



Degradation status and land productivity assessment in drylands using remote sensing and ground survey: Experiences from India and China

Mahesh Kumar Gaur^{1,*}  Haiying Feng², Victor Roy Squires³ 

¹ICAR-Central Arid Zone Research Institute, Regional Research Station, Leh (U.T. of Ladakh), India.

²Qinzhou Development Research Institute, Bei Bu Gulf University, Guangxi, China.

³Formerly, University of Adelaide, Australia.

*Corresponding author: mahesh.gaur@icar.gov.in

Original Research

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Abstract:

The impact of Remote Sensing technologies (RS) on land classification and its potential for various land uses is often taken for granted. Without it, land managers would be unable to implement remedial measures to conserve and restore degraded land. We provide a ‘snapshot’ of how governance in China and India, using new monitoring technologies, can lead to better outcomes for the ecosystems and the people whose livelihoods depend on the flow of ecological goods and services from the vast areas of these two countries. The advent of new technology, including greater reliance on near-Earth platforms to provide extremely high-resolution imagery, augments the data obtained by orbiting land resource satellites. The development and refinement of the Geographic Information System (GIS) in conjunction with RS has allowed accurate differentiation and mapping of multi-attribute land capability. The challenge for government planners and land managers is to find tools that allow relevant data to be collected and analysed. Ideally, such tools should be able to give a rapid assessment, and not involve large teams of highly trained personnel or incur high costs. This paper reports on the development and trial of such tools on a broad scale (millions of km²) under harsh environmental conditions in both India and China. The paper has three main parts. First, we present a brief overview of the current and developing situation in China and India in response to the newly created infrastructure, population shifts and changes in governance and policy initiatives. Next, we build on insights from the literature and fieldwork in remote areas covering a broad spectrum of problems (salinity, mobile dunes, waterlogging, etc.). Here we developed an understanding of the need for tools to help planners and land managers in a range of unique challenging situations. Finally, we re-visit the nexus between monitoring land degradation and the use of remote sensing and allied technologies and offer some insights as to future directions in both data acquisition, analysis and interpretation.

Keywords: Satellite imagery; Near-Earth platforms; GIS; Land capability; Land degradation; Assessment; Governance

Introduction

Assessing and monitoring land productivity in India and China

Monitoring and assessment of the vast and heavily utilized lands of India, especially in the Thar desert and the grasslands of China’s north and north-west have been a challenge as governments in the two countries faced rising populations of both humans and livestock, competition for land and water as vast irrigation and re-settlement schemes were developed. Governance models were tried

and discarded as the rate of land degradation accelerated and poverty levels were on the increase.

Land quality varies and determines to a large extent the land use systems adopted in a region or area (Squires and Gaur, 2020). There are strong links between biophysical processes and economic choices at local, regional and global levels. Understanding the relationships between land attributes, land degradation, agricultural productivity and food security is a major challenge. There is a role for remote sensing, including automatic weather stations, in assessing the nature and extent of major land types.

Monitoring emphasizes change and, where possible, its causes. The important considerations are to ensure that significant changes are measured. Associated with detecting the magnitude and direction of change is taking the appropriate management action.

Models derived from satellite images and data like spectral signatures of vegetation water bodies etc. are needed to monitor the status of terrestrial ecosystems across large spatial scales. A major constraint for doing so is the availability of suitable field data to calibrate remote sensing indicators and, to a lesser extent, the sensitivity of spectral data of available satellite sensors to soil background and atmospheric conditions. In a study the chlorophyll absorption ratio index was the best predictor (Haboudane et al., 2004) (see more below).

Role of remote sensing in monitoring the global drylands

Drylands, areas with a precipitation/potential evapotranspiration ratio below 0.65 are essential for sustaining life on our planet, as they cover around 42% of the global land surface, produce 42% of the world's food and host 30% of the world's endangered species (Gaur and Squires, 2018a). However, drylands are threatened by climate change and desertification (Burrell et al., 2020), which can induce abrupt changes in their structure and functioning. These changes have been associated with increased aridity conditions (Berdugo et al., 2020) or reduced soil fertility and multi-functionality (Berdugo et al., 2017).

Rangeland degradation is often difficult to measure successfully over extensive land areas. Ground-based vegetation sampling techniques must be sensitive to changes in parameters capable of defining this degradation or lack thereof. These parameters include vegetation cover, frequency, density and diversity, along with various surface soil characteristics. Therefore, both the vegetation and the soil must be examined in a monitoring program to determine if grazing practices are successful in maintaining the ecological health of the rangeland. Also, the socio-economic and policy issues must be considered. The process of monitoring includes repeated assessments over time. Reliable rangeland monitoring demands that any short-term fluctuations disguising long-term trends be removed from the overall temporal sequence of vegetation maps. The task is made even more difficult by the fact that the fluctuations are spatial, as well as temporal (Squires, 2007; Gaur et al., 2021). Earth observation satellites are critical for monitoring temporal trends in ecosystem attributes across global drylands. Optical sensors with coarse spatial resolution, such as the National Oceanic and Atmospheric Administration Advanced Very High-Resolution Radiometer (NOAA AVHRR) or satellite passive microwave observation, have provided valuable information on quantifying dryland biomass at the regional scale (Tian et al., 2016).

