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Two-Decade Land Cover Transformation in Bikaner District: A Remote Sensing Analysis Using MODIS Time-Series and Google Earth Engine

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Abstract

Land Use and Land Cover Change (LUCC) changes represent some of the most visible transformations of the Earth's surface, particularly in fragile arid ecosystems. In the Bikaner district of Rajasthan, part of the Thar Desert, these changes have been accelerated by both climatic variability and significant human interventions, most notably the introduction of the Indira Gandhi Canal.

This study utilizes a multi-temporal remote sensing approach to analyze land cover transformations between 2001 and 2024. By integrating MODIS time-series data and cloud-based processing via Google Earth Engine (GEE), a supervised classification was conducted to monitor transitions across major classes, including bare land, cropland, and grassland.

The findings indicate a profound shift in the regional landscape. The analysis reveals a significant decline in bare land from 6,979.00 km² in 2001 to 2,350.22 km² in 2024. In contrast, cropland expanded substantially from 1,043.20 km² to 5,019.87 km², largely due to irrigation development. Grassland also showed a substantial gain, nearly doubling in area, though spatial analysis reveals a more fragmented and heterogeneous pattern in 2024 compared to the contiguous desert surfaces of 2001Grassland increased from 1,930.58 km² to 3,732.03 km², although spatial patterns indicate heterogeneous distribution with localized degradation.

The analysis demonstrates that while Bikaner remains a sensitive arid zone, irrigation-led development has successfully reclaimed vast tracts of barren land. These results provide a critical scientific basis for sustainable land-use planning, resource management, and climate resilience strategies in the north-western desert regions of India.

Keywords- Land Use/Cover Change (LUCC), Bikaner District, Google Earth Engine (GEE), MODIS Time-Series, Arid Ecosystem, Indira Gandhi Canal, Remote Sensing, Sustainable Land Management, Thar Desert.

1. INTRODUCTION

The Land use and cover change (LUCC) has been considered as one of the most prominent and recognizable transformations of the earth's surface. The assessment of land use cover changes at different spatial scales is important for various aspects including environmental preservation, resource management, land use planning, and sustainable development.

Bikaner is a distinguished desert district located in the north-western part of Rajasthan, forming a significant portion of the Thar Desert. The area is characterized by an arid to semi-arid climate which encompasses traits like low and erratic rainfall, high evapotranspiration, and fragile ecological conditions resulting it into highly sensitive to environmental and anthropogenic changes. Earlier the land use in Bikaner was dominated by grazing land, barren desert surfaces and limited rainfed agriculture. But eventually the introduction of irrigation through the Indira Gandhi Canal significantly transformed the landscape by enabling agricultural expansion and settlement development in previously arid zones. It has significantly altered the landscape by facilitating agricultural expansion, settlement growth, and socio-economic development in the region. These changes have not only modified the physical landscape

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but have also influenced ecological processes, biodiversity patterns, and resource utilization practices across the district.

In the span of two decades the landscape of Bikaner district has undergone under significant changes. The Remote Sensing is the eminent tool to recognize the following changes with the help of satellite data like MODIS from 2001-2024. The application of time series analysis to Land Use/ Cover Change (LUCC) dynamics from 2001 to 2024 provides a comprehensive framework to understand the spatio-temporal transformations occurring in the district. Over the past two decades, Bikaner has showed up notable changes i.e. including the expansion of built-up areas driven by urbanization and population growth, conversion of agricultural land into non-agricultural uses, degradation of forest and grazing lands, and fluctuations in water bodies influenced by climatic variability. The extensively increasing intensity of human interventions like mechanized agriculture, groundwater extraction, and infrastructural development that has accelerated land transformation processes. These changes reflect complex and often non-linear interactions between human activities and environmental conditions which makes time series analysis an essential tool for capturing long-term trends, seasonal variations, and transition dynamics.

. The land use changes in Bikaner can be interpreted through transition processes and feedback mechanisms among different land categories. Agricultural land is increasingly being converted into built-up areas due to urban expansion while grazing lands are transformed into irrigated agricultural fields under the influence of canal irrigation.

The integration of time series analysis with geospatial technologies facilitates the assessment of environmental impacts associated with land use changes, such as habitat fragmentation, biodiversity loss, soil degradation, and alterations in micro-climatic conditions. In arid regions like Bikaner, even minor shifts in land use patterns can have significant implications for ecological balance and resource sustainability. Therefore, continuous monitoring and analysis are essential for evaluating the long-term sustainability of development interventions. The insights derived from such studies can inform policy frameworks, land use planning strategies, and climate adaptation measures tailored to the unique challenges of desert ecosystems.

