surveys to validate classified degradation

Methodology

Step1:Data Collection

Landsat-8 Operational Land Imager (OLI) Level-2 Surface Reflectance (SR) products were acquired for the months of **May–June** from 2013 to 2024. This seasonal window was specifically chosen as it corresponds to **peak dry periods in arid/semi-arid part ofcountry,** when vegetation cover is minimal and sandy surfaces are mostly exposed to re-working by aeolian processes. Multiple cloud-free images were selected to ensure temporal consistency and spatial accuracy. Data were sourced from the **USGS Earth Explorer platform** and downloaded in GeoTIFF format.

Step 2: Preprocessing of Data and Generation of FCC (False Color Composite)

- Pre-processing is critical to improve the quality of satellite datasets before analysis: Radiometric Calibration, Atmospheric Correction, Cloud Masking.
- Images were clipped to the Area of Interest (AOI) representing the agro-ecological regions (Hot /Cold Arid and semi-arid regions)
- False Color Composites were generated to visually distinguish between surface features:

NIR (Band 5), Red (Band 4), Green (Band 3) composites of Landsat-8 satellite image were used for vegetation and barren land discrimination. FCCs enhanced visual interpretation and provided a base layer for sand area discrimination.

Step 3: Visual Interpretation of Wind Erosion Features

Visual interpretation techniques were applied to identify sandy features of either aggraded/degraded type and erosion-prone areas. This step utilized both satellite image characteristics and domain knowledge of desert geomorphology/land use-vegetation relationship.

- Sand Dunes (aggraded feature): Identified by their morphology: shapes (elongated, parabolic, linear, crescent shaped, obstacle formation), low or high dunes, pattern: single or isolated or clustered formation, Tone : bright/dull white, vegetated or bare dunes, alignment with wind direction (uni-directional or multi-irectional).
- Deflation Zones (Degraded feature): Recognized as shallow depressions (after removal of surface sand) and left with sediments of coarse textures and bareness.
- Sand Sheets: Characterized by uniform tone and fine textures spread across flat areas and thin verniers of sand deposits. Interpretation relied on photo-interpretation keys such as tone, texture, size, shape, pattern, and association.

Step4: Supporting Indicators-Physical / Field Indicators

Following physical/field indicators matched with terrain types and isohyet variability are considered while mapping the categories of wind erosion (severity classes) (modified CAZRI-2000)

Terrain	Average Rainfall (MM)	Major Indicators for assessment	Severity
Fluvio-aeolian plains	>550	Sand free zone	Negligible
Aeolian plains	400-550	Occasional sand sheets, remnants of earlier sand dunes, irrigated double crop cultivated lands (Ghaghar flood plain, part of Luni basin) and Rann of Kachchh)	Very slight
Flat sandy plains with dominantly loamy sand to sandy loam soil	100-550	Fresh sand sheet up to 30 cm thick; few scattered new fence line hummocks and nebkhas up to 100 cm high	Slight
Moderately sandy undulating plains and sand dunes with loamy sand soils ; thickly sand sheeted plains	> 300	Presence of reactivated fresh sand of 50 to 150cm thickness on stable dunes, sandy plains and fence line hummocks; many recently formed nebkhas	Moderate
Moderately sandy undulating plains and sand dunes with sand to loamy sand soils	< 300	Reactivated and fresh hummocks (nebkhas) and sand ridges of 90-300cm height ; sand sheets of 60-150cm thickness between undulations; reactivated stable dunes with fresh sand deposits of 70 to 200 cm thickness;	Moderate

		exposed plant roots to a depth of 40 to 100 cm in the sandy plans indicate erosion	
Moderate to strongly undulating sandy plains with closely spaced hummocks and high sand dunes with sand to loamy sand soils	100-500	Closely spaced sandy hummocks and sand ridges of 1 to 4m height with fresh sand cover ; Sand deposits of 100-300cm thickness usually present undulations; Highly reactivated sand dunes are covered by fresh sand and superimposed by crescentic bed forms of 2 to 4m height	Severe
Barchan dunes and very thick sandy plains with loose sand throughout the profile	100-550	Areas of drift sand, especially as fields of barchans of 2 to 5m height, which encroach upon roads, settlements and agricultural fields ; also areas with very closely spaced nebkhas of 2-5m height	Very severe