The role and utility of using remote sensing tools is to get a better understanding of the ecology of drylands (arid and semi-arid ecosystems). These tools include not only data derived from satellites but use of near-earth devices like unmanned aerial vehicles (drones) that have an increasingly

important role. Prevention of land degradation relies on the assessment of the present condition of the land and the monitoring of relevant and meaningful changes. Any efforts to induce change require a good knowledge of the current biophysical situation and some objective means of judging the degree of degradation to measure changes. The challenge is to use these tools (remote sensing, GIS and decision-support systems) in a way that provides a feedback loop so that management can reflect the changing land condition.

To understand dryland degradation and restoration, it is crucial to use a functional approach, i.e. to assess dynamic processes that contribute to changing patterns, and to consider feedback between biotic and abiotic processes (King and Hobbs, 2006). Studies that aim at a functional understanding of system response in different hydrologic and climatic settings may improve our understanding of dynamics in drylands. Remote sensing is uniquely placed to achieve that.

Remote sensing provides the opportunity to monitor resource conditions over large areas in 'near real-time' when degradation is occurring. Used in conjunction with ground-based monitoring, particularly by local grassland monitoring personnel at the township or county level, remote sensing has the potential to provide warnings, allowing government and land-user action to minimize damage. Integrating medium spatial resolution image data (30 × 30 m) such as Landsat or Resources at data and field-based observations could improve the assessment of status and trends in a cost-effective and accessible manner.

Landsat, or MODIS have played an essential role in monitoring dryland vegetation dynamics. They have extensive spatial coverage and frequent observations (Rouse et al., 1974), making them useful for this purpose. Landsat has been particularly successful in monitoring dryland vegetation attributes, with reliable accuracy in retrieving fractional cover and leaf area index at the regional scale (Kennedy et al., 2014; Sun et al., 2005; Sun, 2015). One of the methods most widely used to infer vegetation attributes has been the calculation of Remote Sensing Indicators (RSI), such as the Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974). However, NDVI applicability on a global scale is limited due to the spectral influence of mixed sparse vegetation and bare soil (Huete and Jackson, 1987; Huete et al., 1985; Huete et al., 2002). Remote sensing indicators that minimize soil background have recently received considerable attention. Indices such as the soil-adjusted vegetation index (SAVI) (Huete et al., 1985), the optimized soil-adjusted vegetation index (OSAVI) (Rondeaux et al., 1996), the atmospherically resistant vegetation index (ARVI) (Fatiha et al., 2013), the modified chlorophyll absorption in reflectance index (MCARI) (Kaufman and Tanre, 1992) or the global environment monitoring index (GEMI) (Ren and Feng, 2015) are more resistant than NDVI to saturation, background reflectance conditions and atmospheric effects (Squires and Yang, 2009). For instance, ARVI has a similar dynamic range to NDVI, but on average, it is four times less sensitive to atmospheric effects than NDVI (Kaufman and Tanre, 1992).

Studies showed that the modified vegetation indices, such as the SAVI and L-SAVI, improved the detection of spatio-temporal changes in the vegetation in a semi-arid area (Fatiha et al., 2013).

Materials and methodology-China rangelands

This study of China utilized the MODIS (Moderate Resolution Imaging Spectroradiometer) Monthly-L3 data products for the analysis. Specifically, the Normalized Difference Vegetation Index (NDVI) was directly derived from the MOD13A3 product, which provides high-resolution vegetation data. The study extracted data from the red band and thermal infrared band using the MOD13A2 and MOD11A2 products, respectively to assess surface bareness. Additionally, soil temperature data were sourced from the MOD11A2 product. All the MODIS data used in this study were acquired from the NASA Earth Observing System Data and Information System (EOSDIS) Worldview portal (<https://wist.echo.nasa.gov/api/>), covering a spatial resolution of 1 km. The focus was specifically on the growing seasons (from May to September) each year within this time frame. The data processing involved the application of the MODIS Reprojection Tools (MRT) for tasks such as image mosaicking and resampling, ensuring the data was aligned spatially and temporally. To produce monthly datasets, the Maximum Value Composite (MVC) technique was applied, selecting the best quality observation from each pixel during each month of the growing season.

