CE 299 Project Course

Evaluating the Impact of Canal Irrigation on Agricultural Command Areas in India

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ABSTRACT

India, with a large agrarian population, depends heavily on irrigation for food production and economic stability. This project evaluates the effectiveness of canal irrigation systems in transforming agricultural productivity and greening patterns across command areas. Using remote sensing data (NDVI, LAI, LULC, CHIRPS rainfall) and geospatial analysis through Google Earth Engine (GEE), the study investigates vegetation changes before and after canal implementation. Major canals such as the Indira Gandhi Canal, Narmada Canal, and Upper Ganga Canal are analysed to understand their influence under changing climatic conditions and rising resource demand. These results provide extensive information for improving irrigation management and planning sustainable agriculture in canal-fed areas.

INTRODUCTION

India's agriculture sector employs the largest share of the workforce, as shown in Figure 1, with irrigation being its backbone. Canal irrigation, especially after the Green Revolution, has significantly enhanced agricultural productivity. With increasing population and urbanisation, there is a growing demand for food and water. As seen in Figure 2, agricultural productivity in Punjab saw a sharp rise after the mid-1960s, surpassing the national average following the introduction of high-yield seeds and better irrigation techniques. However, the impact was region-specific and did not benefit all farmers equally across India. Canal irrigation projects like the Indira Gandhi Canal and Narmada Canal have played a transformative role in ensuring water supply to arid and semi-arid regions. This project aims to study how such canal networks have influenced land cover, vegetation growth, and water usage patterns using satellite data and remote sensing techniques.

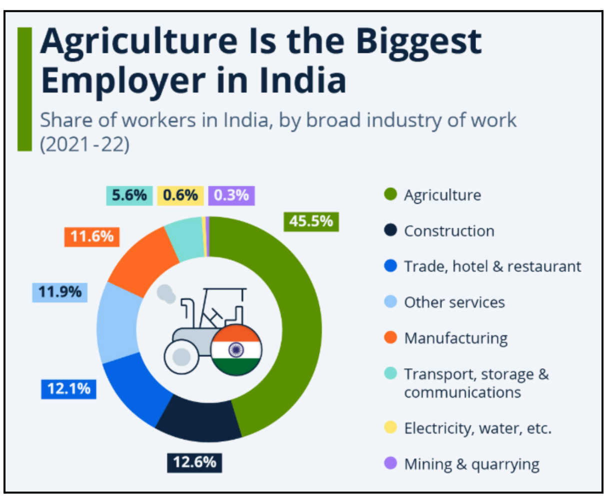

Figure 1: Share of workers in India

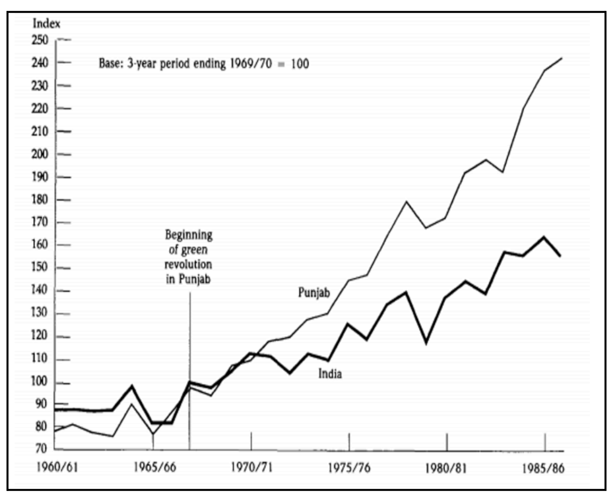

Figure 2: Green Revolution in India

OBJECTIVES

- Evaluate the spatial and temporal changes in vegetation and rainfall within canal command areas.
- Assess the effectiveness of major canal systems in improving agricultural productivity.
- Identify trends and challenges in water supply and demand under changing climatic conditions.

Data Used in this study

Table 1: Different Sources and Satellites used

Data	Source	Spatial Resolution	Temporal Resolution
Rainfall	CHIRPS	5.56 km	Daily (2000-2023)
NDVI	MODIS	250 m	Every 16 days (2000-2023)
LULC	MODIS	250 m	Every 16 days (2000-2023)
LAI	MODIS	250 m	Every 16 days (2000-2023)
NDVI_Spatial	COPERNICUS	10 m	Every 5 days

We used satellite data in Google Earth Engine to see how canals help agriculture in different parts of India. The data showed us things like rainfall, vegetation, and land use over time (from the year 2000 to 2023).

- Rainfall data came from CHIRPS. It gave daily rainfall information across large areas (5.56 km resolution).
- Vegetation was checked using NDVI and LAI from MODIS. These told us how green the land is. The data comes every 16 days and covers areas of 250 meters.
- Land use data also came from MODIS. It showed how the land is being used — for farming, forest, or buildings.
- We also used the COPERNICUS NDVI data, which is very detailed (10 meters). It gave vegetation data every 5 days and helped us look closely at the canal areas.