Overall, the study of LUCC dynamics in Bikaner district with the datasets of 2001 and 2024 using Google Earth Engine provides a robust and data-driven approach to understanding the transformation of arid landscapes under the combined influence of natural variability and human interventions. By capturing long-term temporal patterns and spatial perspective this approach contributes to a more comprehensive understanding of environmental change processes. It also supports evidence-based decision-making for sustainable land management, conservation planning, and climate resilience in arid and semi-arid regions, thereby highlighting the broader significance of integrating time series analysis with advanced geospatial platforms in contemporary environmental research.

2. STUDY AREA

Bikaner district is located in the north western part of Rajasthan, between 27°11′ to 29°03′ north latitudes and 71°54′ to 74°22 east longitudes. Its total area is approximately 30,247 sq.km., with the population of district nearly 23.67 lakh people. Fig.1 shows the location of Bikaner city. It is bordered by Sri Ganganagar district on the north, Jaisalmer district on the west, Jodhpur and Nagaur district on the south, Churu district in the east and Hanumangarh district on the north east. The district is named after Rao Bika, who founded the city. The climate here is hot, dry and receives unpredictable and low rainfall. There is no perennial or seasonal rivers flowing through the district. Three small lakes fed by the small streams flowing during the rainy season, are located in the district, two of these are freshwater lake i.e. Gajner and Kolayat lake whereas one is saltwater lake, named Lunkaransar lake.

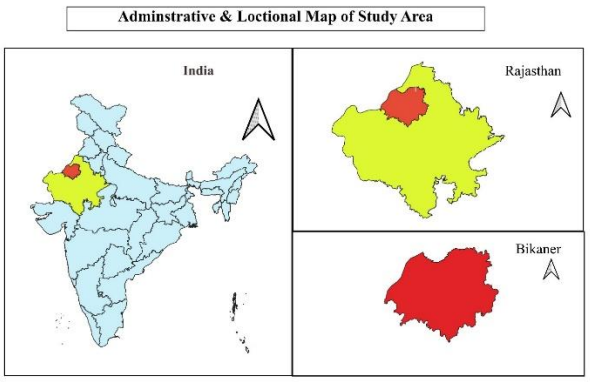

Fig.1. Administrative Boundaries and Relative Location of study area

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The district consists of eight tehsils, out of which seven are covered with desert sand and only the Kolayat tehsil situated in the southwest of the district has a few hills. Fig.2. shows the tehsil map of Bikaner district. Minerals such as gypsum, Fuellers Earth (Multani Mitti), white clay, glass sand and limestone found in the district. The study's objective is to analysis the land use and cover change over the past two decades and make an assessment for the future prediction with the GIS based approach. Urbanisation in Bikaner has accelerated over the past few decades particularly with population growth and improved connectivity. Expansion of residential areas, markets, schools, and healthcare facilities has helped the city grow as a regional centre. Improved road and rail networks have boosted connections with major cities in Rajasthan and nearby states, making trade and travel easier. The development of basic infrastructure, like electricity, water supply, and sanitation, has also raised living standards. The assessment of the study would help to facilitate with urban planning and administration in the city and also provide a thoughtful analysis of the possible environmental impacts.

Fig.2. Relief features and major transportation network of Bikaner district

3. Material &Methods

The present study adopts a geospatial approach to analyse Land Use and Cover Change dynamics in Bikaner over a multi-temporal period (2001 & 2024) by integrating satellite remote sensing data, cloud-based processing using Google Earth Engine (GEE) and Geographic Information System (GIS) techniques. The administrative boundary of the district is delineated by using standard shapefiles, after which multi-temporal satellite data from the MODIS sensor are acquired to ensure consistent temporal coverage and it also shows the high revisit frequency. The due care has been taken to minimize seasonal variability therefore imagery persisting to similar periods of the year is selected.

Pre-processing steps, including atmospheric correction, cloud masking, and temporal compositing, are carried out within GEE to generate cloud-free datasets. A supervised classification approach is then applied to categorize the study area into major LUCC classes such as bare land, grassland and cropland. The temporal trend analysis is conducted to assess patterns such as agricultural intensification, and degradation of natural land covers. The results are finally interpreted to understand the environmental implications of LUCC changes in the arid ecosystem of Bikaner which providing a scientific basis for sustainable land use planning and resource management.

