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Climate Dynamics and Agriculture System in Deserts

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1. Introduction

Deserts are created by aridity plus exceptionally high or low temperatures characterised by more evaporation than precipitation. It can be either hot or cold depending on the atmospheric temperature. As a desert is defined by low precipitation, many experts concur desert as area of land with annual precipitation of less than 25 cm (10 inches). The unique plants and animals in desert ecosystems have adapted to harsh environments in order to survive (Chouhan and Sharma, 2009; Gupta, 2015).

Deserts are created by the perpetual existence of dry air advection and/or subsidence over a region. Reduced rainfall leads to decreased soil moisture, limited vegetation growth, and reduced plant productivity. The extreme temperatures and very high thermal variability coupled with poor water availability culminate in very harsh conditions for the survival of biota. Some deserts are hot all year-round (e.g. Sahara Desert) whereas the others, become quite cold in winter like Thar and Gobi Deserts. The deserts generally experience very high diurnal as well as seasonal variations in temperature with extreme values. Even in polar deserts, temperatures rarely exceed 10°C. The water vapour present in the air is less resulting in low humidity, particularly during the daytime. Rainfall in deserts is typically sparse, erratic, unreliable, and localised both in terms of space and duration. Drought conditions, or effective aridity, define desert environments, with varying durations from temporary to permanent across different desert zones. High wind velocities are common in deserts. The cloud cover is thin resulting in intense solar radiation resulting in near maximum sunshine hours. These conditions lead to very high potential evapotranspiration (PET) rates in deserts.

The soil in deserts is typically sandy and contains very low organic matter. Desert landscapes exhibit diverse topographies, including shimmering sand dunes, hard, flat "pavements," twisting chasms, stark mountains, and scattered boulders. The annual season for plant growth in deserts is extremely short due to the scarcity of water and harsh environmental conditions. Hot deserts face water scarcity, while cold deserts have water present but in frozen form (ice), making it inaccessible to plants and animals. Animals in deserts often face food shortages due to limited vegetation and water resources.

2. Genesis on the Formation of Desert Climate Across the World

Many studies have been conducted on the climate and feedback processes in desert locations (see, e.g., Mahmood, 2014 for a general overview). Self-stabilisation effects in subtropical deserts were first described by Charney (1975) and were linked to feedback processes between precipitation and surface albedo. The feedback mechanisms between vegetation and the hydrological cycle were also taken into account by Prentice et al. (1992). Two stable regimes have been identified in the Sahara: a desert equilibrium with little precipitation, and another through conceptual models (Brovkin et al., 1998) and the linking of a climate model to a dynamical vegetation model (Claussen, 1994).

The Earth's deserts, which cover approximately one-fifth of the land area, have formed based on the global circulation pattern, as illustrated in Fig. 1. The world's deserts can be categorised into five types depending on their aridity: subtropical, coastal, rain shadow, interior, and polar.

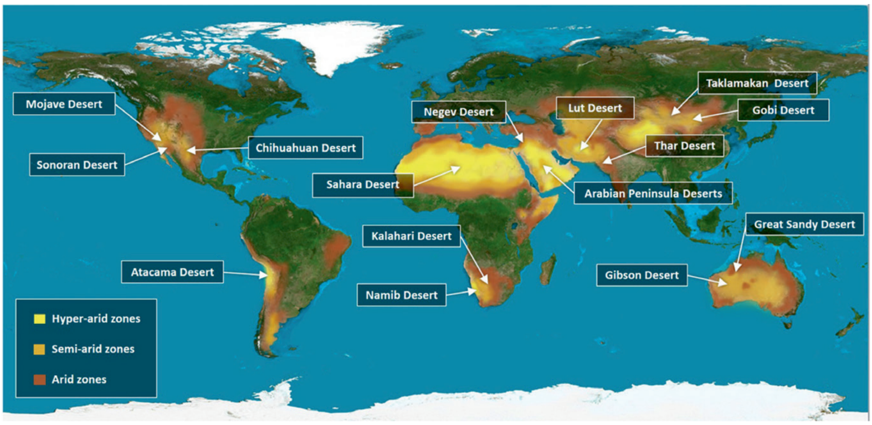


Figure 1: Deserts across the world. (Source: Wiam et al., 2020)

Subtropical deserts are usually found between 15° and 30° north of the Equator or along the Tropic of Capricorn between 15° and 30° south of the Equator. These deserts form mainly because of the sinking of air resulting from the global circulation patterns of air masses along the Tropic of Cancer, leading to arid conditions. In contrast, deserts in middle latitudes are influenced by the flow of the jet stream from the Arctic and subtropical regions. These jet streams influence high-pressure and low-pressure systems, causing fluctuations in weather patterns at any given location over a period of days. In the tropics and subtropics, stable high-pressure and low-pressure ridges dominate. The stable high-pressure ridges in the subtropics contribute to the formation of deserts.

Interior deserts form because they are shielded from moisture-laden winds, which predominantly originate from oceanic areas. This shielding effect often occurs due to the presence of mountain ranges that create a rain shadow effect leading to arid conditions and the formation of deserts in the interior regions. Deserts located around 30 degrees north and south of the equator are typically hot. This is due to the descending air from the Hadley circulation, creating semi-permanent high-pressure areas. Deserts in the Arctic region are formed mostly due to lack of evaporation and stable high-pressure systems (anticyclones) in the troposphere.

3. Aridity and Desert

Aridity is a crucial criterion for defining a desert, often measured using the Aridity Index. Thornthwaite (1948) introduced this concept using the ratio between mean annual precipitation (P) and mean annual potential evapotranspiration (PET), Hyper-arid and arid regions can be identified and stated that aridity index (P/PET) lower than 0.20, which means these areas receive less than 20% of the water required for optimal plant growth (UNEP, 1997).

PET is calculated using Thornthwaite's equations, which mainly depend on temperatures and daylight hours in different temporal scales. In contrast, rainfall is directly measured from weather stations. The most arid regions, based on this index, are the Saharan and Chilean-Peruvian deserts, Arabian, East African, Gobi, Australian, and South African deserts.

An Aridity Anomaly index (AAI) provides information about the moisture stress experienced by plants throughout their life cycle. By visualising the anomalies in aridity, farmers and agricultural planners can identify areas where plants are experiencing significant water stress, allowing for timely interventions to improve plant health and yields, plan irrigation schedules more effectively, ensuring that water is provided at critical times when plants need it the most, allocate water resources more efficiently, focussing efforts on regions with the greatest need and make informed predictions about crop yields based on the extent of moisture stress observed in different regions.