These datasets helped us understand how canals improve agriculture and vegetation in the areas they cover.

Major Canals in India

Canal	Length (km)	Capacity (cusecs)	Command Area (million Ha)	States Covered
Narmada Main Canal	532	40,000	2.128	Gujarat, Rajasthan
Indira Gandhi Canal	650	18,500	1.96	Rajasthan, Punjab and Haryana
Buckingham Canal	796	5,600	0.81	Tamil Nadu and Andhra Pradesh
Tungabhadra Canal	226	6,992	0.65	Karnataka and Andhra Pradesh
Upper Ganga Canal	291	13,066	0.88	Uttarpradesh
Lower Bhavani Canal	201	2,260	0.83	Tamil Nadu
Sutlej Canal	214	10,500	3.5	Punjab, Haryana and Rajasthan
Sirhind Canal	240	12,620	1.42	Punjab
Sharda Canal	44	11,500	1.612	UttarPradesh

Figure 3: Nine Major Canals of India

These nine significant canals were chosen because they reflect India's several geographical regions, agroclimatic zones and irrigation capacities. The length, discharge capacity and command area of each canal vary, providing a thorough understanding of the effects of canal irrigation on agriculture in both water-rich and water-scarce areas. We can investigate the connection between canal infrastructure, vegetation patterns, and climate variability on a national level because these canals together cover the northern, western, southern, and central regions of the nation.

METHODOLOGY

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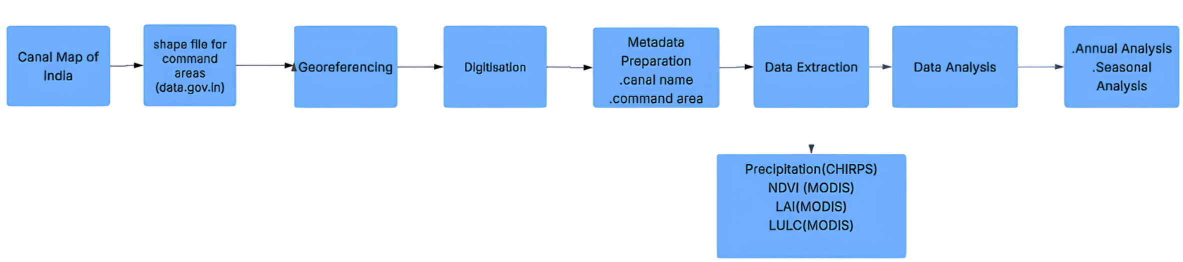
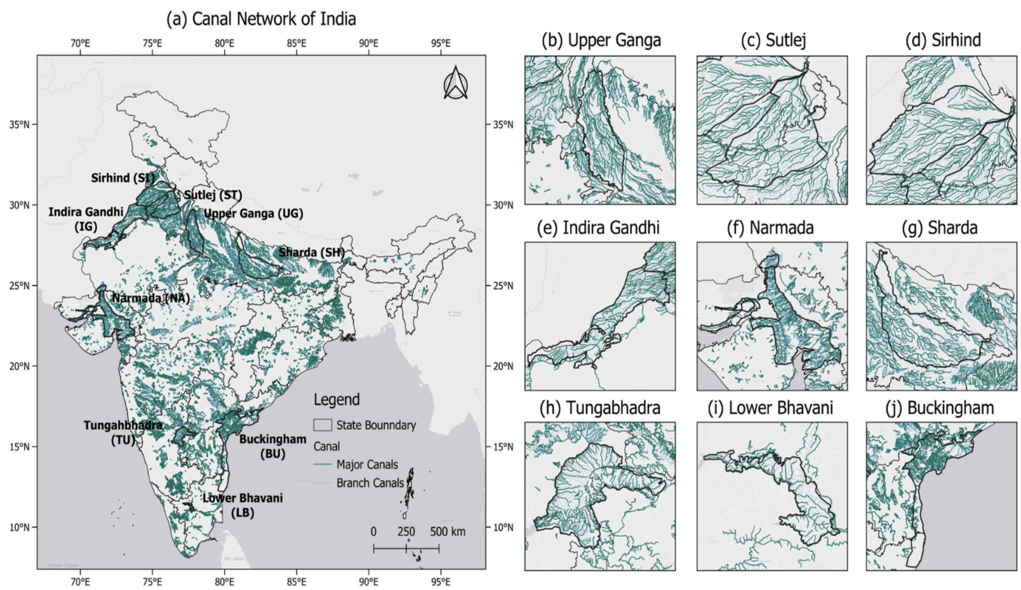


Figure 4: Methodological Workflow for Canal Irrigation Impact Assessment

The study began with acquiring the canal map of India and the corresponding shapefiles for canal command areas from data.gov.in. These shapefiles were georeferenced to align them accurately with real-world coordinates, followed by the digitisation of command areas to create vector layers. Details such as the names of the canals and the size of each command area are included in the metadata that was created. Relevant datasets, such as vegetation indices like NDVI, LAI, and LULC from the MODIS satellite and precipitation data from CHIRPS, were extracted using this spatial framework. After that, these datasets were examined to evaluate temporal and spatial differences within the command areas.Finally, both annual and seasonal analyses were carried out to evaluate trends and changes in vegetation, land use, and climatic patterns across the study region.

