Desertification in India's Arid Zone
Stemming the Flow

Dr. P.C.Moharana , Principal Scientist
Fulbright Fellow
ICAR-Central Arid Zone Research Institute,
Jodhpur, India

When resources are degraded, we start competing for them. [...] So one way to promote peace is to promote sustainable management and equitable distribution of resources.

Wangari Maathai

(First African Woman to win Nobel Prize)

Maathai founded the Green Belt Movement an environmental non-governmental organization focused on the planting of trees & environmental conservation

Sand mobilization in 1950s and 60s was so strong that Indian Parliament created

Desert Afforestation Station at Jodhpur

which was further developed in 1959 as the **Central Arid Zone Research Institute or CAZRI**

Basic objective : Understand the phenomenon and stabilize the sand dunes so that fertile lands do not get encroached upon

Today CAZRI operates with more than 25 scientific disciplines addressing Arid agriculture for a sustainable life

India’s Arid Zone; climate, land and charateristics

India’s Arid Zone : The Operative Environment

Arid regions (12% of national geographic area)

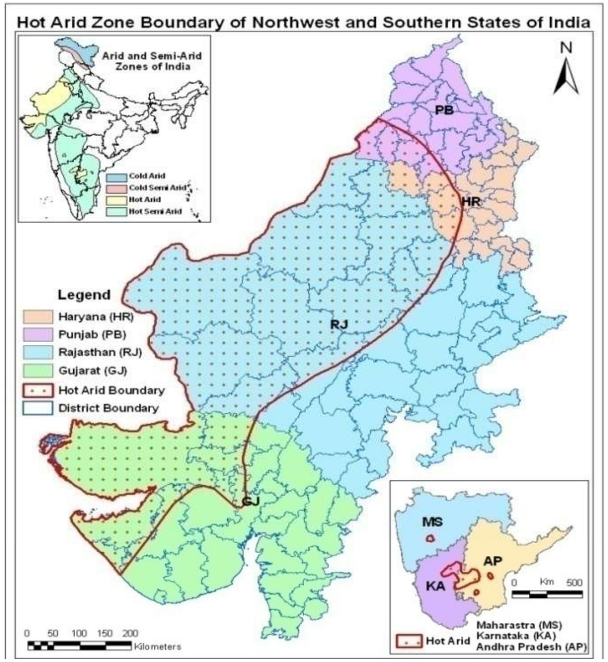
- Hot 31.7 million ha
- Cold 7.2 million ha

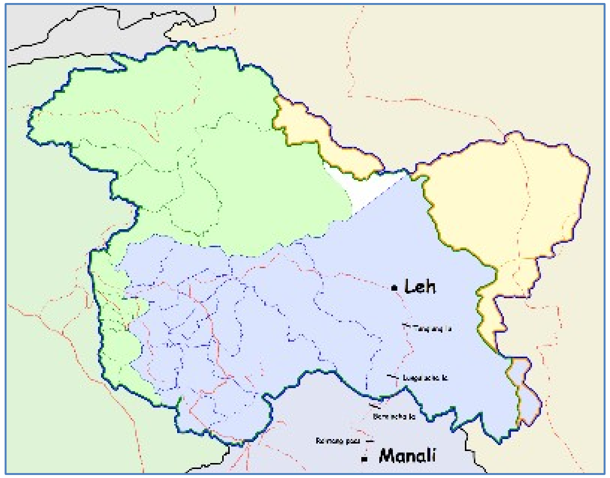
Hot Arid

Rajasthan:	19.60 m ha
Gujarat:	6.22 m ha
Haryana & Punjab:	2.75 m ha
South Peninsula:	3.13 m ha

Cold Arid

Jammu & Kashmir:	6.1 m ha
Himachal Pradesh:	1.1 m ha





Climate change and possible implications

GLOBAL, INDIA AND ARID AREAS

- Global temperature : under the GHG emission of 2000, may increase by ~0.1 degree C per decade.
- Possibility of a prolonged drought phase during 2021-2025

Prediction for India

Mean annual temperature : +3-5 degree C

High disparity in the distributional pattern of Temperature and Rainfall

North India to be warmer than south

By 2071 : overall summer monsoon rainfall : +20%

Predications for arid regions

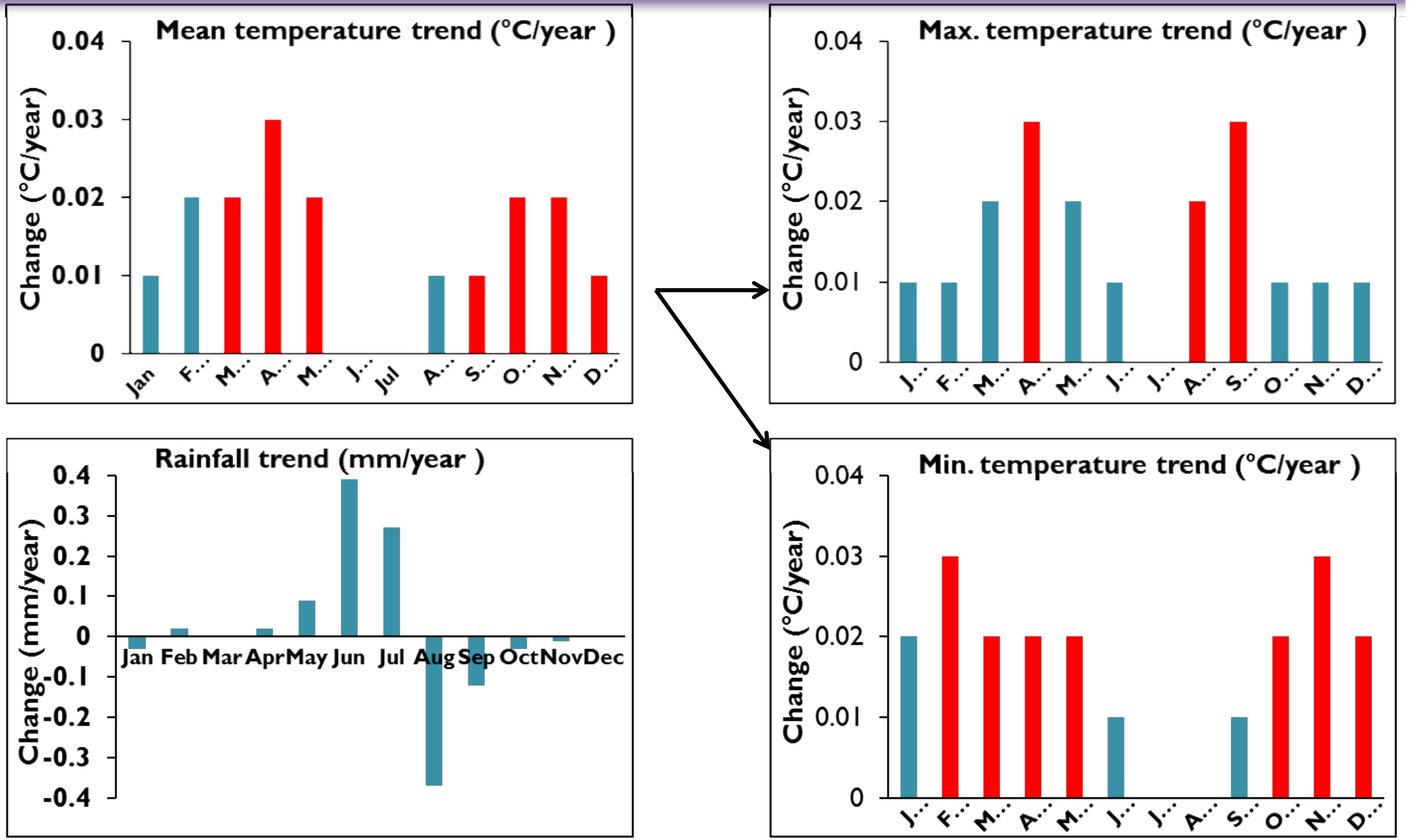
- To experience 15-35% higher monsoon rain (last quarter of century)
- Incidence of tropical storms+ increase in rainfall intensity + high floods in southern Rajasthan
- Rainy days may decline by 10 days, consequently higher incidence of droughts

Possible Implication

On the current understanding of Climate Change (Kar, 2008)

- Hotter and very dry NW Rajasthan & Warmer, moderately wetter Gujarat
- Desert and its eastern margin to be more vulnerable to accelerated wind erosion, and other desertification processes.