3.1. Data Collection

The assessment of land use and cover change (LUCC) change in Bikaner district was carried out using multi-temporal satellite data and the main focus on MODIS imagery for the years 2001 and 2024. This study utilizes MODIS Land Cover Type product (MCD12Q1) with a spatial resolution of 500 meters for the years 2001 and 2024. MODIS data were selected due to their high temporal consistency and suitability for long-term environmental monitoring.

The region presents a challenging arid environment where large-scale, consistent datasets are essential for reliable analysis. The datasets of MODIS (Moderate Resolution Imaging Spectroradiometer) were acquired for both time periods because of their high temporal resolution and suitability for long-term environmental monitoring. The pre-processing steps i.e. data filtering, mosaicking, reprojection and atmospheric correction to ensure comparability between datasets.

A supervised classification technique was applied for LUCC change classification specifically bare land, grassland, and cropland. All these training datasets were generated through a combination of historical reference data and high-resolution imagery interpretation. The use of platforms like Google Earth Engine helped to efficient processing and analysis of MODIS time series data which is useful to enabling consistent comparison between 2001 and 2024. This methodological framework

ensured a robust evaluation of spatial and temporal changes in bare land, grassland, and cropland. It provides a reliable basis for understanding land transformation dynamics in the arid landscape of Bikaner district.

3.2. LUCC classification

A comparative analysis of land use and land cover (LUCC) in Bikaner, using MODIS satellite data for the years 2001 and 2024, shows important changes, especially in bare land, grassland, and cropland. In 2001, the area mainly featured large expanses of bare land. This reflected the dry conditions of the Thar Desert, which had little vegetation cover and scattered grassland that supported traditional herding. Cropland was limited and largely depended on rainfall. By 2024, MODIS classification indicates a clear decrease in bare land area.

This shift is mainly due to the growth of cropland and some grassland recovery in irrigated areas. Irrigation projects, particularly the Indira Gandhi Canal, have been vital in turning previously barren land into productive farmland. Grassland areas show mixed trends; some regions have degraded because of overgrazing and land conversion, while others have improved due to better water availability. Cropland has significantly expanded, reflecting increased agricultural practices and better irrigation access. These changes highlight a move from a mainly desert landscape to a more varied land use pattern. This demonstrates the changing nature of LUCC processes in Bikaner over the twenty-year period.

3.4. Goggle Earth Engine (GEE)

The use of Google Earth Engine (GEE) has emerged as a powerful approach for conducting land use and cover change (LUCC) analyses because of its ability to process large volumes of multi-temporal satellite data with efficiency and consistency. The datasets such as MODIS imagery provides continuous observations over several decades and from which GEE enables high-resolution monitoring of LUCC changes across temporal scales. To minimize seasonal variability, images from comparable time periods were selected.

The use of Google Earth Engine (GEE) offers an effective way to analyse land use and land cover (LUCC) changes in Bikaner district. Pre-processing steps were conducted within Google Earth Engine and included:

- Filtering of datasets
- Mosaicking
- Reprojection
- Cloud masking
- Temporal compositing

This analysis relies on multi-temporal satellite datasets like MODIS. In this study, we use MODIS images from 2001 and 2024 to classify and evaluate changes in key land cover categories, including bare land, grassland, and cropland. GEE's cloud-based processing can handle large-scale temporal datasets, which allows for smooth preprocessing steps such as atmospheric correction, mosaicking, and filtering. We apply supervised classification techniques and use spectral indices like NDVI to differentiate between vegetation and non-vegetation classes.

This helps us accurately identify cropland and grassland from the vast barren areas typical of arid regions. By comparing the classified outputs from 2001 and 2024, we can identify significant changes in land cover. For example, we see bare land converting to cropland due to irrigation expansion, and grassland degradation driven by human activity. Therefore, integrating MODIS time-series data in GEE helps us understand the spatio-temporal dynamics of LUCC in Bikaner. This understanding is essential for sustainable land management and environmental monitoring in desert ecosystems.

4. Results And Discussions

The research for the detection of changes in land use and cover change over the two decades for the Bikaner district with the GIS based approach shows the following results. Fig.3 illustrates the Land Use and Cover Change (LUCC) classification of Bikaner district for the years 2001 and 2024 which highlights significant spatial and temporal transformations in the region’s landscape.