Canal Network of India



Canal Network of India: Major Irrigation Canals and Their Branches

Figure 5: Command areas for major canals of India

The map shows the geographical distribution of India's main canal networks and the branch canals that connect them. The command areas that gain from these irrigation networks are indicated by the highlighted areas. The Upper Ganga, Sutlej, Sirhind, Indira Gandhi, Narmada, Sharda, Tungabhadra, Lower Bhavani, and Buckingham are among the nine major canals that have been chosen for inclusion. This map effectively illustrates how these canals are dispersed throughout the several states, giving various agricultural zones essential irrigation support. It emphasises how crucial canal infrastructure is for enhancing agricultural productivity.

Increasing Pressure on Agricultural Resources due to Urban Expansion

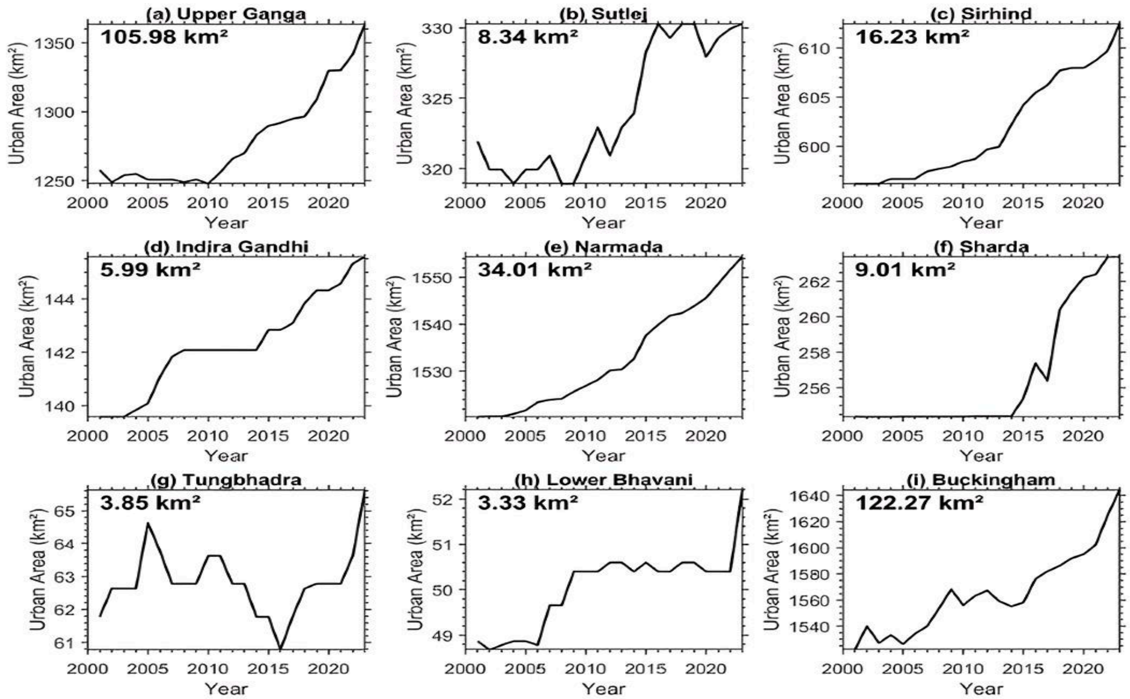


Figure 6: Urbanisation and Growing Demand

The urban area growth over time in areas supplied by nine major canals in India is depicted in the graphs above. The demand for basic resources like food and water is rising quickly along with urbanisation, which is being driven by population growth, infrastructural development, and economic growth. Here, a distinct trend can be seen: urban areas have grown considerably in places with canal systems. This suggests that by ensuring water security for household, industrial, and agricultural demands, the availability of water through canals promotes urban growth in addition to supporting agriculture. The need for continued agricultural work to secure food supply is growing as the urban population rises.Canals play an even more important function because irrigation is a major component of agriculture, particularly in areas with limited water resources. As a result, the need for canal water is indirectly increased by growing urbanisation, which emphasises how crucial it is to preserve and improve canal irrigation systems in these areas.