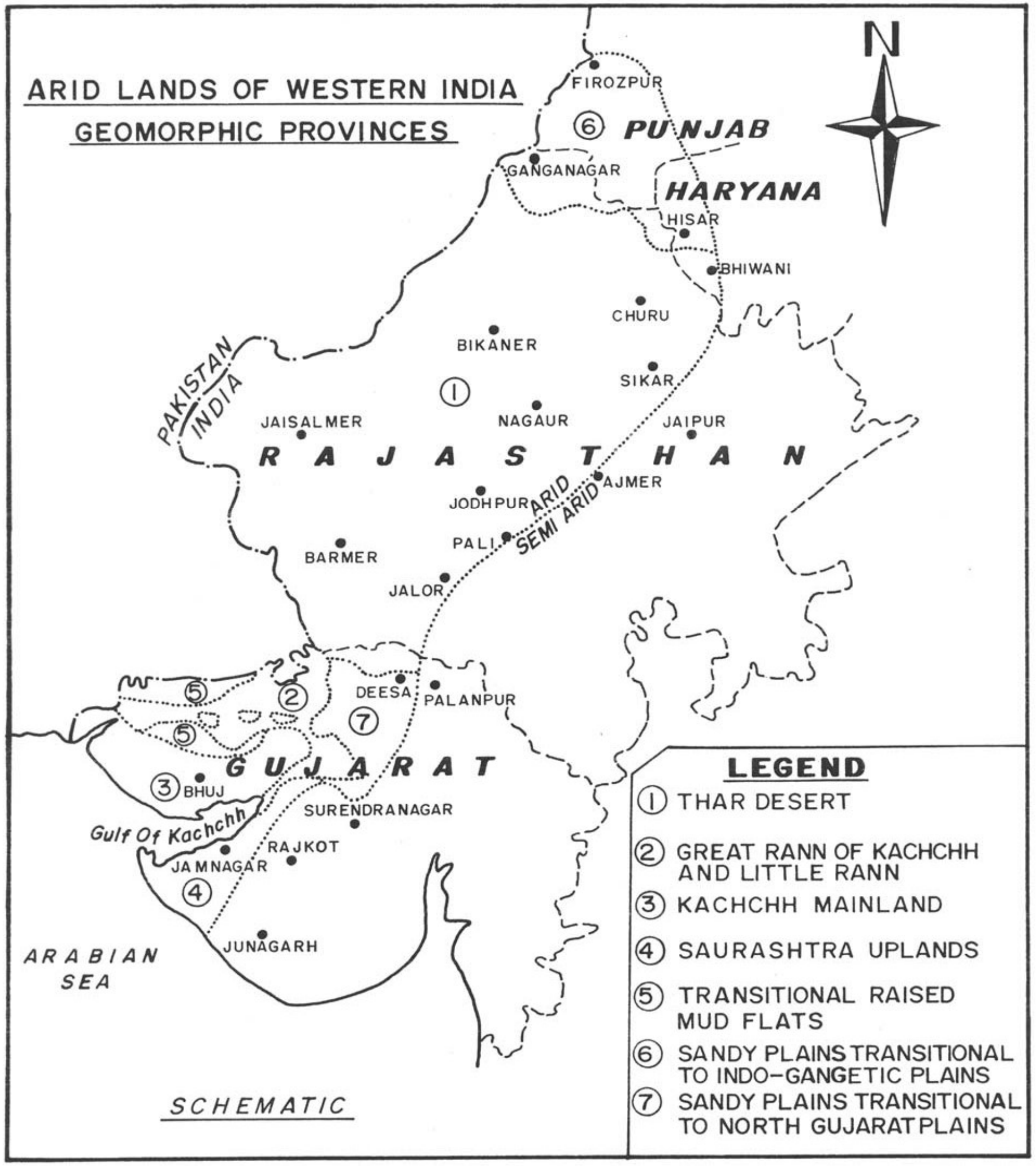
Observed Climate Change in Rajasthan (1951-2010)



Non-significant Trend   Statistically Significant Trend   No Trend

Source: IMD 2013

THAR : a Complex system with more prospects and fewer limitations



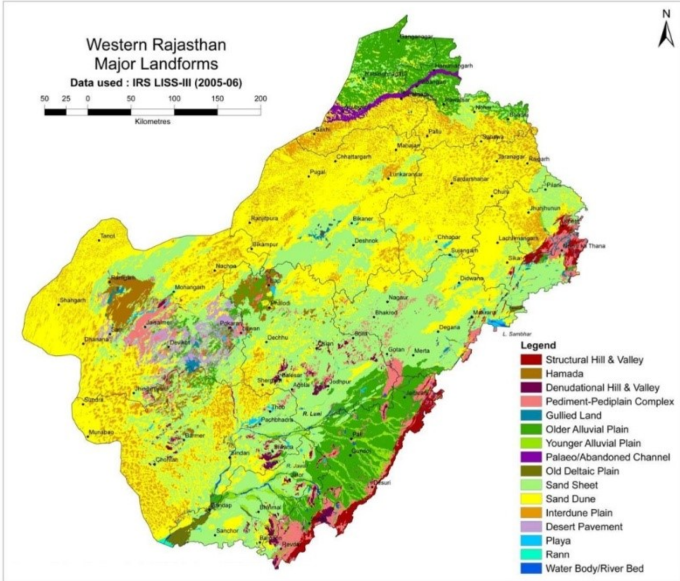
- ~12 % (38 M ha area) of country's TGA is arid, Rajasthan' s share : about 62%
- Country has 120 M ha degraded lands out of which Wind erosion affects 12.40 M ha area

Erosion
and soil forming process in Desert

Rock erosion, horizontal and vertical splits

Hardened sides forming circular rims at Mokal

Exfoliation process of erosion and resistant rock at Roopsi

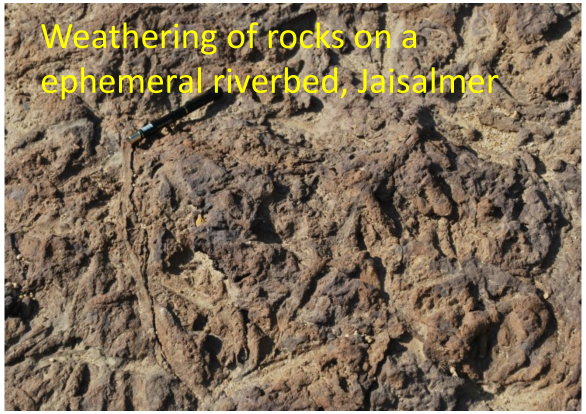


- Structural Hill & Valley (1.37 %)
- Hamada (1 %)
- Denudational Hill & Valley (0.9 %)
- Pediment-Pediplain Complex (4.11 %)
- Gullied Land (0.40 %)
- Older Alluvial Plain (9.70 %)
- Younger Alluvial Plain (2.08 %)
- Palaeo/Abandoned Channel (0.67 %)
- Old Deltaic Plain (0.07 %)
- Sand Sheet (28.05 %)
- Sand Dune (47.9 %)
- Interdune Plain
- Desert Pavement (2.67 %)
- Playa (0.27 %)
- Rann (0.04 %)
- Water Body / River Bed (0.57 %)

Polygenic (Aeolian, Fluvial, Lacustrine and Tectonic), but majority are aeolian in ~80% area

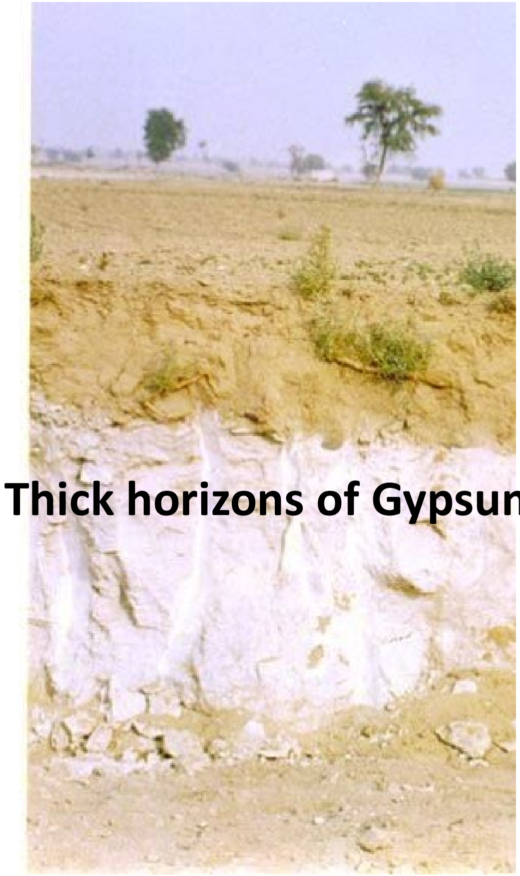
Wind abrasion on limestone

Weathered features (box pattern)



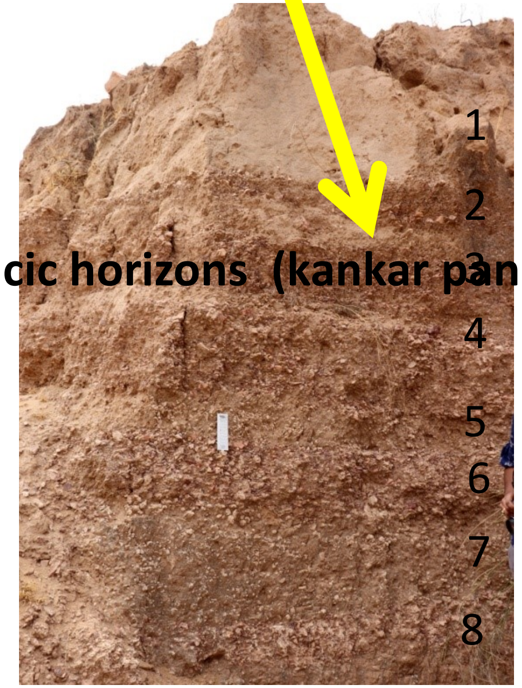
Weathering of rocks on a ephemeral riverbed, Jaisalmer

DRYLAND LANDSCAPE



Thick horizons of Gypsum,

Deep dune soils



Calcic horizons (kankar pans)

Major challenges in Indian arid ecosystem

- **Fragile resource base**
  - **Desertification and land degradation**
  - **Wind erosion**
  - **Poor Soils (Low OC, poor water holding capacity, low fertility)**
  - **Water (lesser availability – both surface and underground; poor quality; and overexploitation)**
  - **Secondary salinization**