The maps are categorized into major land cover classes, including open shrub, savannas, grassland, cropland, built-up areas, cropland/natural vegetation mosaic, and barren/bare land. A comparative visual analysis reveals that in 2001, the district was largely dominated by barren and open shrub land (depicted in brown and light beige tones), indicating the arid nature of the region with limited vegetation and agricultural activity. Grassland and cropland areas were relatively sparse and mainly concentrated in the eastern and southeastern parts, while built-up areas (shown in red) were minimal and confined to small urban centres.

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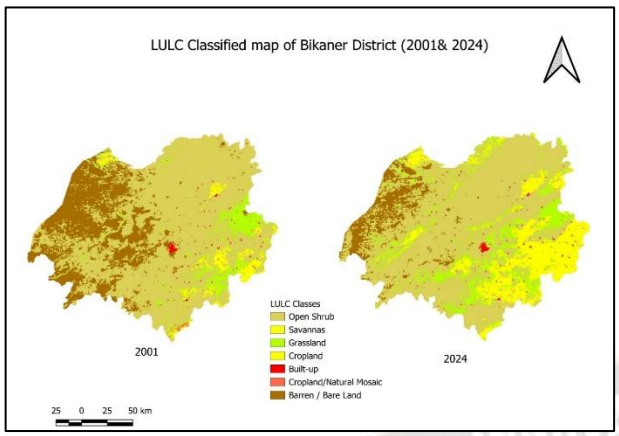


Fig.3 LUCC Classified Maps of Bikaner district (2001 & 2024)

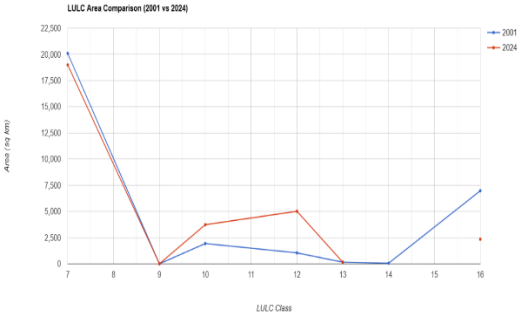
The LUCC analysis reveals significant transformation in Bikaner district between 2001 and 2024. The landscape has transitioned from predominantly barren land to a more heterogeneous system characterized by increased agricultural and vegetative cover.

Class	2001 (km²)	2024 (km²)	Change (%)
Shrubland	20092.8	18995.4	-5.45%
Grassland	1930.58	3732.03	93.30%
Cropland	1043.2	5019.87	381.00%
Built-up	155.16	158.46	2.12%
Bare land	6979	2350.22	-66.33%

Table 1: LUCC Area change in two decades of study time in Bikaner District.

The results clearly indicate a dramatic reduction in bare land and a substantial expansion of cropland, highlighting the impact of irrigation-led development.

By the year 2024, the noticeable changes can be observed in the spatial distribution of these classes. There is a clear expansion of cropland (bright yellow) and grassland (green), particularly in the eastern and canal-command regions, suggesting increased agricultural activity and improved vegetation cover. This transformation is largely attributed to irrigation development, especially from the Indira Gandhi Canal, which has enabled the conversion of previously barren land into productive agricultural zones. At the same time the extent of barren land has slightly reduced or become more fragmented indicating partial land reclamation. And the Built-up areas have also expanded compared to 2001, reflecting urban growth and infrastructural development, particularly around Bikaner city and nearby settlements.



Graph1. Graph shows changes in Various LUCC Classes in 2001 & 2024

The important observation is the increase in cropland/natural vegetation mosaic areas which indicates transitional zones where agricultural activities coexist with natural vegetation. This reflects a dynamic landscape undergoing gradual transformation rather than abrupt change. But some areas still show persistent barren and shrub-dominated land especially in the western part of the district, highlighting the continued influence of arid climatic conditions. The figure effectively demonstrates the spatio-temporal dynamics of LUCC in Bikaner over a 23-year period, showing a shift from a predominantly barren desert landscape in 2001 to a more heterogeneous land-cover pattern in 2024 with increased agricultural and vegetative presence.