Step 5: Supporting Indicators-Visual Interpretation of FCCs of Satellite Image

Erosion Process	Severity classes	Erosion Type	Colour/Tone (FCC-Based)	Texture	Pattern	Shape	Association	Remark
Wind Erosion /deposition	Slight/Very slight	Sheet Erosion/Loss of top Soil (	Various shades of yellow and light grey combination	Smooth to medium	Contiguous/ mottling(in cultivated areas)	Regular/Irregular	Desertic plain areas having signatures of active sand movement	In deserted areas: with little or no vegetal protection
	Moderate	Partially stabilized dunes	Light grey to medium grey with light yellowish tones	Medium	Contiguous/ discrete patches	Regular/Irregular	Desert sandy dunal area	Sand dunes in desert areas with slight to moderate vegetal grass cover
	Moderate	Stabilized dunes	Medium grey with light yellowish tones during dry season.pink mottles during rainy season.	Medium to coarse	Discrete patches/scattered dunes	Regular/Irregular	Desert sandy dunal area	Sand dunes in desert areas with good vegetal/grass cover/presently under cultivation
	Severe/very severe	Un-stabilized dunes	Various shades of yellow and very light grey combination	Smooth to medium	Contiguous/ discrete / Barchans/Bare dunes	Irregular	Desert sandy dunal area / low sand dunes (Barchans)/sand	Sand dunes in desert areas with no vegetal/ grass cover

							drifts/thick sand on dune body	

The visually interpreted features were verified by cross-referencing both physical indicators and satellite image keys. This two-way validation ensured that landforms identified as eroded zones were consistent with both geomorphic evidence (e.g., dune morphology) and remote sensing signatures (tone/texture/association)
(Ref. Remote Sensing and Image Interpretation, 7th edition**)**.

Step 6:On-Screen Digitization and Mapping

Once features were validated, they were delineated through manual on-screen digitization process using ArcGIS/QGIS platform with background FCCs of satellite image (Summer and Rabi Season period). This methodology was chosen over automated classification to achieve higher precision in delineating wind erosion features. Each erosion-prone feature (duny uplands, deflation basins, sand sheets) was digitized as a polygon layer. The resulting spatial database was stored in vector format (GeoPackage/Shapefile).