India Meteorological Department has generated AAI for operational use to monitor the incidence, spread, intensification and cessation of drought (near real time basis) on different temporal scales over the country. Several indices are also used widely across the world in defining the aridity of a region (Alley, 1984; Martínez-Fernández et al., 2015; Cammalleri et al., 2016). Figure 2 indicates the world aridity map.

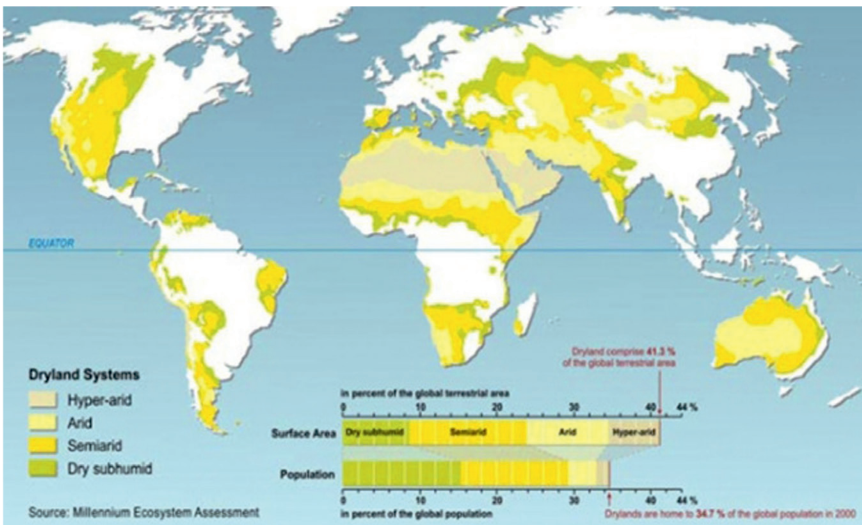


Figure 2: World aridity map. (Source: Millennium Ecosystem Assessment) (https://www.millenniumassessment.org/en/index.html)

4. Drought Monitoring in Desert

The impact of drought is far-reaching and recurrent, affecting numerous aspects of society on a global scale. Tracking drought presents challenges due to its intricate spatial and temporal nature, as well as its severity, which is frequently exacerbated by rising temperatures leading to higher rates of evapotranspiration, even as rainfall patterns may remain relatively unchanged.

Operational drought monitoring, especially in desert regions, is a crucial activity for various National Meteorological and Hydrological Services (NMHS) across the globe. These services display drought information on their websites and other social media and update it periodically. Effective drought monitoring in deserts is essential for making tactical and strategic decisions, particularly in agriculture, to make optimal use of the limited rainfall in these regions.

Integrated Drought Management Programme (WMO, 2006) of World Meteorological Organisation has identified three main methods for monitoring drought for early warning assessment:

- Using a single indicator or index
- Using multiple indicators or indices
- Using composite or hybrid indicators

5. Drought Monitoring Indices

a. Thornthwaite's concept of Aridity describes (Thornthwaite & Mather, 1955) water deficiency experienced by plants. The formula for computing AI is

$$AI = \frac{PE - AE}{PE} \times 100$$

PE is potential evapotranspiration, AE is actual evapotranspiration and (PE-AE) denotes the water deficit. PE is computed by Penman's equation. AE is calculated from the water balance procedure.

Plants use rainfall for evapotranspiration initially. If the potential evapotranspiration (PET) fulfills the plants' evapotranspirative demands completely, any extra rainfall starts to percolate and replenish the soil. This cycle continues until the soil reaches its field capacity, which is the maximum moisture it can hold. Any additional rainfall results in water surplus, as surface or deep drainage runoff.

In contrast, when evapotranspirative demands, of plants are high due to deficient rainfall, it extracts moisture from the soil. This process continues until the soil is depleted of its moisture, affecting plant growth and potentially leading to drought conditions. Soil loses moisture as per the empirical law:

$$S = fc. \exp (Acc(P\text{-}PET)/fc)$$

where S = moisture remaining in the soil as storage, fc is field capacity, P is precipitation, and PET potential evapotranspiration.

The Aridity Index is computed weekly or biweekly to indicate the water stress that plants endure because of insufficient moisture from rainfall and soil. Deviation from the normal value, indicates water shortage. Table 1 indicated the aridity anomaly index and the corresponding drought intensity.

Table 1: Classification of aridity index

Anomaly of aridity index	*Agricultural drought intensity*
1-25	Mild
26-50	Moderate
>50	Severe

5.1 Standardised Precipitation Index (SPI)

The Standardised Precipitation Index (SPI) is a widely used indicator for assessing and monitoring drought conditions (Sergio et al., 2010; Sepulcre-Canto, 2012). It represents rainfall occurrence over a specific period in a region and is calculated using a single parameter: rainfall and its long-term average. The SPI is suitable for monitoring and evaluating climatic conditions on a monthly or longer time frame. McKee et al. introduced the SPI in 1993 and utilised it to evaluate climate and drought variations through the application of an incomplete gamma probability density function to the precipitation series' frequency distribution. The index is particularly valued for its simplicity and effectiveness in characterising meteorological drought. Many National Meteorological Services use SPI as a major indicator to declare a drought and monitor it on different time scales. The real time drought monitoring and bulletins are issued worldwide and can be seen on the website https://www.droughtmanagement.info/drought-monitors-and-products/. Classification of SPI is given in Table 2.

Table 2: Classification of SPI

SPI value range	*Drought class*
>2	More extreme wet
1.5 – 1.99	Severe wet
1 – 1.49	Moderately wet
0 – 0.99	Mildly wet
-0.99 – 0	Mildly dry
-1.49 - -1.00	Moderately dry
-1.99 - -1.5	Severely dry
>-2.00	Less extremely dry

5.2 Combined Drought Index (CDI)

The use of combined indices is a valuable tool for addressing the constraints of basic drought indices. The development of a single combined drought indicator (CDI) integrating meteorological data, soil moisture information, and remote sensing-derived data, enhances the ability to monitor agricultural drought's onset and its development over time and space more efficiently. By combining various data sources, the CDI provides a comprehensive view of drought conditions, capturing different aspects of drought such as meteorological deficits, soil moisture shortages, and vegetation stress. Intensity of drought condition with respect to the CD classes is shown in Table 3. Many researchers across the world have used different single indices together and generated a combined drought index which is gaining popularity in NMSs. Some of the few CDI developed are as follows:

- **Spain**: Developed Combined Drought Indicator (CDI) that integrates rainfall, soil moisture, and vegetation dynamics (Jiménez Donaire et al., 2020).