Climatic stresses

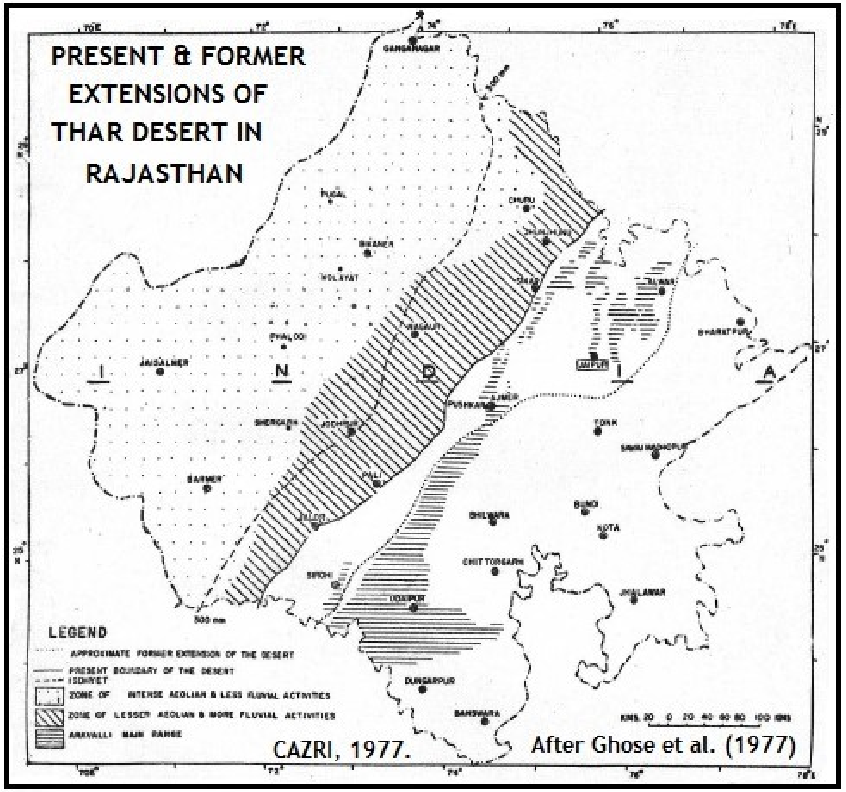
- **Low & erratic rainfall** <450 mm
- **Temperature's extreme**
  - **High** 45-48°C
  - **Low** 0-4°C
- **High wind velocity** 20-40 km/h
- **Very high PET** 1800- 2200 mm/year

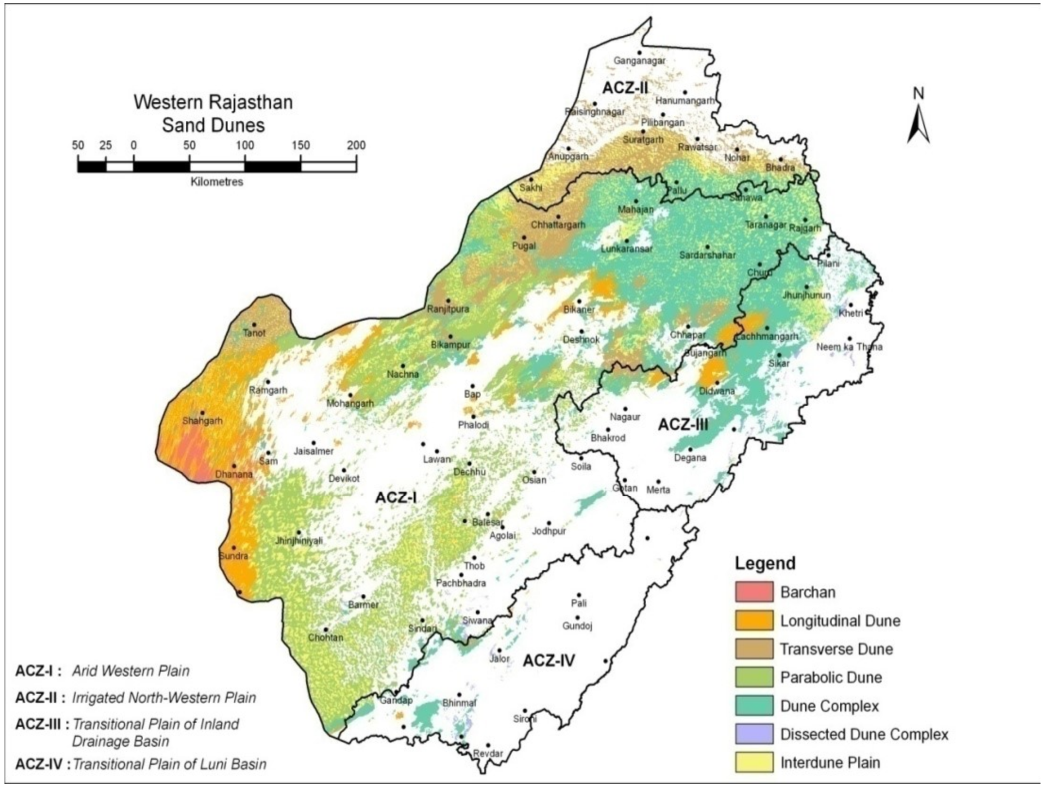
Essentially animal based agricultural economy (Crops-trees/grasses-livestock

- **Higher biotic pressure**
  - **Human (40): Livestock (100)**
  - **High growth**

Highly risk-prone and Stress environment

Extent of Thar Desert and Distribution of Sand Dunes in western Rajasthan



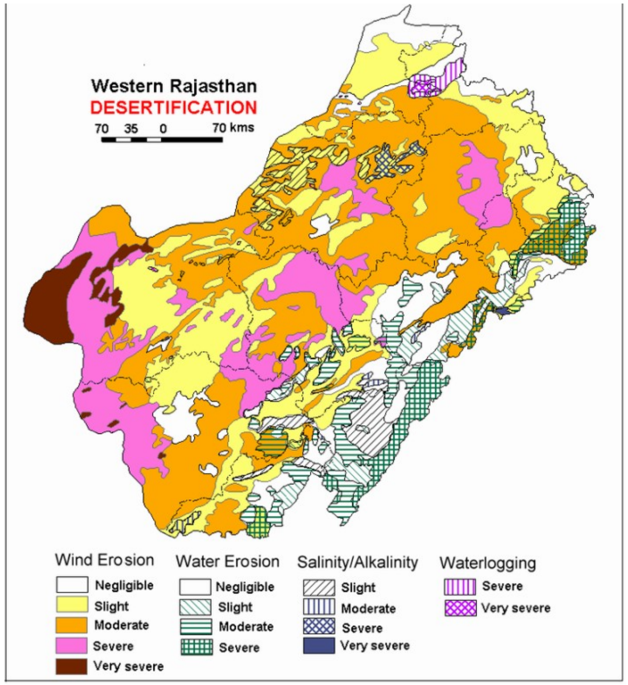


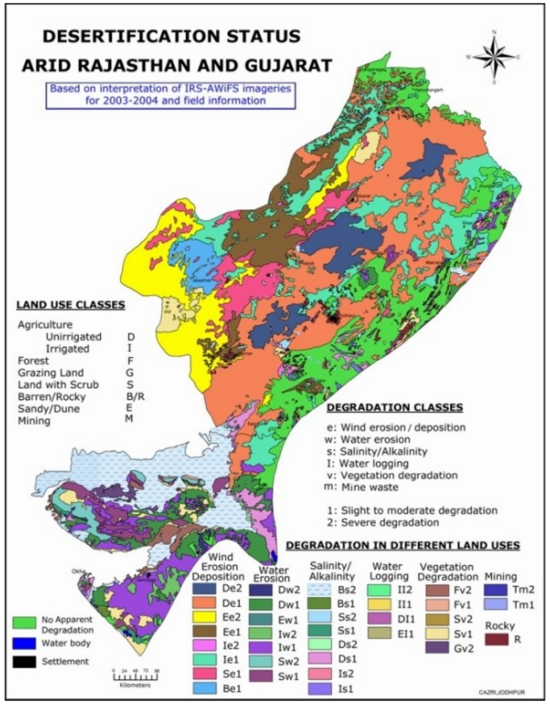
Sand dunes has been mapped in 48 % area of western Rajasthan (Moharana et al 2013). Thus a decrease in its area by ~12 % over a period of 4 decades (earlier data indicated 60 % (Pandey et al., 1964 and Singh et al., 1974)

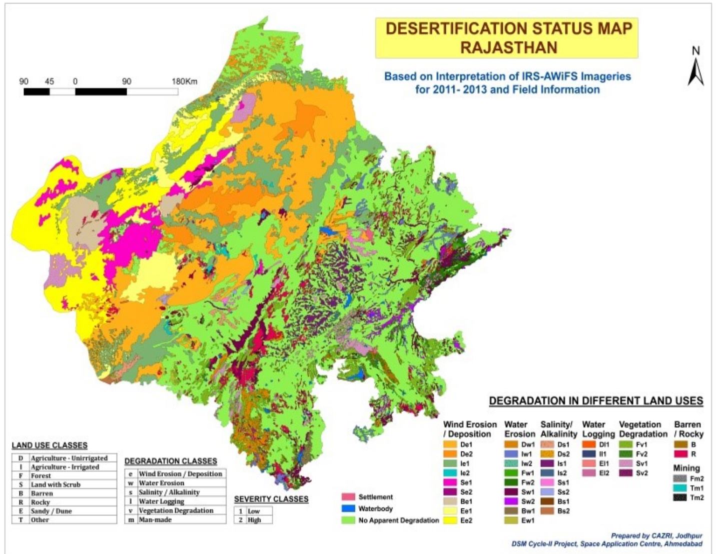
ASSESSMENT OF DESERTIFICATION STATUS

Desertification Assessment

Through a series of temporal database (Maps)