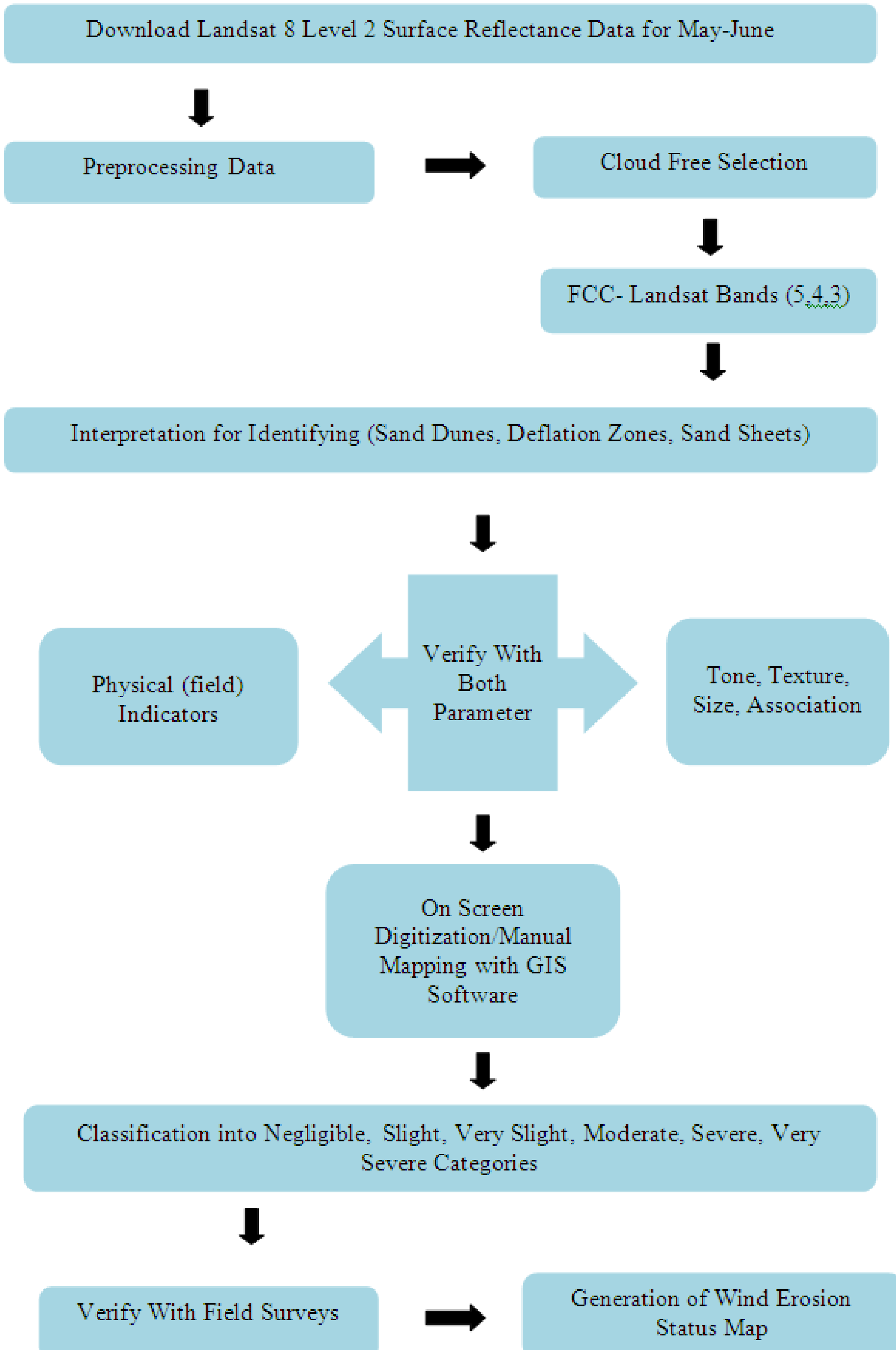
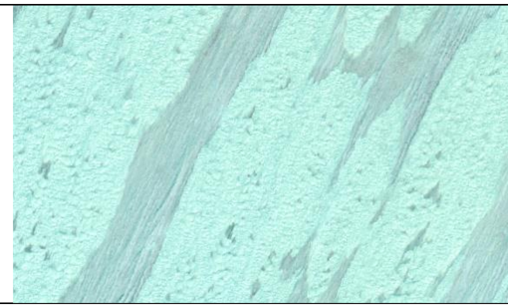
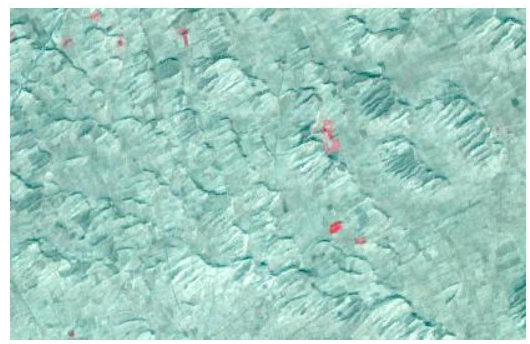
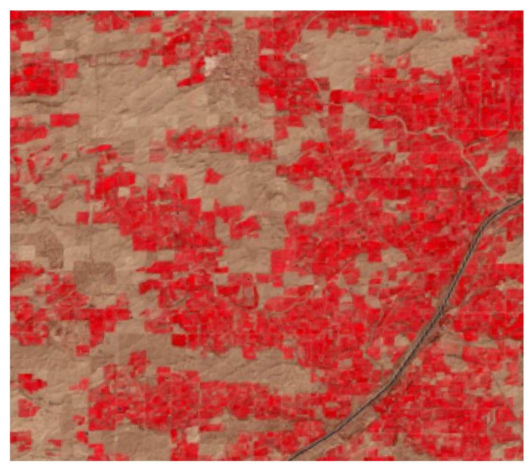
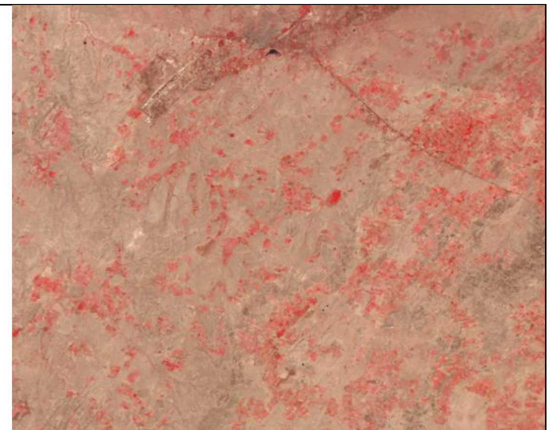
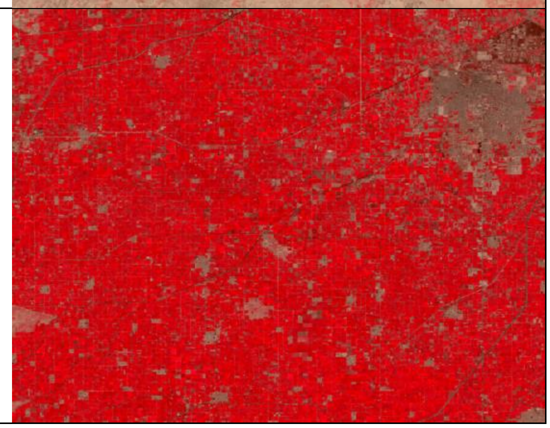