- **Philippines**: Developed a CDI to monitor the transition from meteorological to agricultural drought, combining monthly land surface temperature (LST), normalised difference vegetation index (NDVI), and the three-month rainfall represented by the Standardised Precipitation Index.
- **Sri Lanka** Developed an agricultural drought index (agCDI) using remote sensing and model-based agroclimatic input parameters—NDVI, LST, three-month precipitation z-score (stdPCP), and evaporative demand drought index (EDDI) **(**Yared et al., 2022).
- **Jordan**: Explores and evaluates a CDI based on precipitation (PDI), temperature (TDI), and vegetation (VDI) drought indices to characterise drought variability and trends (Haitham AlAdaileh, 2019).
- **India**: Developed a comprehensive CDI (CCDI) using both satellite observations (RET, NDVI, VCI, VHI, TCI, and ESI) and land-based observations of rainfall and soil moisture, providing a better indicator compared to indices that use only two or three parameters. Figure 3 depicts the flow chart of the Combined Drought Indicator of India (Chattopadhyay et al., 2020)

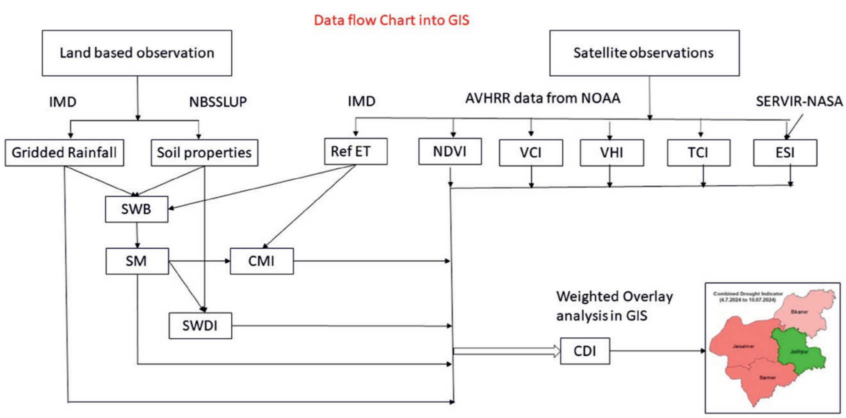


Figure 3: Flow chart of combined drought indicator of India.

The Standardised Precipitation Evapotranspiration Index (SPEI) is an emerging drought indicator that incorporates both precipitation and temperature components, making it particularly suitable for arid and desert regions where temperature plays a critical role in drought conditions. The SPEI measures the balance between precipitation and potential evapotranspiration, providing a comprehensive assessment of drought severity (Fig. 4). Its ability to account for the effects of temperature on water balance makes it a valuable tool for monitoring and analysing drought in diverse climatic regions, especially those prone to high temperatures and variable rainfall.

Traditional drought indices often lack the spatial resolution needed to capture local-scale variations in drought severity, offering a broad, generalised

Table 3: Classification of CDI

Classes	*Classification*
1-3	No drought
4-5	Mild drought
6-7	Moderate drought
8	Severe drought
9	Extreme drought

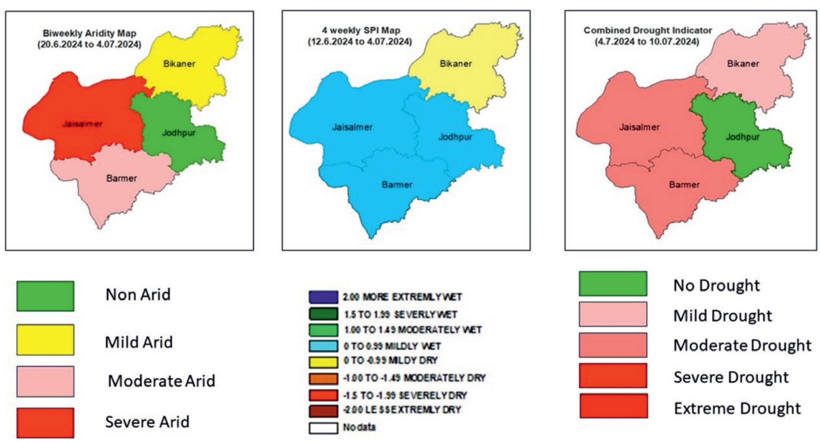


Figure 4: Aridity, SPI and CDI indices.

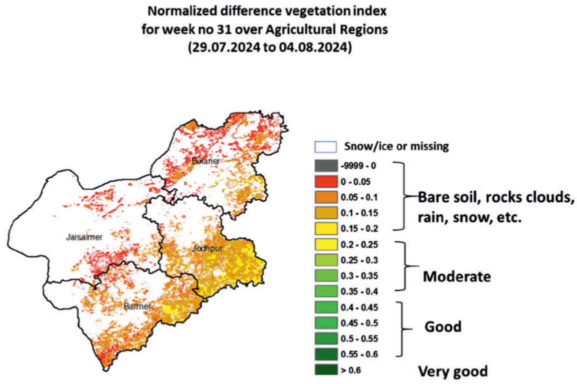
view that may not accurately reflect specific landscape conditions. This limitation can reduce their effectiveness for localised early warning systems and proactive drought planning.

Indices based Remote Sensing Data: Remote sensing information is extremely useful for monitoring drought over large areas as it can offer detailed and frequent observations (Quiring and Ganesh, 2010; Peng et al., 2019; Kogan, 1995; Anderson et al., 2011).) Several satellite-derived vegetation indices, such as the Normalised Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI), have been developed to monitor drought from local to global scales. These indices help assess drought-related vegetation stress and are often validated against ground observations. Figure 5 indicates the satellite based indices for monitoring drought in desert.

Hybrid Drought Indices: Hybrid drought indices have become more prevalent in the last few years, combining climate data, satellite observations, and environmental parameters. This integration results in a more thorough and precise evaluation of drought conditions.