Climate data, including monthly average temperature, precipitation, and total solar radiation, were obtained from 50 standard meteorological stations provided by the China Meteorological Science Data Service Center (<http://cdc.cma.gov.cn>). This climate data was specific to the study region (TRSR and its surrounding areas). The climate data underwent spatial interpolation using the specialized program ANUSPLIN (version 4.3), ensuring that the interpolated climate raster data matched the spatial resolution and geographical projection of the MODIS NDVI data. Additionally, soil texture data were obtained from the Harmonized World Soil Database (HWSD), version 1.1, which provided detailed information about soil properties across the study area. This database is widely used for various environmental studies, offering high-quality global soil data for a range of applications.

Thus, this study integrated remote sensing data from MODIS with high-quality climate and soil datasets to explore the dynamics of vegetation, climate, and soil interactions.

China's experience in monitoring and inventory of rangelands

China's desertification-prone region (DPR) stretches from central Asia in the western direction to north-eastern China in the eastern direction, covering an area of more than 1.2 million km². At present, more than 60% of the DPR is managed using traditional pastoral and agricultural systems, and the impacts of desertification on farming and grazing affect the lives of over 47.9 million people. Despite the enormity of the task, China carries out a National monitoring and

assessment of the entire area of rangelands (over the 'core' 300,000 km²) every 10 years. This assessment involves tens of thousands of technicians both for the processing of imagery and for on-the-ground validation.

Methodologies for dealing with this huge tract of land and with the climatic, topographic and socio-economic realities are applied. In addition, there is a great degree of complexity when the policy environment is taken into consideration. Drylands, mostly grasslands and rangelands, occupy a significant portion of China's mainland.

National environmental protection was guided from the 1990s by the China Agenda 21 Policy framework and by a number of key policy guidelines. The laws provide broad guidelines only and the specific rules and regulations for implementation are established at the lower levels, mainly at the county level. As set out in China's National Action Plan to combat land degradation and desertification inventory and assessment of conditions and trends are carried out periodically (figure 1). These evaluations influence the 're-sets to policy' (which ones impede progress and which are beneficial).

Remote sensing tools are a major part of the process and over the years have become more specific and focussed on key indicators. New technologies with better satellite capability and the use of Lidar and unmanned near-Earth monitors (drones) have helped enormously, especially in rugged and largely inaccessible areas.

China's fight against desertification in northern China has yielded major achievements over the past 45 years. The program has tackled land degradation (arrest and reverse) and curbed desertification in key areas. The extent and severity of land degradation (all types) have been mapped by a combination of remote tools and other allied tools. By exploring the rangeland ecosystem productivity and landscape ecological patterns of the main pastoral grasslands in China, there is a theoretical basis for the rational management of dryland resources across the whole country (figure 2). At its core is the data that is generated, analysed and archived. Such data helps assess priority areas (hot spots) and plan and execute strategic interventions.

Materials and methodology-India land degradation status

Anthropogenic processes are quite dominant and cause land degradation over an area of 6548 km². It also includes industrial effluent zones, mining, dumping, and brick kilns. The most severely affected states due to anthropogenic activities leading to land degradation are Karnataka, Rajasthan, and Andhra Pradesh. Mining and brick kilns are the two anthropogenic activities that caused the most land degradation in Telangana state (Gaur et al., 2021; Sreenivas et al., 2021). Ladakh, Jammu & Kashmir, Rajasthan, and Gujarat have the greatest expanses of barren rocky outcrops, riverine sand, mass movement, and other land degradation processes. These processes account for 12.1% of the total land degradation or 3.4% of total geographical area (TGA). Barren rocky deserts are regarded as degraded land without any more scope for further improvement. The mass movement activities severely affect the foothill zone of the Himalayan region