4.1 **Bare Land Dynamics**

The Fig.4. compares the distribution of barren land in Bikaner district for the years 2001 and 2024, showing significant changes over time. In the 2001 map (left panel), barren land is spread widely, especially in the western and north-western areas of the district. These regions show dense and continuous patches, typical of a desert landscape with sandy surfaces, little vegetation, and minimal human activity. The central region also has scattered patches of bare land, reflecting widespread dryness and low productivity during that time. In contrast, the 2024 map (right panel) reveals a noticeable decrease and fragmentation of barren land. The dense clusters seen in 2001 have become more scattered, and the overall area of bare land appears smaller. This change is particularly clear in the central and eastern parts of the

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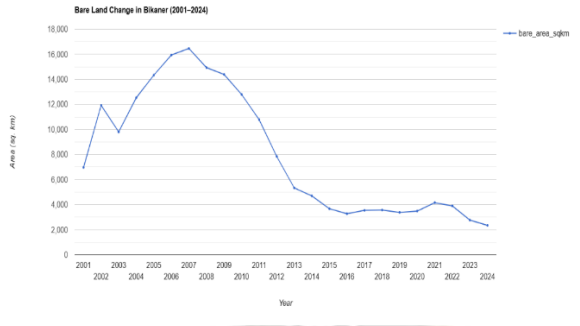
district, where barren areas have been replaced or disrupted by cropland or grassland. The western region still has higher concentrations of bare land, suggesting that extreme dry conditions remain in those areas.



Graph 1. Graph shows Changes in Bare land in between 2001 and 2024.

The decrease in barren land over the 23-year span is mainly due to increased human activities, especially irrigation development from the Indira Gandhi Canal. This development has allowed previously unproductive land to be turned into agricultural fields. Improved land management practices and the growth of vegetation have also played a role in this change. However, the ongoing presence of barren patches in some regions indicates that climatic factors, such as low rainfall and high evaporation, still hinder complete land recovery. Overall, the comparison shows a clear shift from a more continuous barren landscape in 2001 to a more reduced and fragmented pattern in 2024. This change highlights both the benefits of development efforts and the persistent challenges of managing land resources in a dry environment.

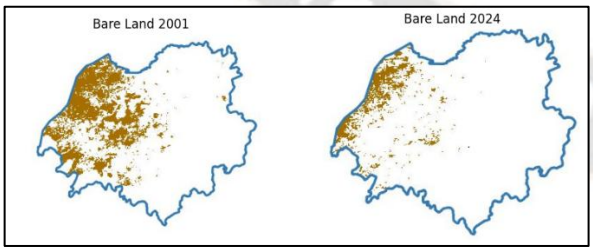


Fig.4. Changes in Bare land LUCC between 2001 & 2024 of Bikaner district

4.2. Cropland Expansion

The comparative spatial distribution of cropland in Bikaner district for the years 2001 and 2024(Fig.5.and 6) highlighting the temporal transformation of agricultural land over a period of more than two decades. In the 2001 map, cropland areas are relatively limited in extent and appear as small, scattered patches and primarily concentrated in the eastern and southeastern parts of the Bikaner district. This pattern reflects the dominance of arid conditions where agriculture was largely dependent on limited water availability and also confined to areas with relatively better soil and moisture conditions.

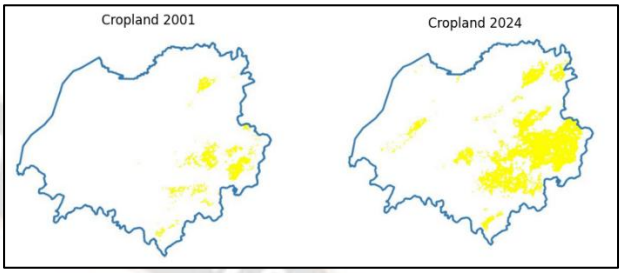


Fig.5. Changes in between Cropland LUCC 2001 & 2024 in Bikaner district

But in the contradiction of the 2001 map, the 2024 map shows a significant increase in both the extent and density of cropland. The yellow patches are more widespread and form larger, more continuous clusters mainly in the eastern, northeastern, and central parts of the district. This expansion indicates a substantial transformation of the landscape whereas previously non-cultivated or marginal lands have been brought under agricultural use. The spatial continuity of cropland in 2024 suggests improved irrigation access and intensification of agricultural activities.