Satellite-Based Instruments: Advances in satellite technology have enabled the estimation of key drought-related variables, including:

Satellite based indices
(Data source: https://www.star.nesdis.noaa.gov)



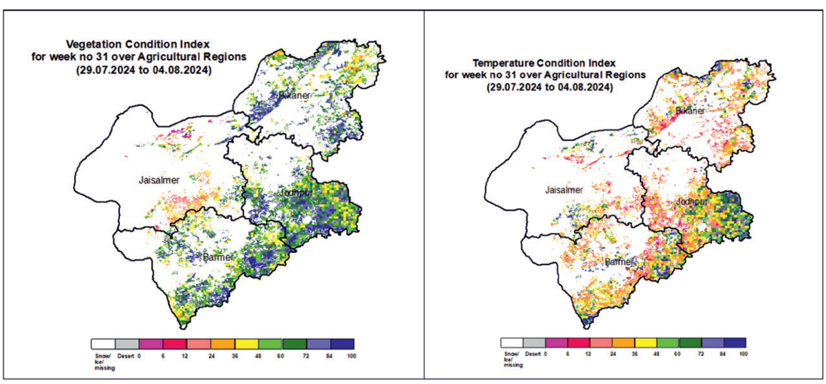


Figure 5: Satellite based indices for monitoring drought.

- Land Surface Temperature (LST)
- Evapotranspiration (ET)
- Soil Moisture
- Precipitation

Satellite data is increasingly utilised for weather monitoring, leading to more frequent use of microwave and radar technology to gauge soil moisture and rainfall. This improved approach provides crucially accurate information for effective drought monitoring.

6. Climate of Indian Desert

High evaporation and scant, very unpredictable precipitation are characteristics of Indian desert regions. Drought is a common occurrence in deserts because of the scarcity of moisture. These areas are easily defined by their plant life, which mainly comprises xerophytes and short-lived annuals. The sparse vegetation is a result of limited water resources and challenging weather conditions.

a. Hot Desert

The Thar Desert of Rajasthan, also known as the Great Indian Thar Desert, is a large arid region situated in the northwestern part of India (Fig. 6). It is a natural boundary running along the border between India and Pakistan, covering an area of more than 100,000 square kilometres in the Indian state of Rajasthan covering the districts of Jaisalmer, Barmer, Bikaner, and Jodhpur, and extends into some regions of Punjab and Haryana. The north boundary is the large thorny steppe to the north, is ill-defined and bordered by the Aravalli ranges in the East, towards the south salt marsh known as the Great Rann of Kutch, which is included in the Thar and river Indus in Pakistan marks the western boundary. The Thar Desert is characterised by its arid climate, unique flora and fauna, and significant cultural and historical heritage, making it an important geographical and ecological region in India.

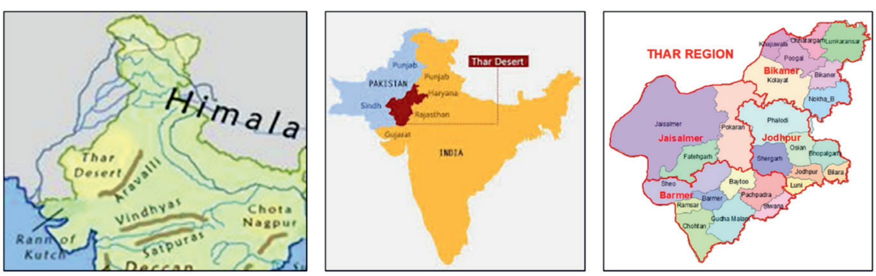


Figure 6: The position of Thar desert
(Source: 1. https://www.pinterest.com/pin/658299670520101779/
2. https://www.beautifulworld.com/asia/india/thar-desert)

The districts under the Thar Desert, face significant challenges due to its arid climate and dependency on rainfall for agriculture and daily water needs. South West Rajasthan receives the lowest annual normal rainfall in the country. The region's economy, primarily based on agriculture and animal husbandry, heavily relies on this limited rainfall. The monsoon season in this region is very short, lasting only about two months and it exhibits large variability both in terms of amount and spatial distribution. This variability impacts agricultural productivity, as kharif crops (monsoon crops) are entirely rain-fed. Understanding the characteristics of rainfall in this region is essential for effective water management, agricultural planning, and industrial development. It helps in determining irrigation strategies, crop selection, and resource allocation. The arid conditions pose challenges for sustainable development, but the region's inhabitants have developed resilience strategies over generations to cope with the climatic constraints.

Weather in Thar Desert

The Thar Desert of Rajasthan experiences a dry and hot climate characterised by three main seasons: summer, rainy, and winter.

Temperatures: The Summer season begins in mid-March and continues up to the end of June with May and June being the hottest months. During summers, typically maximum temperatures range between 45 deg. Celsius to 49 deg. Celsius on many days causing heat waves and hot day conditions. In contrast, nights are quite pleasant because of its soil characteristics. The unusually high temperatures lead to the occurrence of strong hot winds that raise dust during the afternoon, known as *andhis*. Figure 7 gives a picture of monthly normal maximum, minimum temperature and mean temperature over the region.

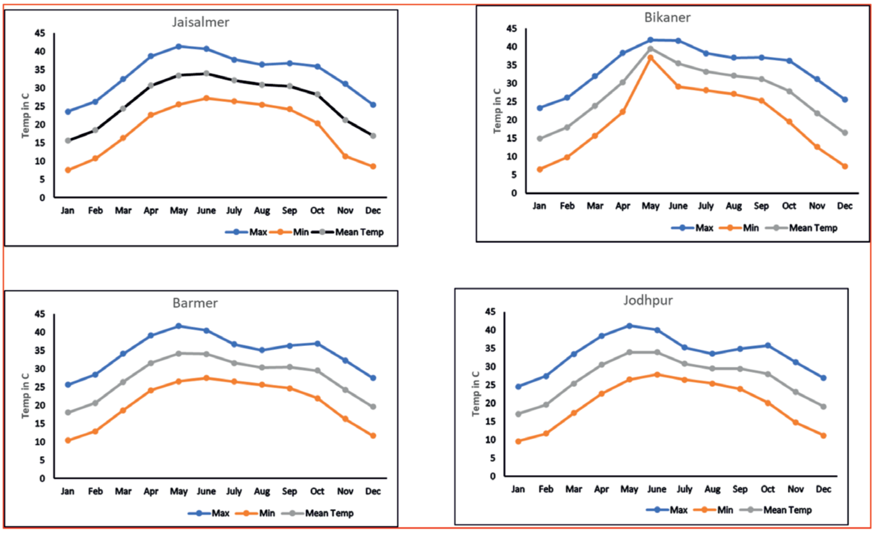


Figure 7: Monthly temperature normal for the Thar Region (Source: Climate Diagnostic Temperature, Website of India Meteorological Department, Pune)