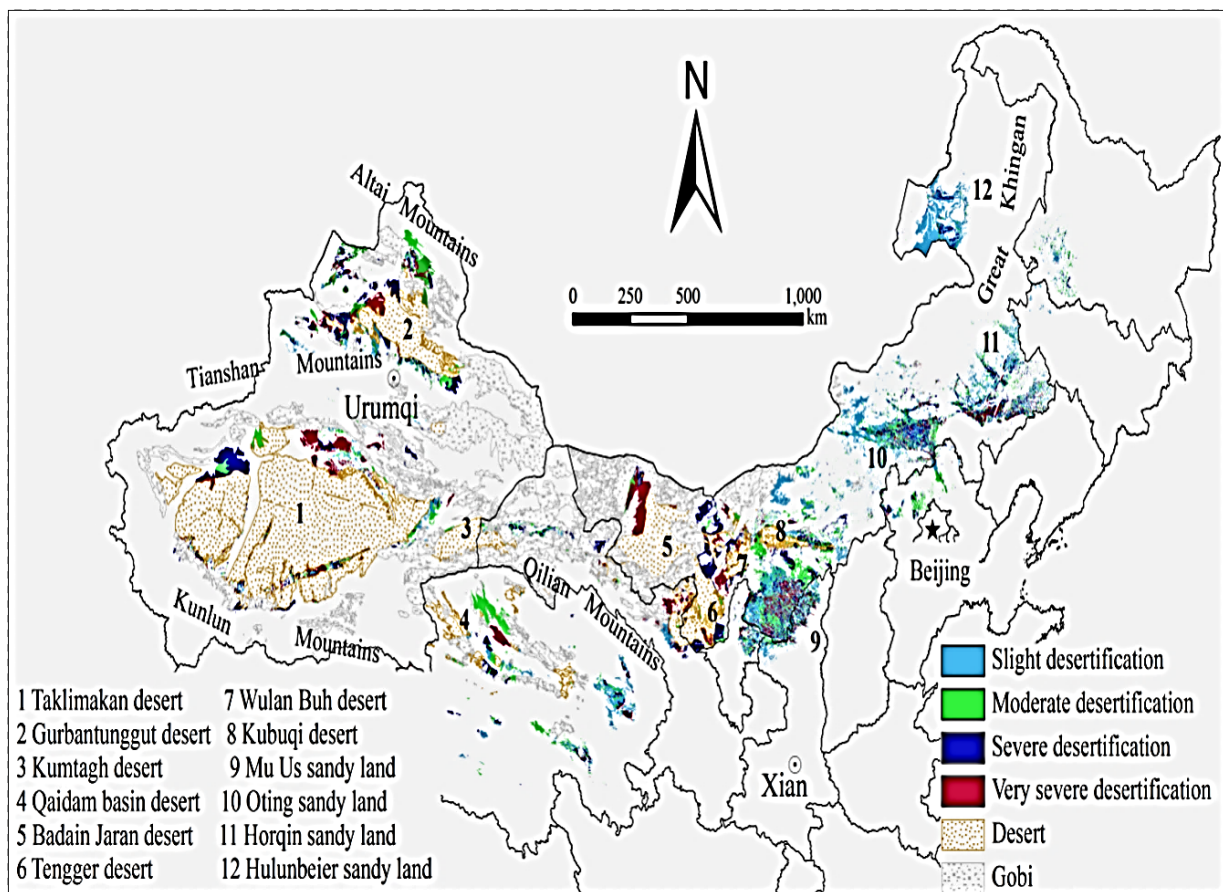


Figure 1. Northwest China, bordering several countries including the Qinghai-Tibetan plateau and part of the Hindu Kush has the most extensive rangelands but much of Inner Mongolia has been so classified.

(Gaur et al., 2021; Sreenivas et al., 2021; Bhattacharyya et al., 2015).

The overall aim of a recent survey, on a part of the drylands, was to apply a method to provide a reliable database with spatially explicit, up-to-date information on the condition of the land, the forces encouraging land degradation and the efficacy of management (Gaur and Squires, 2018a; Sreenivas et al., 2021; Bhattacharyya et al., 2015; Singh et al., 1994).

Study area in India

The western arid Rajasthan of India or the Great Indian Desert is comprised of twelve districts namely, Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jalore, Jaisalmer, Jhunjhunu, Jodhpur, Nagaur, Pali, and Sikar. It extends between $24^{\circ}37' - 30^{\circ}11' N$ and $69^{\circ}29' E - 76^{\circ}06' E$ and is spread over an area of 208,751 km² (figure 3). This hot arid region is characterized by low and high erratic rainfall, high evaporation loss and extremes of diurnal and seasonal temperatures. The average annual rainfall varies from 456 mm in the northeast to less than 100 mm in the westernmost part of Jaisalmer district. The coefficient of variability of annual rainfall varies from 40 to 70%. About 95% of the rainfall is received during the June to September months. The probability of drought occurrence varies between 50 – 60%. Dominant landforms are the sandy plains with varying degrees of hummocks and dunes. The vegetation of this region is quite sparse with a limited number

of xerophytic plants and thorny bushes. The drainage, except the ephemeral Luni River system, is mostly internal. It harbors a total domestic livestock population of about 30 million heads—an increase of 14.6 million heads (94.7%) over the 1956 census Figures. The desert region has about 52.3% of the State's livestock. As per 2011 census, the region has just over 27 million human population. The density per km² of human population varies from 17 in Jaisalmer to 361 in Jhunjhunu district and livestock inventories vary from 83 in Jaisalmer to 274 in Sikar (Gaur and Squires, 2018b).

Land degradation status mapping of India

Satellite and ancillary data were required for mapping of land degradation classes and supported by the ground truthing. Details are as follows:

Ancillary data: Land use/land cover maps derived from IRS LISS-III satellite data for the years 2005 – 2006 and 2011 – 2012 (LISS IV); land degradation mapping (Cycle 1) in 2005 – 2006 from IRS LISS-III data; SRTM digital elevation models (DEMs) of 2007 and wasteland mapping from IRS LISS-III data in 2015 – 2016 and NDVI data from Sentinel-2 satellite scenes of 2015 – 2017 provided the basis for the generation of present land degradation maps.