The main reason for this expansion is the development of irrigation infrastructure, particularly the Indira Gandhi Canal, which has enabled water availability in an otherwise water-scarce desert region. As a result, barren and fallow lands have been converted into productive agricultural fields. Additionally, advancements in agricultural practices, increased use of technology, and policy support have contributed to the growth of cropland in the district.

Despite this expansion, the western part of Bikaner continues to show limited cropland presence in both years, indicating that extreme arid conditions and sandy terrain still restrict agricultural development in those areas. Overall, the comparison clearly demonstrates a marked increase in cropland from 2001 to 2024, reflecting the impact of irrigation, human intervention, and land development strategies in transforming the agricultural landscape of Bikaner district.

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4.3 **Grassland Dynamics**

The comparison of grassland distribution in Bikaner district between 2001 and 2024 reveals a clear and positive transformation in vegetation cover (Fig.7 and 8). In 2001, grasslands were sparse, highly fragmented, and mostly confined to small, scattered patches, particularly in the eastern and southeastern parts of the district, while large central and western areas remained largely barren, reflecting the arid conditions of the Thar Desert.

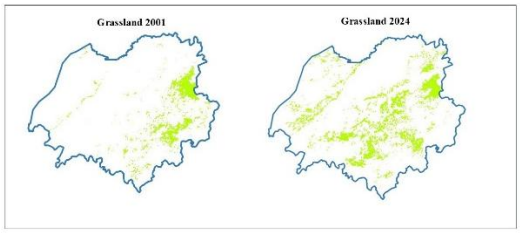

Fig.7. Grassland change between 2001 & 2024 in Bikaner district

By 2024, however, there is a marked increase in both the extent and density of grasslands, with more continuous and widespread coverage across central, southern, and eastern regions. Grassland area nearly doubled, increasing from 1,930.58 km² to 3,732.03 km². However, the dynamics reveal a dual trend:

- Expansion in irrigated regions
- Degradation in overgrazed areas

This indicates spatial heterogeneity in ecological responses and reflects the combined influence of natural and anthropogenic factors.

The fragmentation observed earlier has reduced significantly, and many isolated patches appear to have expanded and merged into larger clusters. This improvement may be attributed to factors such as better rainfall patterns, enhanced land management practices, afforestation efforts, and the influence of irrigation systems like the Indira Gandhi Canal. Overall, the change indicates a substantial ecological recovery, contributing to improved soil stability, increased grazing potential, and reduced risk of desertification in the region.

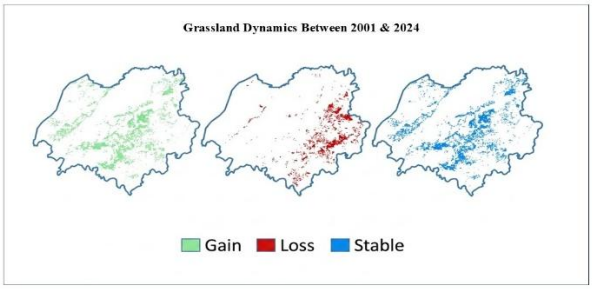

Fig.8. Grassland Dynamics between 2001 & 2024 in Bikaner district

The grassland dynamics between 2001 and 2024 indicate significant conversion of grassland into non-vegetated and agricultural land, suggesting increasing anthropogenic pressure and land degradation in the Bikaner district.

5. Conclusion

The two-decade assessment of Bikaner District (2001–2024) underscores a remarkable transition from a predominantly barren desert landscape to a more heterogeneous land-use pattern. By leveraging the computational power of Google Earth Engine and the temporal depth of MODIS data, this study successfully mapped the spatial footprints of human intervention and natural variability.

The most transformative factor identified is the expansion of the Indira Gandhi Canal, which acted as a catalyst for agricultural intensification. This is evidenced by the massive conversion of unproductive bare land into productive cropland, particularly in the central and eastern tehsils. Furthermore, the increase in grassland density suggests a degree of ecological recovery and improved soil stability, though the coexistence of "loss" and "gain" in vegetation classes highlights ongoing pressures from overgrazing and urban sprawl.

However, the persistence of bare land in the western regions serves as a reminder of the district's inherent climatic constraints, such as low rainfall and high evapotranspiration. The study concludes that while the greening of Bikaner marks a socio-economic milestone, it necessitates cautious resource management to prevent long-term soil degradation and groundwater depletion. The methodologies and findings presented here provide vital baseline data for policymakers to balance

developmental goals with the preservation of the Thar Desert's unique ecological integrity.

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