The Thar region's temperature data over the past decade shows interesting patterns. It has been observed that long-period average temperature variation ranges from 0°C to 0.5°C with an exception in 2020. Some pockets in this region experienced temperatures exceeding 42°C during certain periods (Table 4). Extreme temperatures occurred in May 2020 and 2021 wherein in many areas, temperatures exceeded 42°C. During the crop growing season (July to September/October) general trend of maximum temperatures did not exceed 40°C with exceptions in July 2018 and 2019 which experienced temperatures exceeding 42°C. This data suggests a relatively stable temperature range during April over the past decade, with occasional spikes in certain years and areas. However, there has been a noticeable increase in

Table 4: Actual maximum temperature range

Year	*Maximum temperature in °C*					
	April	*May*	*June*	*July*	*August*	*September*
2015	38-40	40-44	38-42	36-40	38-40	36-38
2016	38-40	40-44	40-44	36-40	36-40	36-38
2017	38-40	40-44	40-42	38-42	36-40	>38
2018	38-42	40-44	40-44	38-42	36-38	36-40
2019	38-42	40-42	40-42	38-40	34-38	36-38
2020	38-40	>42	40-42	36-40	36-40	38-40
2021	38-40	40-42	38-42	38-40	36-40	34-38
2022			NA			
2023	36-39	36-39	40-44	38-40	32-36	34-38

(Source: IMD)

extreme temperatures during May in recent years, and occasional extreme heat during the crop-growing season, particularly in July 2018 and 2019.

Monsoon in this region advances during 1st week of July and withdrawal occurs by the first week of September. The monsoon season is a critical period for the Thar region, with most rainfall influenced by complex interactions between low pressure systems and geographical oscillations. Both the Bay of Bengal and the Arabian Sea play crucial roles in contributing to the region's rainfall, especially during interactions with western disturbances. Understanding these patterns helps in anticipating rainfall distribution for agriculture and water management in the region.

Rainfall: Despite annual and monsoon rainfall showing an increasing trend, variability persists across different districts. (Singh et al., 2014). Jodhpur is an exception in receiving sufficient rainfall during the 2014 monsoon when other districts faced deficits. Barmer district exhibits a unique pattern of alternating between deficit and adequate monsoon rainfall every other year. This variability highlights the complexity of rainfall distribution in the Thar region, influenced by geographical, atmospheric, and possibly local factors. Understanding these patterns is crucial for effective water resource management and agricultural planning. Figure 8 indicates the annual and district-wise variation of rainfall in the Thar region for the past decade.

The Thar Desert, primarily known for its arid and harsh climate, has been experiencing noticeable changes in its monsoon patterns over the past decade. The Southwest Monsoon, which is the principal rainy season for the region, has shown a trend of setting in earlier than usual. Normally, the monsoon onset in the Thar Desert occurs around July 1st. However, recent observations indicate that the monsoon is arriving 4-5 days earlier than this traditional date.

Moreover, the withdrawal of the monsoon has also been delayed, extending the rainy season by an additional 9-10 days beyond the typical withdrawal

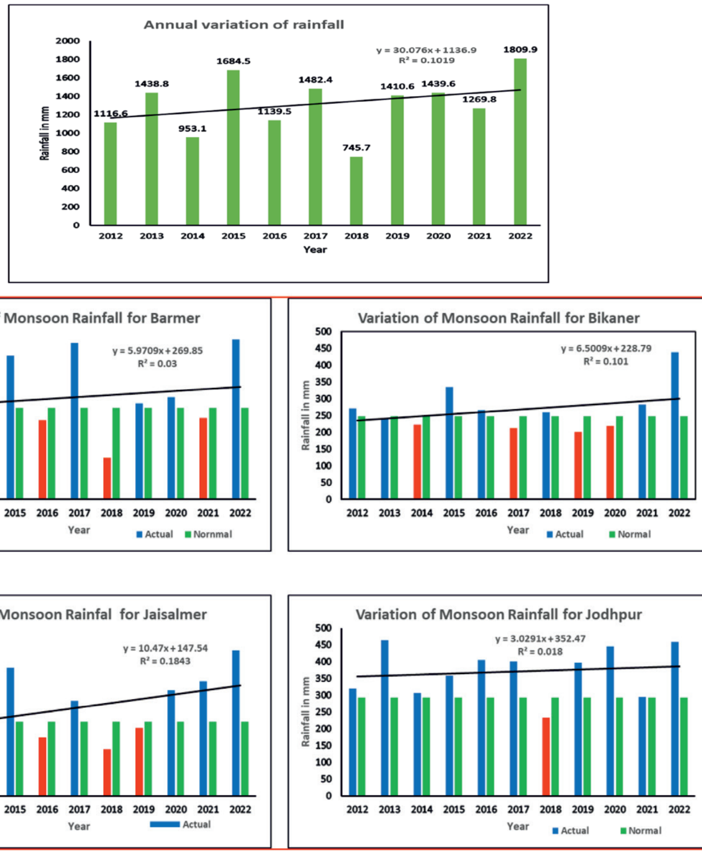


Figure 8: Variation of monsoon rainfall (Source Rainfall Statistics of India, 2012-2022, India Meteorological Department).

date of September 20th. This extension has contributed to an increase in the duration of the rainfall period in the Thar Desert during monsoon season.