Ground truth data: Ground data forms an important source of information for mapping and accuracy estimation. Details are usually recorded along with information about the topography, position (latitude-longitude) and land cover of

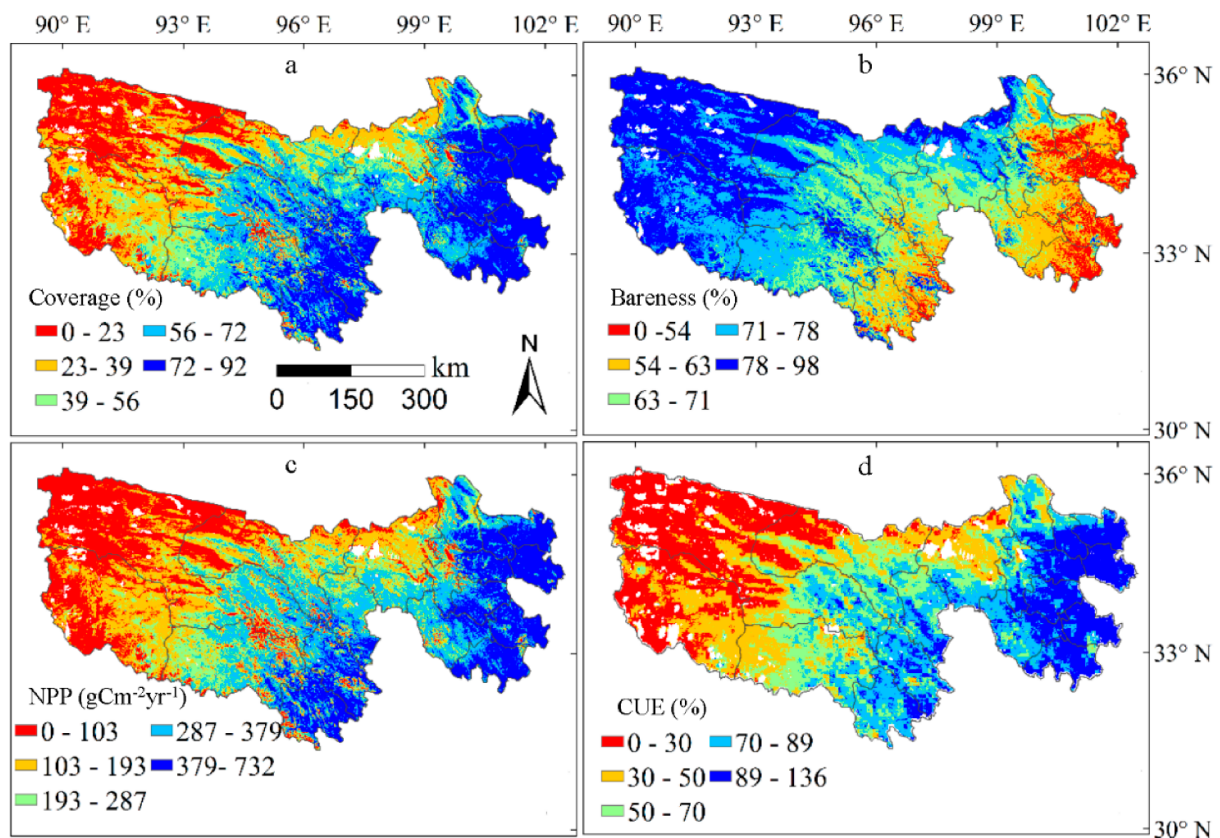


Figure 2. NPP: Net Primary Productivity, CUE: Carbon Use Efficiency
Remote sensing and ground truthing were used to generate maps of four important rangeland attributes (Zhang et al., 2019).

each field observation point.

A detailed classification into land use/land cover classes was performed using multispectral indices and standard protocols. The vector layers of NBSS & LUP (2005) were used pertaining to soil series, order, land capability, etc.

Land degradation processes continuously occur in the absence of any anthropogenic interference. However, accelerated land degradation is most often caused as a result of human intervention in the natural environment. The effects of these interventions are determined by the geomorphic landscape. The most frequently recognized main causes of land degradation include (Gaur and Squires, 2018b; Gaur, 2018):

- Overgrazing of grazing and pasture lands,
- Over-cultivation of cropland,
- Waterlogging and salinisation of irrigated lands,
- Deforestation, and
- Pollution and industrial causes.

Biophysical conditions also influence the initiation and trajectory of land degradation. The effect of a land degrading process differs depending on the inherent characteristics of the land, specifically soil type, slope, vegetation and climate. Thus, an activity that in one place is not degrading may in another place cause land degradation because of different soil characteristics, topography, climatic conditions,

or other circumstances.