Fig.1 Overall methodology for wind erosion degradation mapping

Step 7: Classification of Wind Erosion Severity

The mapped units were categorized into six severity levels:

Mapping unit/Severity class	**Field indicators amenable to satellite images**	**Location**	**Sample representative Images**
Very severe	Barchans/devoid of any desertic vegetation, 40-50 m high dunes, thick sand deposits, barchanic crests and active shifting dunes	Extreme western part of Rajasthan, Jaisalmer district (Murar, Dhanana, Sam)	
Severe	Extensive dune fields, clustered formations (very clearly visible on surface), reactivated sand on the dune slopes,deflation hollows, occurrence of scattered desert shrubs/grasses/bushes	NW Jaisalmer, west of Barmer, central part of Bikaner, western Churu and northern Jodhpur etc	
Moderate	Sand dune area, many of the dunes are nearly stabilized due to anthropogenic interventions (shelterbelts plantations, afforestation over duneslopes, occasionallycultivated with irrigation facility/ visible sand sheet with occasional dunes at some areas)	IGNP canal area in Jaisalmer/ eastern part of Barmer and northern part of Bikaner and eastern Churu In Leh (Shey, Choglamsar, Thik Shey, Rambirpur), the wind erosion affected areas occur on hill slopes/and valleys. In Nubra, near Hunder and Dikshit villages, a significant area is under barchan formations.	

Slight	Erosional features (desert pavements, eroded rocky features, occasional or isolated stable dunes, patches of sand sheets etc	Mainly surrounding Jaisalmer town/Nagaur/southern part of Jodhpur/ foot slope of Aravalli	
Very Slight	Cultivated lands, previously under sand dunes that has been levelled and presently under double cropping with irrigation. Sands appear on fallow lands.	North of Rajasthan (SriGanganagar-Hanumangarh, arid districts of Punjab/Haryana and Gujarat)	

Negligible – stable surfaces with sand free/ little or no evidence of wind erosion activity.

This classification followed desertification assessment guidelines by ICAR-CAZRI and NRSC standards.

Step8: Field Validation

Field surveys were conducted at representative sites across western Rajasthan, part of Punjab, Haryana and Gujarat and In cold arid region of Leh and Nubra valley.

Field validation involved:

(1) Direct observation of sand accumulation, erosion scars, and dune morphology, (2) recording soil texture and vegetation conditions at ground checkpoints, (3) comparing field GPS points with satellite-derived maps for accuracy assessment. The validation exercise strengthened the reliability of the erosion classification.

Step9: Generation of Wind Erosion Status Map

The final step involved integrating satellite-based mapping, classification, and field validation into a Wind Erosion Status Map. This thematic map provides:

- Spatial distribution of wind erosion-prone areas.
- Intensity classification from negligible to very severe.
- Key zones requiring soil conservation and land management interventions.

This output forms the basis for regional-scale desertification monitoring, land-use planning, and sustainable management of arid and semi-arid ecosystems in Western Rajasthan, Part of Punjab, Haryana, Gujarat and Cold Arid region of India.

Conclusions

The present SOP demonstrates a systematic approach for assessing wind erosion in agro-ecological regions (Arid and semi-arid regions) using Landsat 8 satellite data, geospatial analysis, and field validation. Through pre-processing, visual interpretation, and integration of physical indicators, key wind erosion features such as sand dunes, deflation zones, and sand sheets were successfully identified and mapped. The classification into severity levels—ranging from Negligible to Very severe—provides valuable insights into spatial variability of wind erosion across diverse terrains.