Climatologically, there has been an overall increase in monsoon rainfall activity, with the region experiencing approximately a 7% rise in rainfall during the monsoon season.

b. Cold Desert in India

In the northernmost part of India, between latitudes 32°–36°N and longitudes 75°–80°E (ASSOCHAM, 2021) cold desert of India is situated called Ladakh which is bordered by Tibet to the east, Kargil to the west, China to the north, and Himachal Pradesh to the south (Fig. 9). Ladakh is situated 3000 to 8000 m above mean sea level and has extreme climatic conditions, including very low temperatures, minimal precipitation, and intense sunlight. The geography includes high mountains and elevated plateaus, and the climate is characterised by significant diurnal temperature variations. The region's low atmospheric pressure and oxygen levels present challenges for human

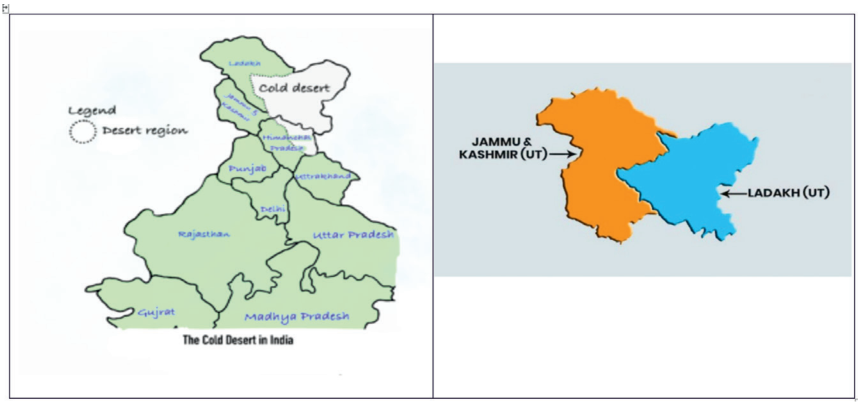


Figure 9: Cold desert.
(Source: 1. https://www.studyiq.com/articles/deserts-of-india/)

habitation, necessitating physiological adaptations. Water is primarily sourced from snowmelt, which is vital for the region's ecosystem and human activities.

Ladakh faces significant agricultural and hydrological challenges. The narrow crop growing period is restricted to valleys and coincides with scant rainfall, leading to severe limitations in water availability. The region's precipitation is less than 15% of the mean annual PET, highlighting a large moisture deficit. Evapotranspiration is minimal when temperatures are below freezing, resulting in negligible vegetation cover as indicated in Fig. 10. PET is higher in Kargil than in Leh and Drass. The major water supply during winter is snow, with little change in rainfall from April to October, exacerbating the gap between water demand and supply. The general increasing trend of monsoon rainfall is observed during the past 10 years indicated in Fig. 11.

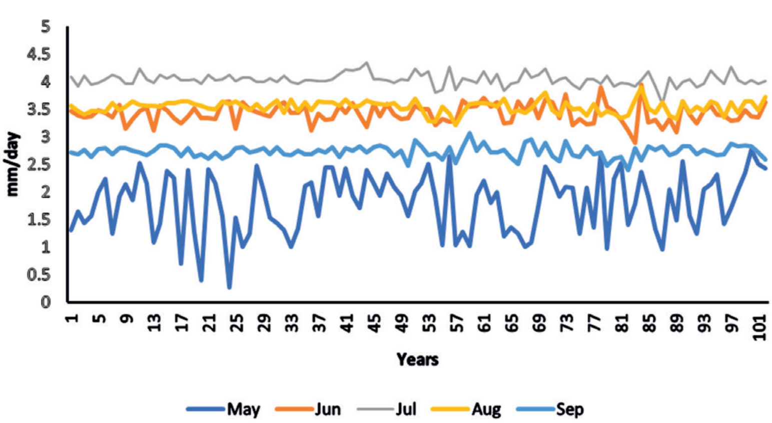


Figure 10: PET Trends over past 100 years in Ladakh. (Source: Consolidate studies on the weather pattern of Leh, Ladakh from 1901 to 2000. India Meteorological Department)

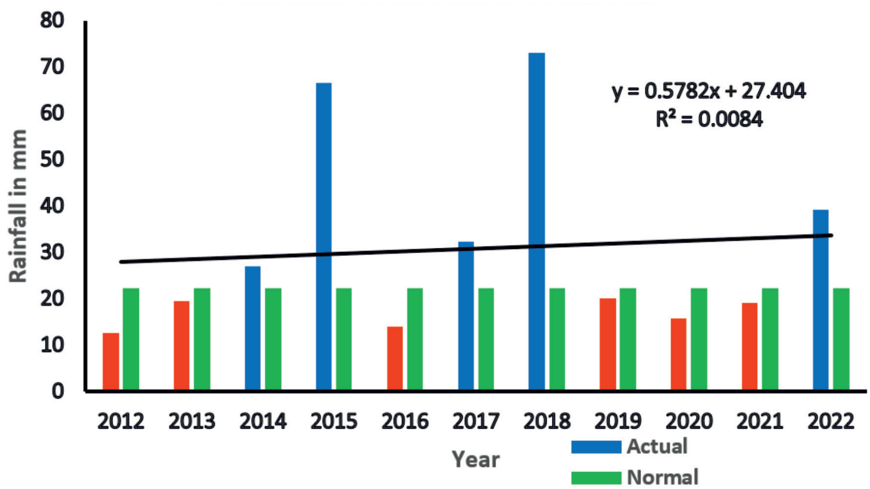


Figure 11: Variation of Monsoon rainfall over Ladakh region (Source Rainfall Statistics of India, 2012-2022, India Meteorological Department)

c. Coastal Desert

In the southern peninsula of the country, the Thoothukudi district of Tamilnadu which is notable for its distinctive red colour sand dunes has unique formation history, originating from the marine sediments of the Quaternary Period. These dunes have very low water and nutrient retention capacities, making them inhospitable for most types of vegetation. The dunes are highly susceptible to aerodynamic lift, which allows sand particles to be easily moved and reshaped by the wind. This dynamic nature of the dunes highlights the ongoing influence of wind on their structure and distribution.

The distinctive red-coloured dunes near Tiruchendur owe their unique hue to iron-rich minerals such as ilmenite, magnetite, garnet, hypersthene, and rutile, which undergo leaching and oxidation in the semi-arid climate. The dunes are located in the Kuthiraimozhi theri and Sathankulam reserves forest areas along the Bay of Bengal. The red loam is carried to Tiruchendur during the southwest monsoon season (May to September) by dry winds that have lost moisture over the Mahendragiri peak and the Aralvaimozhi gap of the Western Ghats, which are roughly 75 kilometers away. The lack of vegetation in the Aralvaimozhi gap and the Nanguneri plains exacerbates wind erosion, facilitating the transportation of red loam.