Wind erosion is the major process causing land degradation in the hot desert region of western Rajasthan (Venkateswarlu, 1993). It occurred over 90.9% of its Total Ground Area (TGA). Except for the Pali district, all the districts are severely affected by sheet erosion. Stabilised dunes occupy 2,538,167 ha whereas unstabilised dunes occupy 3,491,667 ha. Pali (0.1%), Jalor (21.1), Sikar (27.5%), Jhunjhunun (32.4%), Ganganagar (38.9%), and Nagaur (46.7%) have smaller areas under the unstabilised dunes. About 90% area of western Rajasthan is affected by wind erosion. About 7,362,300 ha has been classified under sheet erosion. Bikaner (92%), Jaisalmer (87.9%), Barmer (87.5%), Churu (77.8%), Jodhpur (73.9%), and Hanumanagar (56.9%) are the districts affected with the highest level of wind erosion. Wind erosion is a predominant process causing land degradation in arid districts, mostly in Rajasthan (hot desert). Unstabilised dunes formed due to localized sand deposition are the main form of wind erosion, followed by the removal of fine soil in the form of sheet erosion (Gaur and Squires, 2018a; Lu et al., 2023). Lack of natural vegetation cover due to the prevailing arid conditions and poor binding capacity of soils are the main reasons for wind erosion in this zone. Accelerated wind erosion problems in western Rajasthan are attributed to anthropogenic activities (Singh et al., 1994). Aeolian activity in the Thar Desert is mainly restricted to the period of summer winds associated with the southwest monsoon. Wind erosion is the major source of land degradation in northwest

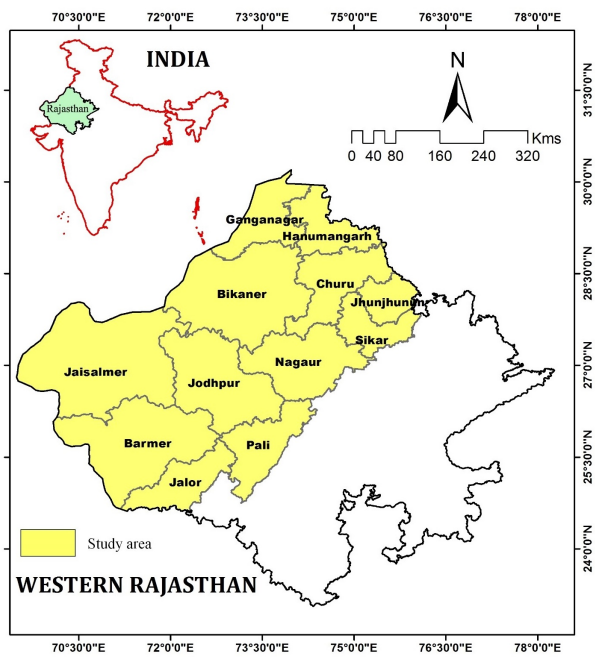


Figure 3. Study area.

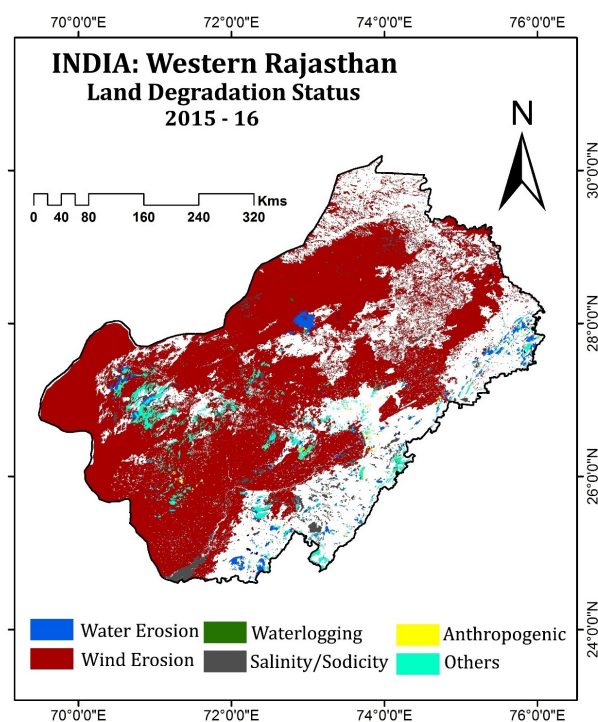


Figure 4. Land degradation status in western Rajasthan, India (2015 – 2016).

India (figure 4). The most important serious agriculture-related threat of wind erosion is the injury to the young plants during sand storms as roots are exposed along with sandblasting of leaves and stems. Furthermore, the small plants may be buried under a thick pile of sand where newly mobile sand encroaches on a site (Gaur et al., 2020). Temporal analysis of changes in land degradation in western Rajasthan are shown in Table 1.