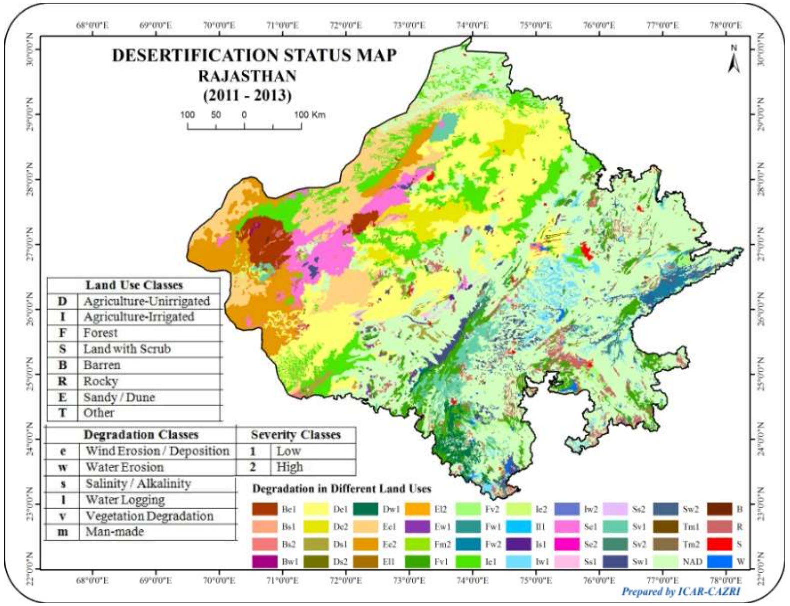




1992 **2003-05** **2011- 13**

Western Rajasthan	1992	2003-05	2011-13
Total Degraded area	191218 km^2 (91.6%)	176418 km^2 (83.85%)	166692 km^2 (79.8%)
Wind erosion	**158220 km^2 (75.8%)**	**152375 km^2 (73%)**	**151978 km^2 (71.4%)**

Desertification Status; Rajasthan (2011-13)



Scale of mapping : 1:500,000

	2011 - 13		2003 - 05		Change in Area (ha)
Processes of desertification	Area (ha)	Area (%)	Area (ha)	Area (%)	2011-13 - 2003-05
Vegetation degradation	2606221	7.62	2596003	7.59	10218
Water erosion	2116314	6.18	2116082	6.18	233
Wind erosion	15197874	44.41	15332054	44.8	-134180
Salinity	363768	1.06	365666	1.07	-1898
Waterlogging	18421	0.05	18421	0.05	0
Man made	53058	0.16	50865	0.15	2193
Barren/rocky	1052374	3.07	1047818	3.06	4556
Settlement	118482	0.35	98696	0.29	19786
Total Degraded area	21526512	62.90	21625604	63.19	-99092

Highlights : 101646 ha under rainfed croplands and 21390 ha irrigated croplands have been reclaimed (from degraded in 2003-05 to No Apparent degradation in 2011-13)

Reclaimed land from other land use types

Open Scrub : -2404 ha,
Sandy/Dune : -1068 ha
Mining : +2193 ha

Source : http://vedas.sac.gov.in/vedas/downloads/atlas/DSM/Desertification_Atlas_2016_SAC_ISRO.pdf

Desertification in all arid states of India

States	2003-05	2011-13	Change (2011-13) - (2003-05)
	Area (%)	Area (%)	Area (ha)
Rajasthan	63.19	62.90	- 99,092
Gujarat	51.35	52.29	+1,84,186
Haryana	7.12	7.67	+ 24,382
Punjab	1.85	2.87	+51,538
Andhra Pradesh	14.16	14.35	+31,030
Karnataka	36.19	36.24	+10,057
Maharashtra	43.38	44.93	+4,77,331

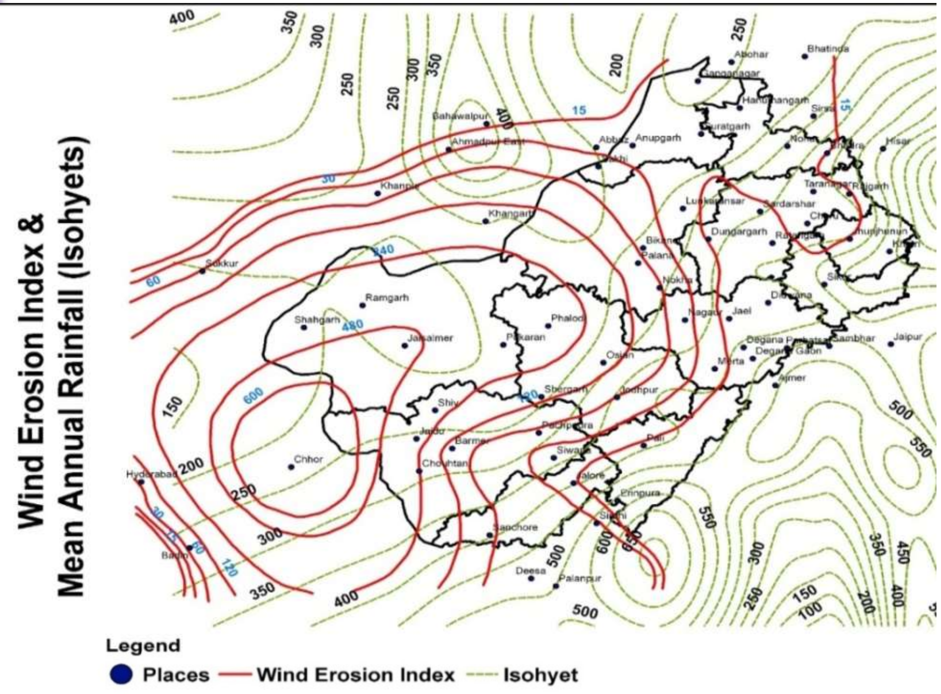
Source: Desertification and Land Degradation Atlas of India, SAC/ISRO, 2016

Compared to other arid states in India, Rajasthan has experienced improving situation of desertification

Wind Erosion: The major source of degradation in NW India

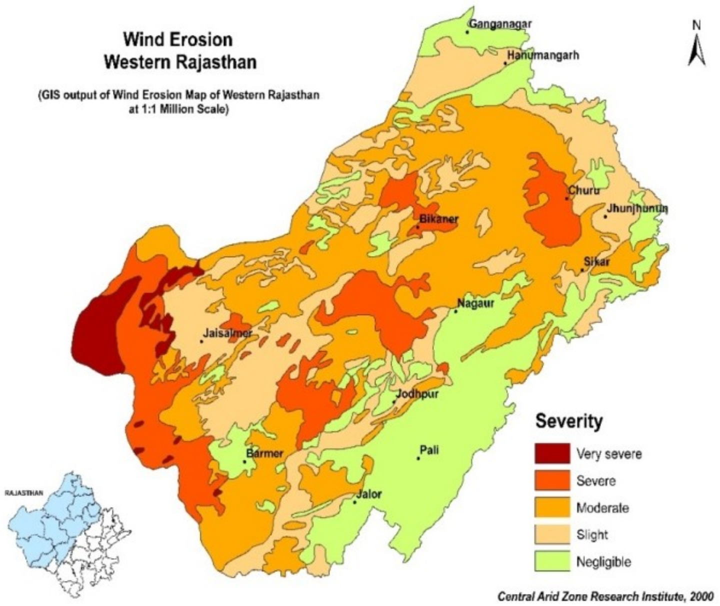
Aeolian activity in the Thar desert is mainly restricted to the period of summer winds associated with the south-west (SW) monsoon

Wind erosion index : a basis for understanding the spatial pattern of sand mobility and dune formation with reference to wind erosivity



Wind erosion index	Category	Annual soil loss rate	Stations in NW India
480 and above	Extremely high	83.3 t ha-1 yr-1	Jaisalmer
120-479	Very high		Phalodi
60-119	High	50 t ha-1 yr-1	---
30-59	Moderate	12.2 t ha-1 yr-1	Bikaner, Jodhpur, Pachpadra, Barmer
15--29	Low	1.3 t ha-1 yr-1	Ganganagar, Churu, Nagaur
1-14	Very low		Hissar, Sikar, Ajmer

Wind erosion/deposition & Impacts



Erosion/deposition class	Affected Area (km^2)	% of total area affected
Very severe	5800	2.78
Severe	25540	12.23
Moderate	73740	35.32
Slight	52690	25.24
Negligible	50981	24.43

Soil nutrient loss (kg/ha/year) and wind severity class

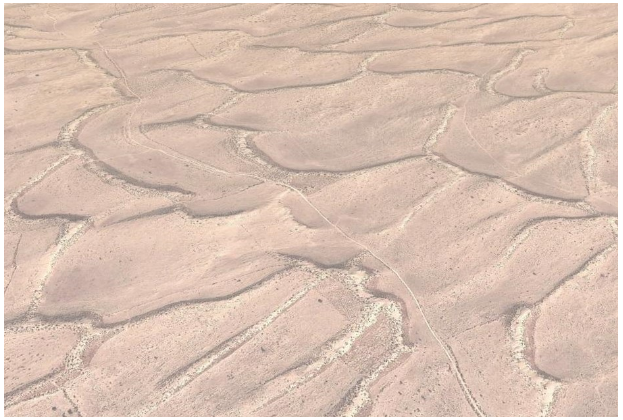
	N	P2O5	K2O
Very severe	7.58	1.25	14.79
Severe	4.55	0.75	8.87
Moderate	1.11	0.18	2.16
Slight	0.12	0.02	0.23

Yield loss (kg/ha/year) of major crops and wind erosion class

Crop	Very severe	Severe	Moderate	Slight
Pearl millet	195	117	29	3
Moth bean	93	56	14	1
Clusterbean	229	137	33	4