As the monsoon winds blow with high velocity, they lift and carry the red loam in large columns until they encounter sea breezes near the coast, where the sand is eventually deposited. This process, known as Aeolian activity, involves the erosion, transport, and deposition of sediments by wind. It leads to continuous redistribution of sand, forming characteristic sand dunes when wind-blown sand encounters obstructions such as vegetation or man-made structures.

7. Agriculture in Different Deserts in India

Desert environments are typically characterised by sparse vegetation due to the lack of water and the harsh climatic conditions. Trees are generally absent, and shrubs or herbaceous plants provide only limited ground cover. In some deserts, flora is almost non-existent due to extreme aridity. This aridity can be exacerbated by human activities, such as excessive cattle grazing, which put additional stress on an already fragile environment.

Human disturbance, particularly overgrazing, can lead to further degradation of the land, reducing the already limited vegetation cover. This, in turn, can increase erosion and reduce soil quality, making it even harder for plants to survive and grow. The combination of natural aridity and human impact creates a challenging environment for flora to thrive, resulting in the characteristic sparse vegetation of desert landscapes.

i. **Agriculture in Thar desert**
   The Thar Desert, located in Rajasthan, India, is home to about 40% of the state's population. and is the most densely populated desert in the world with a density of more than 80 people per square kilo meter compared to the average of 7 in other deserts. The primary occupations here are agriculture, tourism and animal husbandry. However, due to increasing human and animal populations, there has been significant degradation of vegetation resources and soil fertility. As agricultural activities in this region are rainfed crops, they are sown after the onset of monsoon. Major crops grown are bajra, pulses (such as guar), jowar, maize, sesame, and groundnuts. However, due to rainfall variability, about 33% of these crops fail annually. With the development of canals and tube wells, the region has also started producing rabi crops like wheat, mustard, cumin, and other cash crops. Opium is significantly produced in the Thar region.

The major crops grown along with area (in 1000 ha) sown are indicated in Table 5 and Fig. 12 indicates the total area, net area and double area sown in the Thar desert.

Challenges in Agriculture in the region are the region is prone to frequent droughts, high animal populations lead to overgrazing, which, combined with wind and water erosion and mining activities, results in severe land degradation and due to inconsistent rainfall, agriculture is not always dependable. Given the challenges in crop production, animal husbandry, along with agroforestry practices like intercropping trees, grasses, vegetables, and fruit trees, is considered a more viable livelihood model for the region. Understanding these features and challenges is crucial for effective planning

Table 5: Major crops grown along with area sown in Thar Region

District	*Wheat*	*Kharif Sorghum*	*Sorghum*	*Pearl Millet*	*Barley*	*Chickpea*	*Minor Pulses*	*Groundnut*
Barmer	17.61	6.61	6.61	795.06	0.02	2.01	329.38	4.06
Bikaner	113.18	0.04	0.04	117.99	4.52	226.59	424.75	174.95
Jaisalmer	9.99	3.13	3.13	98.69	0	152.93	58.14	19.79
Jodhpur	77.94	44.47	44.47	417.35	0.38	19.07	387.5	115.45
	Sesamum	*Rapeseed and Mustard*	*Castor*	*Cotton*	*Fruits and Veg*	*Onion*	*Fodder*	
Barmer	6.28	14.43	22.83	0	0.52	0.12	419.46	
Bikaner	9.4	71.79	0.1	0.66	1.83	1.08	829.01	
Jaisalmer	6.39	43.82	4.25	0.04	0.49	0.03	599.16	
Jodhpur	28.55	143.64	26.19	40.55	24.5	18.77	228.71	

(Source: ICRISAT District level crop data)

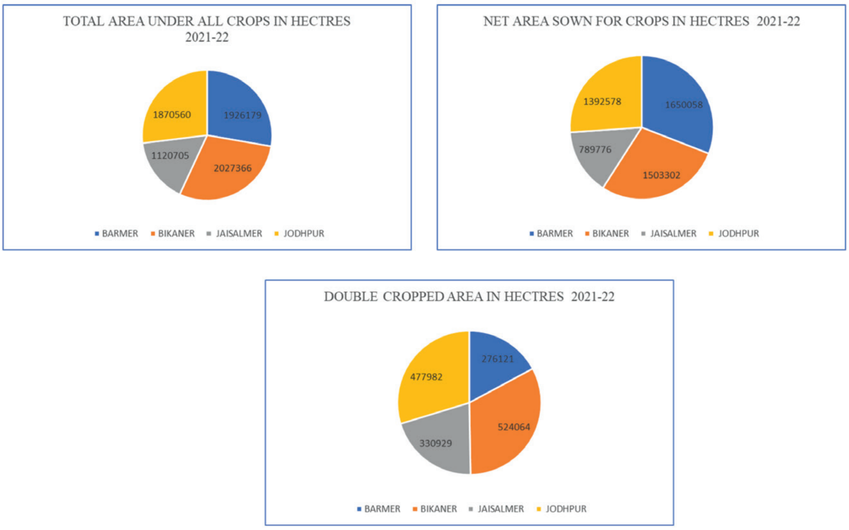


Figure 12: Total area of the crops sown with net area and double cropped area in hectres over Thar region. (Source Directorate of Economics and Statistics Rajasthan, 2021-22)

in water management, agricultural operations, and industrial development in the Thar Desert (Kar, 2019; Kaur and Singh, 2023).

In recent years, there has been an increase in both human and animal populations in the Thar Desert of Rajasthan challenging farming conditions and making animal husbandry a popular and crucial livelihood for many residents. Compared to the other farming areas in the country, farmers in the region have ten times more animals per person contributing to issues like overgrazing and environmental degradation. The primary livestock includes cows, buffaloes, sheep, goats, camels, and oxen. Barmer district has the highest cattle population, with sheep and goats being the most common. Thar region, is the largest wool-producing area in India, contributing 40-50% of the country's total wool production. *Proposis cineraria* species, known locally as Khejri, is vital for the livelihood of Thar Desert communities. It provides fodder, fuel, and other resources essential for daily life. The dependency on animal husbandry and the significant wool production highlight the importance of sustainable practices to mitigate environmental degradation and support the local economy.

ii. Agriculture in Cold Desert

Ladakh, a cold arid desert region, faces unique challenges and opportunities in agriculture due to its harsh climate. Roughly 70% of the people are directly or indirectly dependent on agriculture. The cropping season in this region is only four to five months every year (April to October) depending on different altitudes. Single cropping is the norm in the region as agriculture is entirely dependent on irrigation with a cultivable area of 10,223 ha. The major crops cultivated included Grim (Naked Barley), wheat, peas and alfa-alfa for fodder. The workforce is entirely focused on agriculture and social structures and customs are all based on an agrarian way of life. Mostly agricultural lands are restricted to the comparatively lower regions that align with the river valleys. This region's economy has always been centred on cattle raising and subsistence farming. In this area, cultivation primarily depends on snowmelt, which provides irrigation water. The residents in the area conduct self-sustainable agriculture in spite of severe environmental restrictions. In this area, polyhouses are used primarily by farmers to cultivate vegetables. Utilising polyhouses lowers the area's irrigation costs.