Water erosion is another major process causing land degradation in western Rajasthan, accounting for 2.4% of total land degradation in the geographical area of western Rajasthan. Districts like Ganganagar, Hanumangarh, Churu, and Barmer have minuscule (less than 1%) areas affected by water erosion whereas Jaisalmer, Jodhpur, and Nagaur have the area under less than 1.5% area under water erosion. Sikar district has 7.5% area under water erosion followed by Jalor (5.7%), Jhunjhunun (4.6%) and Pali (3.7%) (Gaur et al., 2021). High rainfall variability and intensity, undulating terrain conditions and moderate to high erodibility of soils were the major factors for extensive water erosion in these

districts. The undulating terrain conditions and cultivation practices along the slopes are the main factors for sheet erosion by water. The decadal changes in soil erosion status (as shown by the data generated by remote sensing) indicate a marginal decrease in the spatial extent. However, a substantial decrease in the severity of water erosion classes was noticed, associated with better land cover conservation measures mainly through surface canopy cover (NRSC, 2019). The salinization/alkalization (comprising various categories like saline, sodic and saline-sodic and rann) was spread over 375,329 ha, accounting for 2.5% of the total land degradation (LD) of the arid zone. This process occupies 1.3% of total district area of Barmer, 0.9% of Bikaner, 1.1% of Churu, 0.9% of Ganganagar, 1.9% of Hanumangarh, 0.6% of Jaisalmer, 8.8% of Jalor, 0.2% of Jhunjhunun, 1.2% each of Jodhpur and Nagaur, 7.8% of Nagaur and 0.6% of Sikar (Gaur, 2018). An area of 217,062 ha has been

Table 1. Temporal change analysis of land degradation in Western Rajasthan, India (13 districts including Sirohi) at 1:50,000 Scale.

LD Process-wise categories	2005 – 2006	2015 – 2016
Wind Erosion	64.99	64.49
Water Erosion	2.31	2.31
Waterlogging	0.04	0.04
Salinisation/Alkalisation	1.80	1.80
Anthropogenic*	0.12	0.23
Others [§]	3.09	3.05
Normal	27.65	28.08

* includes: Industrial-effluent affected areas; Mining & dump areas; Brick kiln areas

[§] includes: Barren rocky/Stony waste; Miscellaneous-Riverine sands areas

classified under the saline category, while, saline-sodic occupies 54,406 ha and the area under sodic lands was 70,497 ha. The area under rann (a site characterized by saline soils and desert-like conditions) was only 33,364 ha. The salt-affected areas are mainly saline-sodic and sodic with geogenic origin from alluvium and continuous application of saline water for irrigation. Distribution of sodic soils showed common occurrence in the arid and semi-arid regions (Mandal et al., 2009). Besides, these are affected by poor-quality groundwater (Goyal and Gaur, 2020). Continuous use of pumped water for irrigation has contributed to the problem of salinity and sodicity (Bhalla et al., 2011). In the Nagaur district, groundwater's electrical conductivity (EC) ranges between 1380 to 16240 $\mu\text{S}/\text{cm}$. Higher EC values have been observed in the west-central part of the district and depressions near the saline lakes. Similarly, fluoride concentration over the maximum permissible limit of 1.5 mg/L has been found in the central and north-eastern parts of the Nagaur district. Whereas, EC in most of the Jalore district is below 3000 $\mu\text{S}/\text{cm}$ except western part of Sanchore, the northern parts of Jaswantpura and Jalore, the eastern part of Bhinmal and the majority of Sayla and Ahore blocks. Fluoride concentration has been found to range from 0.9 to 2.4 mg/L. High fluoride contents (> 1.5 mg/L) were found in the Sanchore, Raniwara and Bhinmal blocks and parts of Sayla and Jaswantpura blocks (Gaur and Squires, 2018b). Waterlogging was found in about 0.1% of the total geographic area of western Rajasthan that can occur in canal-irrigated areas like, Barmer, Bikaner, Ganganagar, Hanumangarh, Jaisalmer and Nagaur districts. The occurrence of waterlogging in Barmer and Jaisalmer is a recent phenomenon due to introduction of a canal. Water logging is confined to the lower elements of slope due to accumulation of sub-surface seepage from the adjacent upland fields where excessive and uncontrolled irrigation is the norm. The duration of water logging in these areas is mostly seasonal except Hanumangarh and Jaisalmer districts (Gaur and Squires, 2018a; Gaur et al., 2021).

The anthropogenic processes which include industrial effluent areas, mining, waste dumps and brick kilns extended to an area of 46843, accounting for 0.31% of total degraded land in the arid western Rajasthan. The extent of land degradation due to anthropogenic activities was worst in the districts of Jodhpur (9916 ha) and Nagaur (9347 ha) followed by Barmer (6255 ha), Pali (5914 ha), and Jaisalmer (4386 ha). Hanumangarh district has the least area (101 ha) under this class. Human activities have severely degraded common property resources of the drylands (NRSC, 2019). The main source of land degradation due to anthropogenic activities was mining, followed by brick kilns. Barmer, Jaisalmer, Jodhpur, Pali and Sikar districts are influenced by mining activities (Mandal et al., 2009) whereas Nagaur district has areas affected by industrial effluents. Brick kilns in Ganganagar and Hanumangarh districts are quite common and occupy much land (Gaur et al., 2020).