The results highlight that areas with active dunes, thick sandy deposits, high wind erosion index, lower rainfall regimes are most vulnerable, often leading to severe to very severe erosion, while flatter sandy plains exhibit only slight degradation. The mapping also indicates transformation of severity classes for example, change from severe to moderate or slight at places. Such changes are dynamic looking at the role of climate change, especially, rainfall pattern or impact of Anthropogenic or man-made actions. Much of the lands have been improved due to more vegetation cover (both tree and crop types), shelterbelt plantations or through sand dune stabilization. How ever, one needs to be careful while affixing the severity category to any land. For example, plantation on sand dunes in <200 mm rainfall zone may enhance sand depositions, but such type of effort in canal command area may reduce the sand transportation. Thus, mapping the wind erosion for a region like arid-Rajasthan needs more clarity on the genesis of problem, type of interventions being in place and prevailing rainfall pattern. The integration of field surveys further validates the reliability of the outputs, ensuring that the generated **Wind Erosion Status Map** serves as a credible decision-support tool.

Overall, this SOP establishes a replicable methodology that can be adopted for monitoring aeolian processes, supporting land degradation studies, and guiding sustainable land and water management practices in arid regions. The approach is flexible and can be scaled or adapted for other desert-prone regions facing similar environmental challenges.

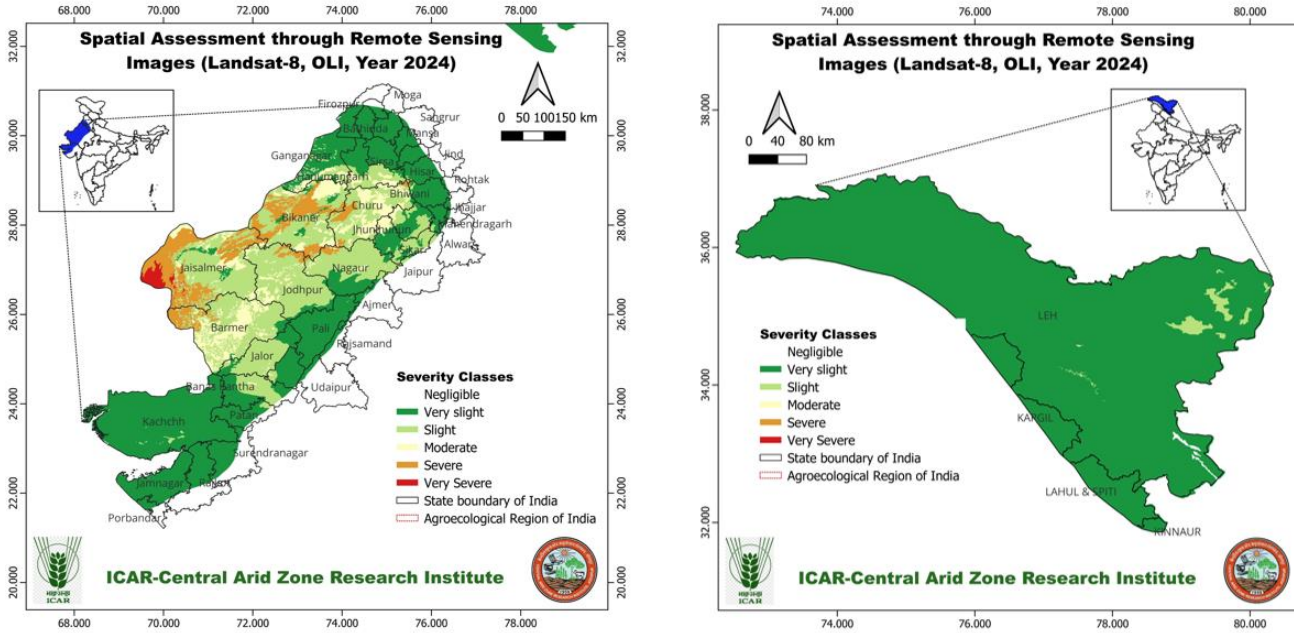


Fig 2: Wind Erosion Status Map Using Spatial Assessment Indicates Severity level in Hot Arid Region Map (Left) and Cold Arid Region (Right) of India.