Ladakh's cold desert environment presents unique agricultural challenges, but with the adoption of innovative techniques, the region can significantly improve its agricultural productivity and sustainability. Here are some techniques that can change the face of agriculture in Ladakh.

- Water management and solar energy utilisation
- Protected cultivation and precision Farming
- Emphasise research and training programs to promote natural farming practices.
- About soil health and nutrient management

These suggestions collectively form a comprehensive strategy to address the unique challenges of agriculture in Ladakh, contributing to sustainable development and the well-being of resource-poor farmers in this cold desert region.

iii. Agriculture in Coastal Desert

The coastal desert situated in Kuthiraimozi Theri Reserved Forest. Soil in this area is lost due to its close proximity with the Bay of Bengal causing wind erosion. As a protective measure to reduce wind erosion, it is necessary to maintain vegetative cover over the land by constructing wind break or shelter belts.

Based on the soil type, climate, rainfall and availability of soil moisture, vegetation cover should be selected in this region. Rainstorms in these areas temporarily form lakes and ponds. As it is a reserved forest land, government is encouraging the farmers to grow drumstick plants, palm trees and cashew nuts in this region.

8. Summary and Conclusion

Deserts are characterised by unique climatic, topographic, edaphic, and biotic features, with aridity being a common feature across all deserts for most or all of the year with significant fluctuations in day and night temperatures, and between seasons. Temperatures across the polar desert also do not go beyond 10°C. Low humidity during the day and relatively higher humidity at night are typical. Precipitation deficiency is a defining feature, characterised not only by the low amount of rainfall but also by its unpredictability in timing and quantity. Rain in the desert is often seasonal, unpredictable, inconsistent, and restricted to specific areas and time periods.

Deserts located around 30°N and 30°S are typically hot due to the global circulation patterns, particularly the descending air from the Hadley circulation. This descending air creates semi-permanent high-pressure areas at these latitudes, leading to abundant sunshine and high surface temperatures. Subtropical deserts form due to these air circulation patterns. Deserts in rain shadows develop on the side of mountains that don't face the prevailing wind, causing arid conditions due to blocked wet weather systems. Deserts in the interior of continents form because they are not reached by moisture-carrying winds. Coastal deserts, affected by cold ocean currents, may receive very little rain but can be moist with fog as the chilly ocean air warms up over the land. Hyper-arid and arid regions are defined by an aridity index (P/PET) lower than 0.20, indicating less than 20% of the water requirement is met by rainfall for optimal plant growth. Key meteorological indicators for monitoring agricultural drought include the Standardised Precipitation Index, aridity anomaly index, and combined drought indicator.

Desert areas in India, such as the Thar Desert in Rajasthan, have low and unpredictable rainfall, along with high rates of evaporation, resulting in frequent occurrences of droughts. The Thar Desert experiences very high daytime temperatures, ranging from 45°C to 49°C. Despite increasing trends in annual and monsoon rainfall, variability persists across districts. Ladakh, a cold desert, features high altitudes, extreme climatic conditions, very low temperatures, minimal precipitation, and intense sunlight. It includes high mountains and elevated plateaus.

The Thar Desert has seen significant changes in recent years, with the increase in both human and animal populations. With the onset of monsoon (in June and July) *Kharif* crops like bajra, pulses (guar), jowar, maize, sesame, and groundnuts are sown and harvested in September and October. Animal husbandry is crucial due to challenging farming conditions, leading to issues like overgrazing and environmental degradation. The region has a high livestock-to-person ratio, with cows, buffaloes, sheep, goats, camels, and oxen being the primary livestock. Sustainable practices are essential to mitigate environmental degradation and support the local economy.

In the coastal desert of Tamil Nadu's Thoothukudi district, the soil has low water and nutrient retention capacities, making it inhospitable for most vegetation. Agricultural areas are typically confined to river valleys, especially in central and western Ladakh.

To protect the land from wind erosion, maintaining vegetative cover and constructing wind breaks or shelter belts is crucial. Tree species for wind breaks should be selected based on soil type, climate, rainfall, and moisture availability.

Ladakh's cold desert environment presents unique agricultural challenges. However, innovative techniques can significantly improve agricultural productivity and sustainability in the region. These include:

- Water Management and Solar Energy Utilisation: Efficient use of water resources and harnessing solar energy for agricultural activities.
- Protected Cultivation and Precision Farming: Using greenhouses and precision farming techniques to optimise resource use and increase crop yields.
- **Research and Training Programs**: Promoting natural farming practices and educating farmers about soil health and nutrient management.

These strategies aim to address the unique challenges of agriculture in Ladakh, contributing to sustainable development and improving the well-being of resource-poor farmers in this cold desert region.

Global climate change is having a pronounced impact on desert regions, affecting them more significantly than many other areas. Deserts are experiencing higher temperature increases compared to other regions. This intensifies evapotranspiration rates, further drying out already arid areas. While deserts typically receive minimal rainfall, climate change is causing more erratic and extreme precipitation events leading to flash flooding and increased erosion, disrupting the fragile desert ecosystem. The frequency and severity of droughts in desert regions are increasing. Increased temperatures and prolonged droughts put additional stress on desert vegetation, which is already adapted to harsh conditions. Higher temperatures and reduced vegetation cover can lead to soil degradation. Communities living in or near desert regions are facing greater challenges due to water scarcity, reduced agricultural productivity, and increased heat stress. This can lead to migration and socio-economic instability. Efforts to monitor and mitigate these impacts include advanced remote sensing technologies, incorporating new data, methodologies, and metrics to improve the capability to monitor regional-scale agricultural drought conditions accurately. The use of geospatial technology allows for precise mapping and tracking of drought conditions across different regions, facilitating targeted interventions.

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