Other land degradation processes like mass movement/mass wastage, barren rocky outcrops/stony waste, and riverine sand mining were detected from remote sensing and revealed that the situation was serious in the Barmer,

Jaisalmer, Jalore, Jhunjhunun, Nagaur and Jodhpur districts. Hanumangarh (101 ha) whilst Ganganagar (736 ha) had the smallest area under this category. Barren rocky areas are regarded as degraded land having no further prospect of further change (Gaur et al., 2020).

Governance experiences of China and India's

China: Governance in China went through a number of stages after the foundation of New China in 1949. Herding systems that had endured the harsh conditions for centuries were thrown into disarray as pasture land and livestock were declared to be the property of the State. A network of large State farms incorporated herder and agro-pastoralist households into communes. With the reforms of the 1980s, the communes were abandoned and the livestock was divided up among households based on the number of members, but the land remained as the property of the State. Livestock inventories soared (a four-fold increase) and land degradation, dust and sandstorms were on the increase (Squires and Yang, 2009). A true "Tragedy of the Commons" unfolded. To remedy this, the government passed several laws (Du and Hannam, 2011). The Grassland Law was enacted in 1985 and revised in 2002. Later, the Law on Desertification was enacted. At the grassroots level, several major policies were introduced. These were designed to control grazing pressure and arrest, prevention became a key goal in a program whose aim was to arrest and reverse land degradation. Measures such as fencing and grazing bans were trialled. As tools such as remote sensing became available, regular monitoring was possible. Using time-series sets to provide trends and identify 'hot spots' allowed governments to compensate land users whose "footprint" was acceptable and allow time to follow up on miscreants whose management was abusing the land, vegetation and water. Coming up with a mutually acceptable management plan for the use of the Commons is a work in progress.

India since independence: The Thar desert has many remarkable features, one of which is the distinction of supporting the highest human population density of any desert in the world. Land use has changed dramatically in the past decades as vast new irrigation schemes and canal networks have been established (Dhir, 2018). Arable land is in short supply, and the demand for fodder/forage for the herder's flocks and herds is on the increase (Dhir, 2018) provides more detail. Various governance schemes have been tried. Much faith and support was given to the notion of Commons where land was assigned to a group to manage and control to apply principles of land stewardship and avoid the exhaustion of resources on which the flow of environmental goods and services depends. Many problems were encountered and the idea has been all but abandoned. The State is still searching for a suitable model that will protect biodiversity, curb land degradation and support livelihoods, including lifting people out of poverty.

Conclusion

Vast areas of land in both India and China suffer from land degradation, affecting remote regions that were once difficult to assess. However, the advent of Earth-monitoring

satellites like NOAA, Landsat, ResourceSat, and Sentinel has revolutionized land monitoring. These satellites provide near-global coverage and regular, high-resolution data, offering a synoptic view of land conditions. For instance, NOAA delivers low-resolution imagery every 24 hours, while Landsat orbits every 16 days, enabling detailed and frequent observations. In addition to satellite data, emerging sources like tethered balloon cameras and drones have augmented the data, allowing for more precise and localized assessments.

These advanced data collection methods have significantly improved the understanding of land capability for agriculture, pastoralism, and infrastructure planning, such as electricity transmission lines, pipelines, highways, railways, and wildlife reserves. Researchers now have access to detailed data on how land can support various uses, informing policies and land management strategies.

In both India and China, land degradation is compounded by climate change and unsustainable practices. In western China, artificial oases have been created along endorheic rivers in the northwest, while India has developed extensive canal irrigation networks to support agriculture in arid areas. However, these interventions have sometimes led to problems like secondary salinity due to inefficient irrigation, contributing to land abandonment. Overgrazing and over-cutting of fuelwood in desert margins have also accelerated rangeland degradation, particularly in nomadic pastoral regions.

Remote sensing has enabled a more comprehensive and accurate assessment of land productivity and degradation, facilitating the development of interventions, both technical and policy-based. For example, studies by Heshmati and Squires (2013) have highlighted technical solutions, while Feng et al. (2019) have focused on the role of policy and governance in managing land degradation. By combining satellite data with ground verification, these approaches ensure rapid and reliable assessments, offering valuable insights for sustainable land management in these regions. Therefore, remote sensing technology has transformed the understanding of land degradation in India and China, providing the data needed for more effective land use planning and policy interventions.

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Authors Contributions

MKG, HF and VRS: conceptualization and formulation of broad framework, VRS and HF: analysis, investigation and writing work on China; MKG: investigation, analysis, ground truthing, visualization and writing work for western Rajasthan, India specific study. MKG, HF and VRS: final writing, review and editing. All authors have read and agreed to the submitted version of the manuscript.

Availability of Data and Materials

All available and required data have been incorporated in the manuscript.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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