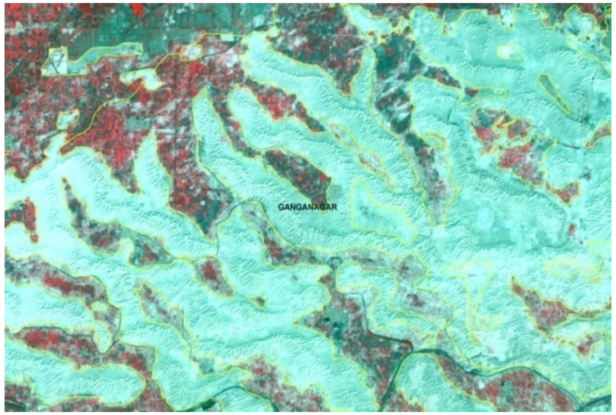
Major sand dune types in Thar Desert : a view from satellite images

Parabolic Dunes (Vegetated)



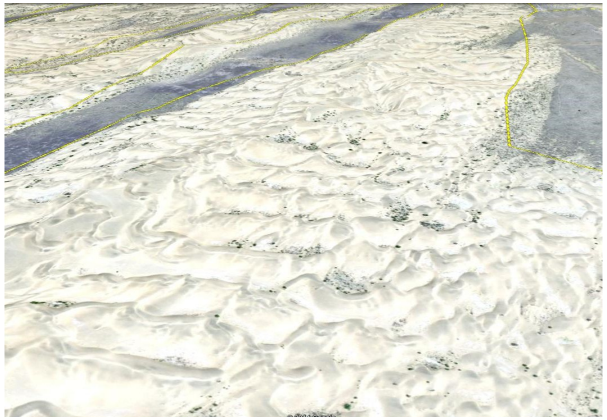
Transverse Dunes (highest sand volume, but suitable for cropping)

Linear Dunes (aligned in the dominant wind direction and supports natural vegetation



Network dunes, limited sites, occur in chains having several peaks

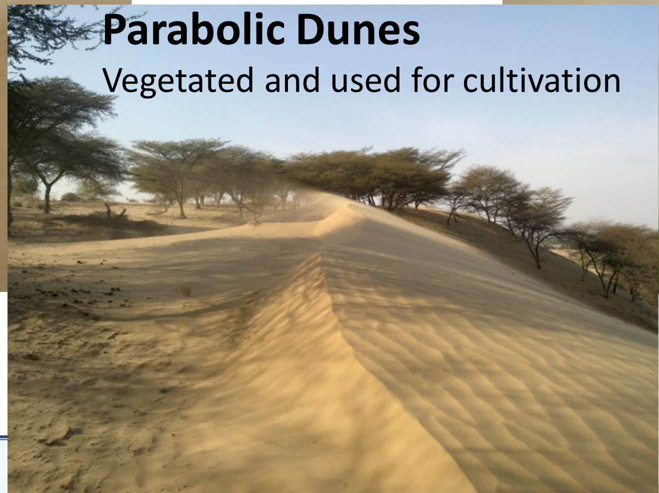
Sand streaks also called shrub-copice dunes mainly flank the fields



Barchans and Barchanoids; mobile dunes occur in 200 mm isohyet conditions

Sand dunes : The major physical indicators of wind sorted degradation


Barchan Dunes , NW of Jaisalmer Town


Parabolic Dunes
Vegetated and used for cultivation


Mega-barchanoids, SW of Jaisalmer

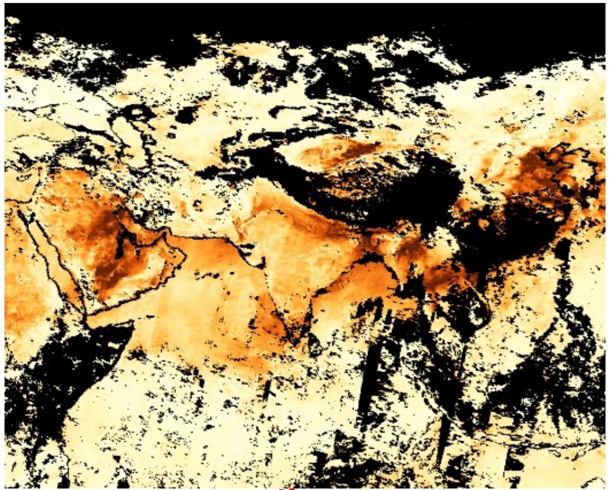

Nebkha dune, Jaisalmer


Transverse Dune, Bikaner

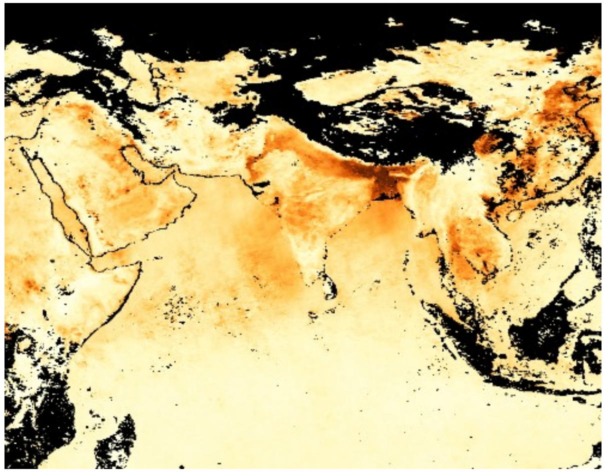
Mobility : 3-5 m/year for old & stable dunes and ~33 meters for barchan dunes

Problems of Dust storms (Aerosol Extent) over India's Thar Desert and northern plains

Aerosol Optical Thickness (AOT)



23 April 2018

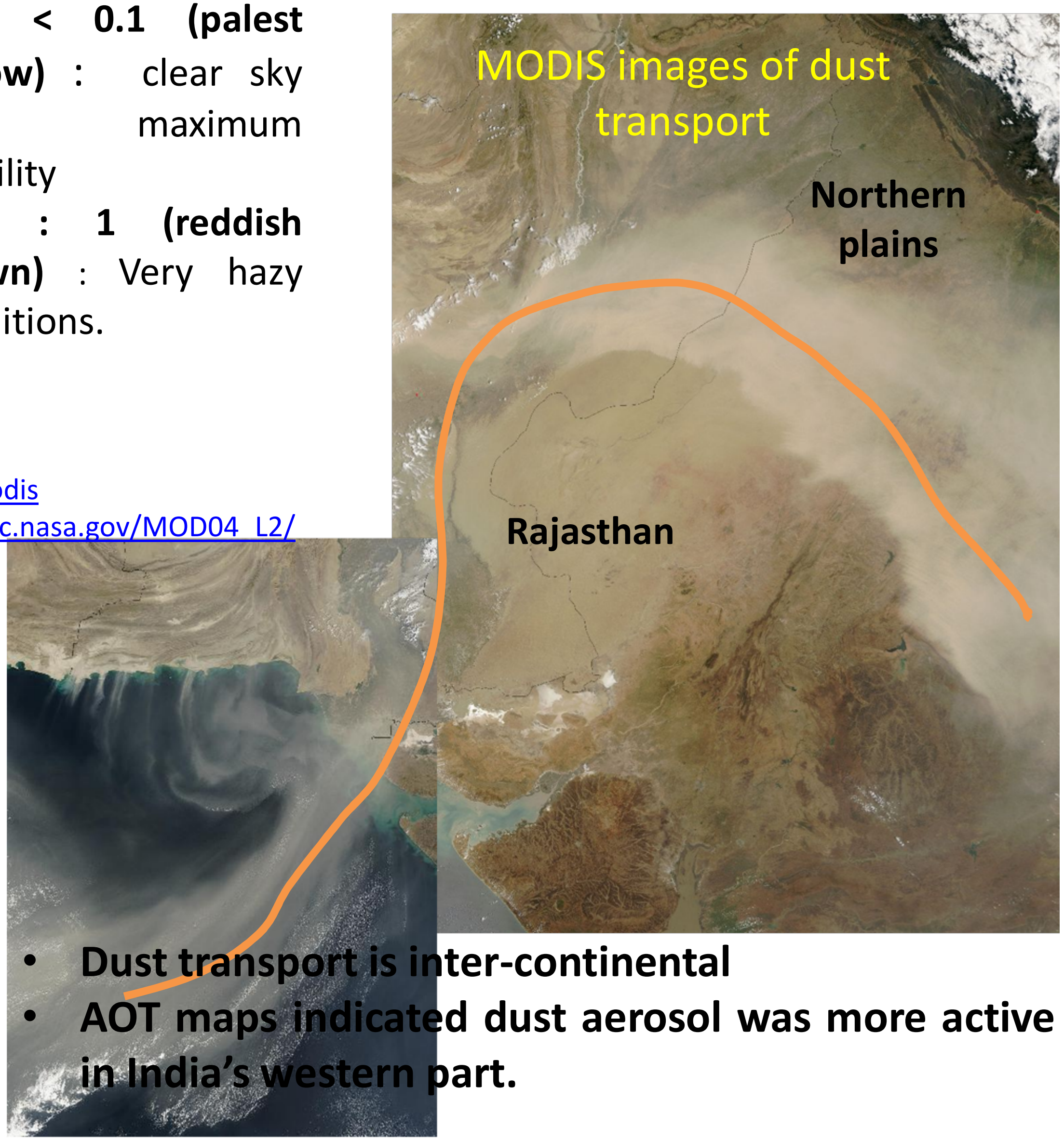


1 February 2018

AOT < 0.1 (palest yellow) : clear sky and maximum visibility

AOT : 1 (reddish brown) : Very hazy conditions.

http://modis atmos.gsfc.nasa.gov/MOD04_L2/



- **Dust transport is inter-continental**
- **AOT maps indicated dust aerosol was more active in India's western part.**

Water Erosion / Flash Floods and Impacts

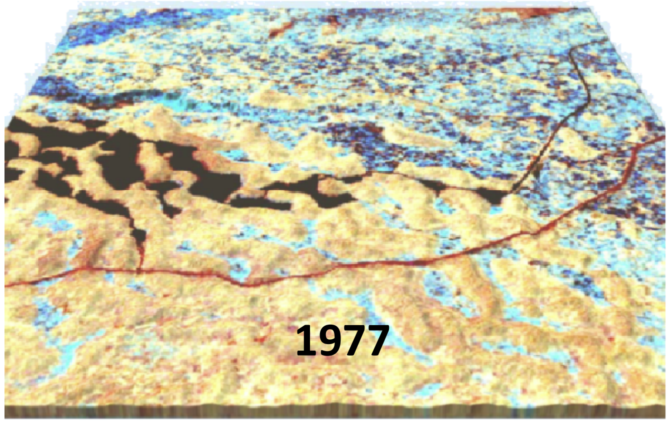
While wetter parts of the arid zone and the semi-arid areas are more vulnerable to water erosion, flash floods and high intensity rain events have proved to be an opportunity and also known for its menace in desert districts

- **Among the heavy metals, concentration of zinc, iron and copper ranged from 0.01 to 0.12, 0.19-0.65 and 0.03 - 0.22 ppm respectively**
- **Concentration of sodium, potassium and calcium ranged from 1.38 – 12.88, 0.05 – 6.63 and 13 – 40 ppm respectively**
- **Electrical conductivity varies from 0.07 – 0.4 dS/m while pH ranged from 7.6 – 8.7**

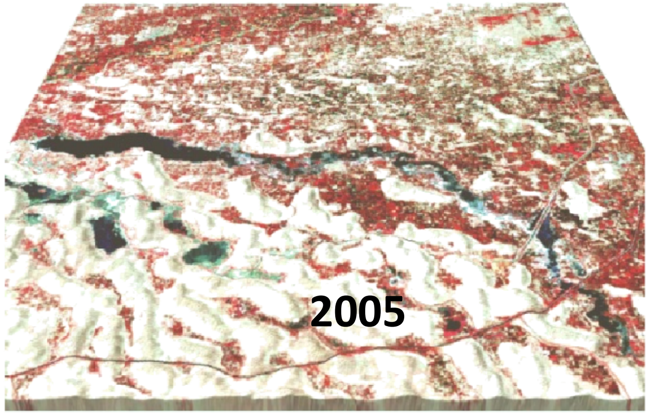
The above initial analysis suggest that the flood water is suitable for irrigation use.

Water Logging : Causes of Degradation from Irrigation Sources in Canal Command Areas

IGNP Command area in North Rajasthan



Gypsum layer



Secondary salinization, Industrial Effluents and Rock mining add to deterioration in Land quality in NW Rajasthan

Combating Strategies

Combating strategies : Sand dune stabilization – a pioneer work of CAZRI

Adaptation : About 4 lakh ha area in western Rajasthan has been adopted for sand dune stabilization using all these techniques.

Shelterbelt plantation for sandy plains

Shelterbelt plantations (SB) are vegetative barriers of tree/shrub/bushes

Ideal form of shelterbelt : Pyramidal with fast growing tall trees in the central row, flanked by fast growing + high branching trees of medium height, + outer rows to be planted with low and much branched shrubs.

- 800 km length for shelterbelt plantation in participatory mode with the Govt. of Rajasthan.

Impact

- Reduction in wind velocity by 50 % at 2 to 10 times height distance in a 8 years old plantation.
- Reduction in average loss in crop productivity due to cold and hot waves: 30 % (without SB) to 17 % (with SB)
- Pan evaporation values reduced by 5-14% on either side of belts.
- Increase in organic carbon and Ec of soil nearer to shelterbelts.
- Reduction in sand deposits by 513 m^3 per km with one year old canal side plantation
- From entire Tube well and canal command with shelterbelts, the additional income only from crops and trees is estimated around Rs. 71342 millions in last 15 years at current price.

Ecosystem services of trees in sand dune stabilization

Tree component- *Acacia species* (10 year old tree)

- Provisioning service
  - **Fodder** – Average green fodder(leaf + pod) yield :**14-16kg/yr**
  - **Fuel** - Average fuelwood production: **20-50 kg/yr** (Calorific value 4400 kcal/kg)
  - **Timber-** Yearly production – **1.06 cu.ft/ tree**
- Regulating services
  - **Soil fertility-** One tree **adds 0.70 kg N, 0.04kg P and 0.20 kg K** per year
  - **Soil erosion control-** Tree having 20m^2 crown area **saves 15kg soil from erosion**
  - **Water conservation- 26% reduction in run off**
  - **Carbon sequestration- 9 kg/tree/yr**
  - **Shade**

Strategies for Rain water Conservation

Thatched tanka

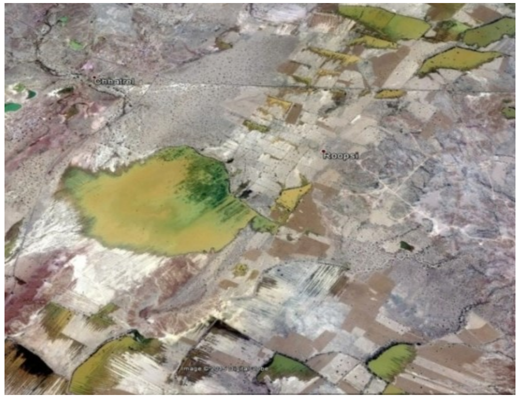
Pucca Tanka (10 to 60 thousand litres capacity)

Village Pond (Nadi)

Village Baobari (man made structure)

Ancient systems

Rooftop rainwater harvesting tanka



Khadin or run-off farming system

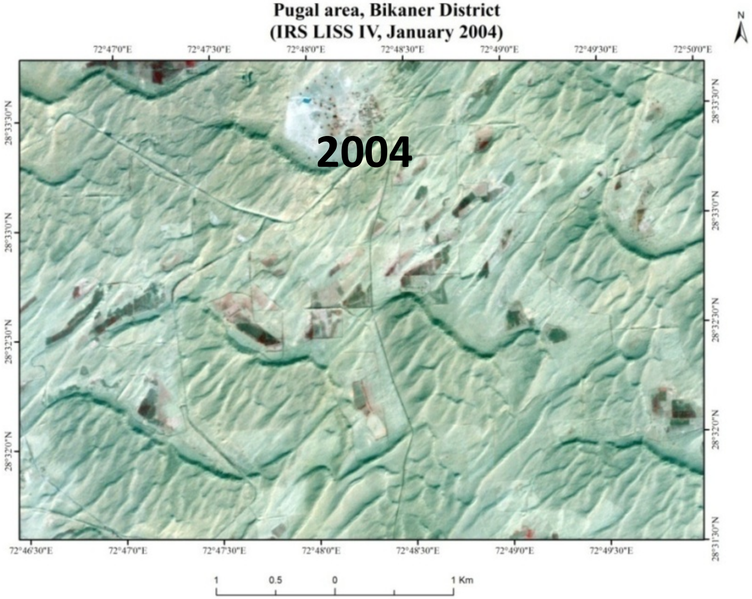
Winter crops in khadin system

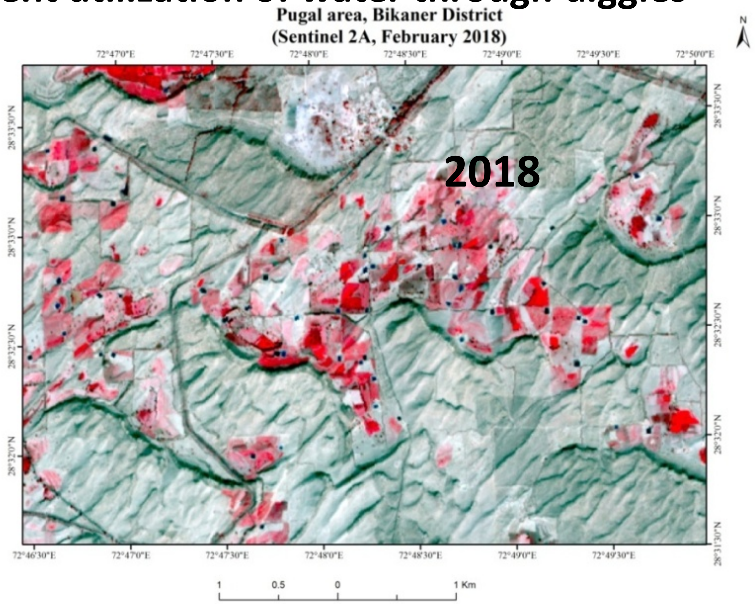
Reservoirs and Tanks

Recent Approaches : Transferring canal water in Diggi (micro-farm structures) for reutilization as per requirement , a popular concept in Canal command area of Desert area

Diggies viewed on satellite images

Impact : Increase in irrigated cropland area due to efficient utilization of water through diggies





Increase in number of diggies : from 241 (2004) to 3162 (2018)
Increase in area covered by Diggi structure ; from 85.94 ha during 2004 to 324 ha in 2018.

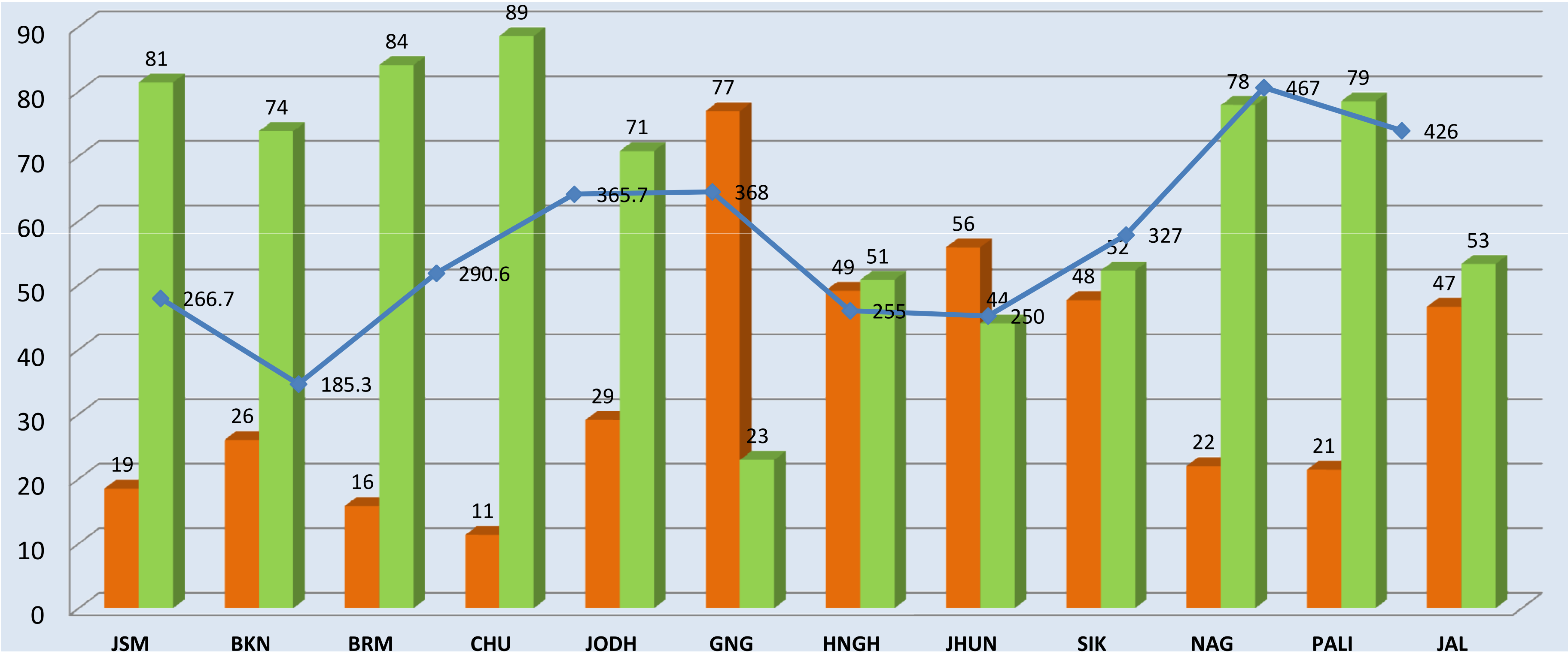
Land use change; expanding cultivation and efforts to bring more area under green cover

Prosopis Cineraria tree **: the mainstay of Agro-forestry for rural livelihood**

Tractor driven operations : Helping deep ploughing of sand dunes causing loss of native vegetation and reason for sand movement

Impact : Increasing area under Irrigated crops even in rainfed regions of Rajasthan (2014-15)

Hyper arid partially irrigated western plain	Arid western plain	Rajasthan irrigated NW plain	Transitional zone of Inland drainage basin	Transitional plain of Luni basin



BRM : Barmer, JSM : Jaisalmer, BKN : Bikaner, CHU: Churu, JOD : Jodhpur, GNG: Ganganagar, HNG: Hanumangarh, NAG: Nagaur, JHU: Jhunjhunun, SIK: Sikar, JAL: Jalor, PAL: Pali

Irrigated

Un-irrigated

Overview of land use changes Western Rajasthan

Land use	1957-58 Area (%)	2005-06 Area (%)	2014-15 Area (%)
Net sown area (NSA)	35.51	51.19	53.76
Double crop area (DC)	0.70	9.96	15.45
Forest	0.69	2.19	2.30
Culturable waste(CW)	24.18	17.67	15.39
Current fallow(CF)	9.07	7.36	7.43
Old fallow(OF)	14.24	8.20	7.34

(Total reported area : 20818129 ha)

Area under NSA, DC and Forest : increased and area under CW,CF and OF have decreased over a period

Indirect impact of wind erosion control

Avg. 12000 tons additional grain production yr^{-1}

Direct Impact (conversion of sand dune area (by 12 %) to cropping) : 1.5 m tons pearl millet and 0.50 m tons pulses per year

Interventions

- Canal (IGNP – 15 lakh ha; and Narmada – 2.5 lakh ha)
- Rural electrification leading to increased use of underground water
- Improved connectivity (road network)
- Increased demand of food, fodder, fruits and fuel
- Adoption of improved technologies in farming
- Demand for land for other activities like tourism, mining and infrastructures







Other Innovative CAZRI technologies

Institute has evaluated several combination of field crops, grasses, shrubs, trees, horticultural crops and livestock for Agroforestry, Agri-horticulture, Horti -pasture, Silvi-pastoral systems for imparting greater stability to arid production system.

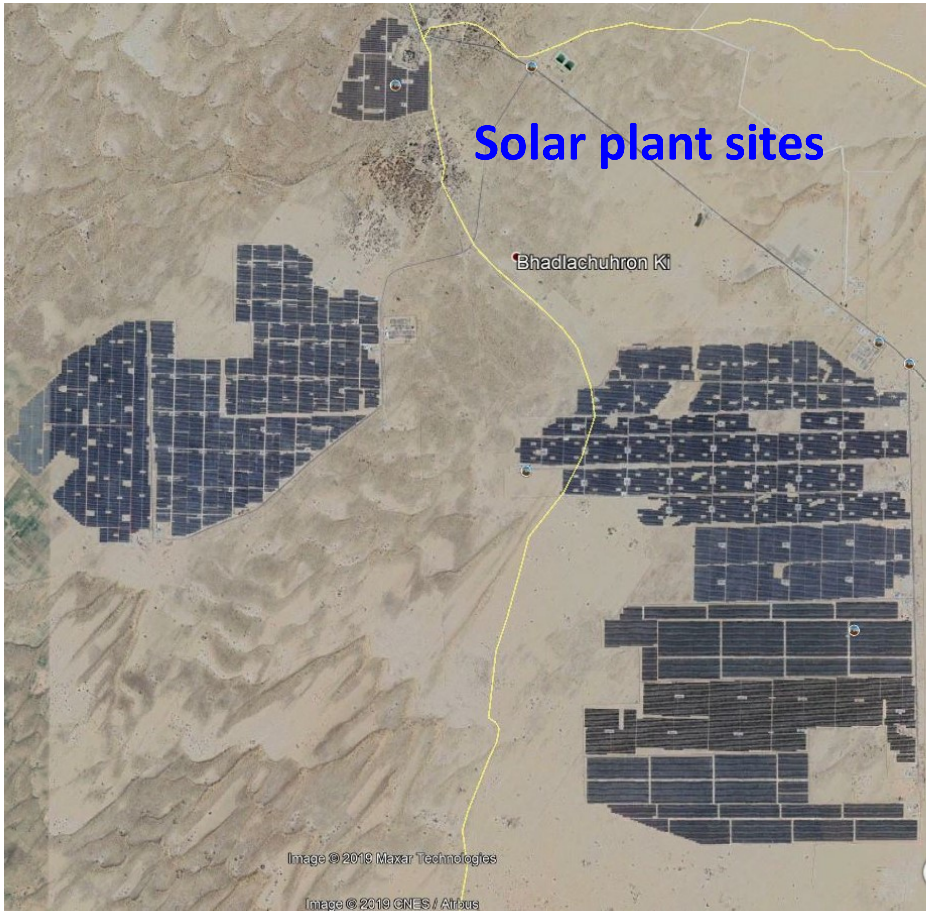
- **Agroforestry** : Khejri (Prosopis cineraria) system > *Tecomella undulata* (Rhohida)> *Hardwikia binata* (Anjan)> *Ailanthus excelsa* (Ardu) are identified for Integrated Farming Systems. Introduction of budded khejri : excellent quality pods (sangri)

- **Agri-horticulture** (Arable crops+horticultural plants) : Suitable for >300 mm rainfall zone. Pomogrante was compatible with pearlmillet, moongbean, isabgoal and cumin while ber based rainfed sytems was suitable with moth bean, cluster bean and cowpea.

- **Silvi-pastora**l (Trees with grasses): Best suitable for <200 mm rainfall zone. Highly compatible trees with grasses are: *Acacia senegal* (Kumat), *Acacia tortilis* (Israeli babool), *Tecomella undulata* (Rhoida) and *Ziziphus rotundifolia* (desi ber)

Improved Technologies for Renewable resources

Solar, Wind and proposed hybrid systems on Sandy, Rocky and Saline wastelands



Pomegranate cultivation on sandy wastes (sand dunes) in <300 mm rainfall zone.
4500 ha cropland area under Pomegranate crop

Agri-voltaic system (105 kW) at ICAR-CAZRI Jodhpur

Crops grown in the inter panel spaces

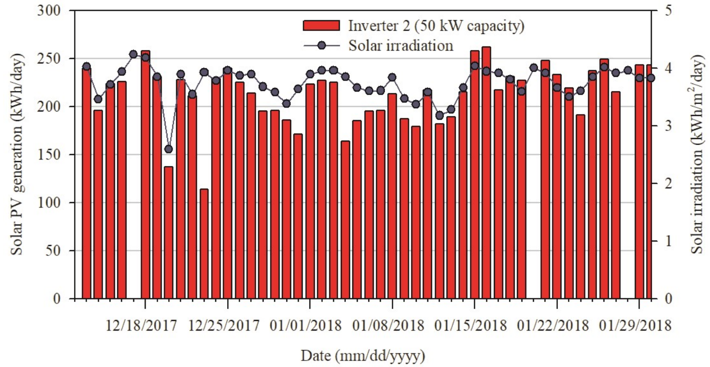
Crop	Growth characteristics and Yield	Control	Block-2 (Two row PV module)	Block-3 (Three row PV module)
Moong bean	Biomass at 60 DAS (g plant^{-1})	50±20.396	41.67±2.87	33.67±4.02
	Yield (kg ha^{-1})	897±168.4	786±31.7	684±354.3
Moth bean	Biomass at 60 DAS (g plant^{-1})	45±7.36	38.6±7.4	36.67±4.64
	Yield (kg ha^{-1})	148±34.01	225±73.2	225±90.2
Clusterbean	Biomass after 60 DAS (g plant^{-1})	36±3.56	35.67±6.24	31±3.27
	Yield (kg ha^{-1})	330±101.4	397±112.5	226±63.8

Rainfall from 20 July to 15 September = 202.9 mm
Efficiency of the system = 69.2%.
Total harvested rainwater = **62,583 litre**

Rainwater harvesting system

Average PV generation of the system is 338 kWh per day

Inverter 1 (50 kW) = 130 kWh/day
Inverter 2 (50 kW) = 213 kWh/day



Rehabilitation of Mine wastelands in Indian Desert

Before **After**

Gypsum mine spoil area

Rehabilitation Process

(1) Topographical survey, Compaction, Land shaping for rainwater harvesting, soil profile modification ,plantation of appropriate plant species designed for a Silvi pastoral system

(2) Reclaimed area : 36 ha area in Two mine sites of western Rajasthan

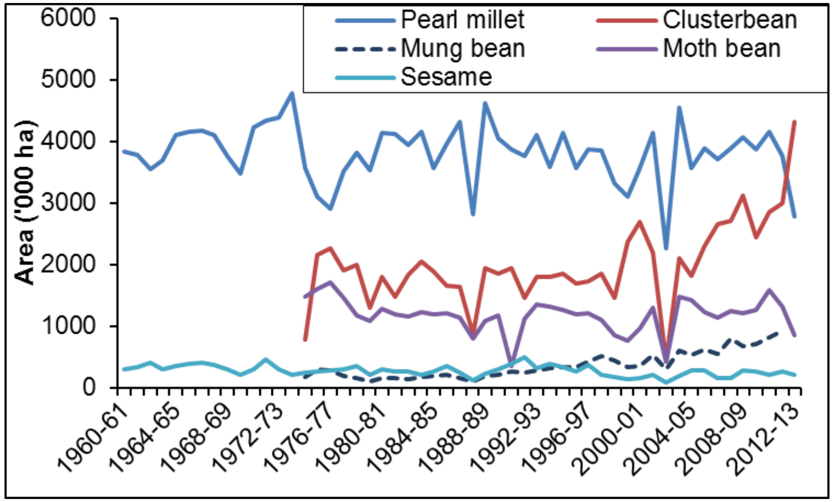
(3) Result : Increase in soil moisture storage, natural regeneration of native plant species richness, evenness and diversity

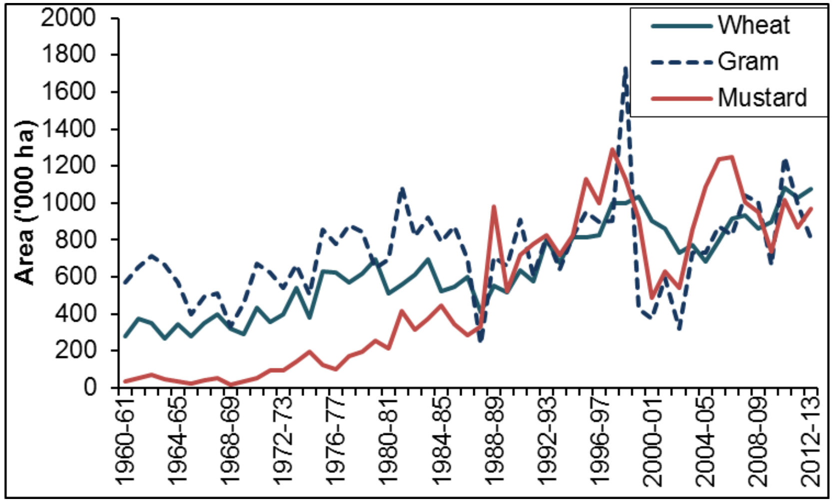
Limestone mine spoil area

Impact and benefits

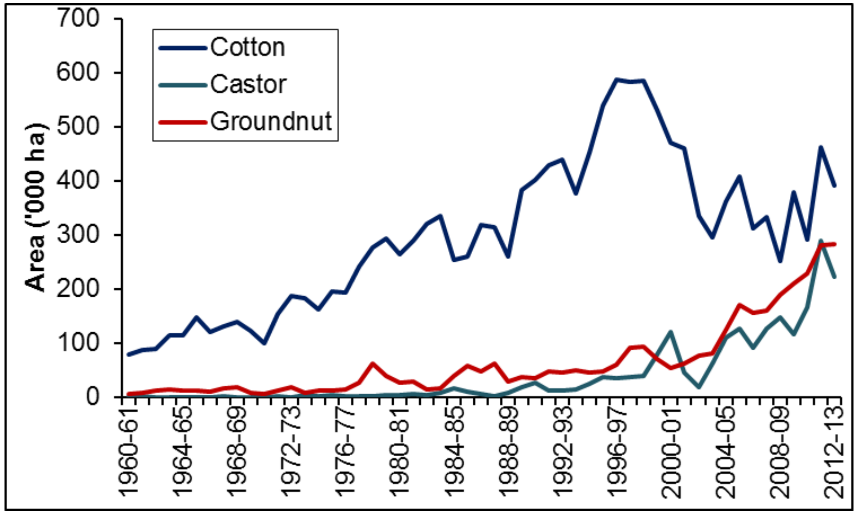
- Sand dunes cover **reduced** from **58 %** in 1990s to **48 %** to 2013.
- Dust storms from **17 in 1966 to 2.5 in 2000**
- Decrease in wind erosion affected area from **75 % earlier (1990's) to 73 %** at present as per 2011-13 database.
- Sand dune stabilization technology spread in about **4 lakh ha** and about **800 km length** for shelterbelt plantation.
- **Decrease in desertification/land degradation** from 64% in 2002-03 to 63% in 2012-13 (99,092 ha)

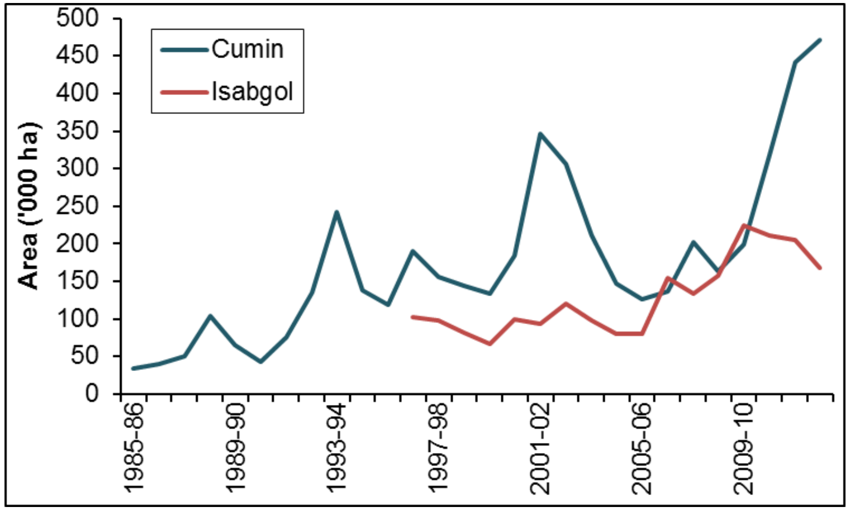
Eco-system Services – Provisioning (expanding cultivation)





Area ('000 ha) under major crops in arid Rajasthan





Desertification in NW arid region : the Synthesis

- Address top three environmental issues of NW India: water availability, land quality and dust emission

- Responsibility to conserve and utilize water from two major canal Projects (IGNP and Narmada)
- In the event of increasing summer wind strength in future, the present day land tillage practices may lead to more sand mobilization, therefore, critical changes in land use/land cover, will play major role in determining the future status of desertification,

if this happens, eastern part of Rajasthan which is a stabilized land may be more vulnerable to sand mobilization

Developments	Impacts
Drinking water supply through the pipeline grid helped rural people	Neglect of the traditional water harvesting structures
Progress in Rural electrification	>80 % water used for irrigation resulting in groundwater depletion, increasing cost of agricultural operation and now Irrigated farming is becoming un-remunerative
Mechanization of agricultural operations (Tractors for ploughing the Sand dunes)	Whole of sand dunes is under deep ploughing, loss of vegetation and increasing sand movements

Desertification (land degradation and decline in productivity) is an outcome of local survival system of past (Suitable landuse and management systems of farming, pastoralism and animal husbandry) vs over-exploitation of the resources at present for increasing demand.

Land care and water conservation are in-built in the traditional customs and agricultural practices of the rural population

Traditional Practices	What now ?
Land fallowing for some seasons to regain the soil nutrients	Land fallowing has reduced due to intensive form of agriculture
Erecting fences around fields during summer to trap the suspended silt that blows in from the fertile plains during sandstorms (*aandhi)*	Still a prevailing practice
Lopping of trees (rather than felling) for fuel and fodder	Due to higher prices for lopping , such practices are discouraging many poor farmers
Management of permanent pastures and village common property lands by stake holders	Permanent pastures have become almost devoid of ground flora and browse worthy shrubs; role of villagers has reduced.
Provision of space for fodder crops within the crop field	Almost no such practice in the irrigated croplands

The Thar Environment : Then and Now


Acknowledgements
ICAR, New Delhi
DIRECTOR, ICAR CAZRI, Rajasthan
HEAD and all my Colleagues at
Division of Natural Resources
Thank You