However, it is important to note that agriculture may not be completely dependent on canals alone. While canals play a significant role in irrigation, especially in regions where surface water is easily accessible, groundwater and wells also contribute significantly to agricultural water supply. Farmers in many places use groundwater as an alternative to canal water, particularly in dry seasons or when canal systems aren't working well. Furthermore, the construction of borewells and tubewells has made it possible to irrigate areas outside the reach of canal systems, offering a more adaptable and often more consistent supply of water.

Impact of Rainfall and Vegetation Dynamics on Water Availability

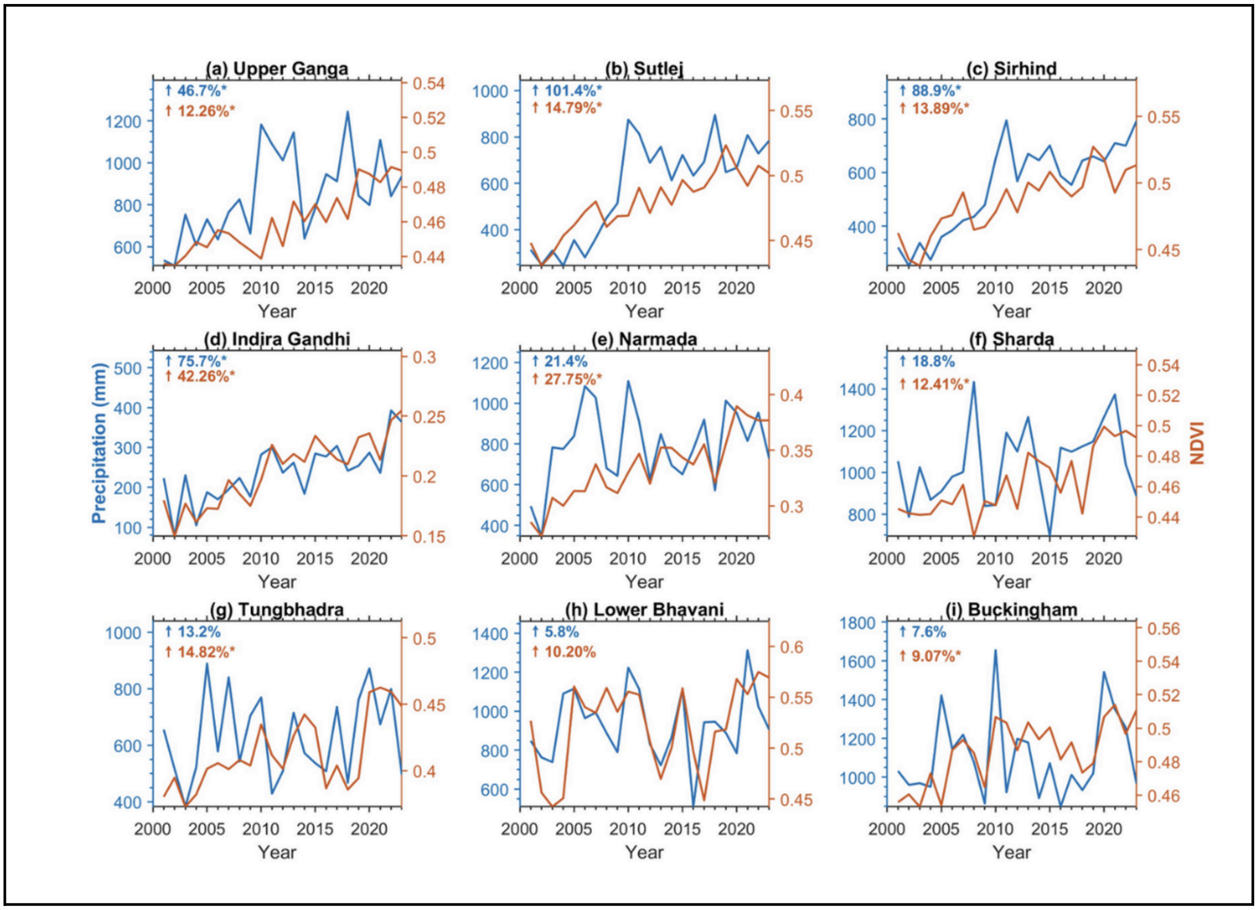


Figure 7: Precipitation and NDVI trend of Canals

Climate variability determines the performance and sustainability of canal systems. The graphs shown above illustrate the trends in annual rainfall (blue) and Normalised Difference Vegetation Index (NDVI, in orange) across nine major canal command areas from 2000 to 2022. NDVI is a satellite-derived index that measures the density and health of green vegetation, with values ranging from -1 to +1 – where values closer to +1 indicate dense, healthy vegetation, and values near or below 0 represent barren land, water bodies, or non-vegetated surfaces.

In most regions, there is a positive correlation between rainfall and NDVI, suggesting that increased water availability contributes to improved vegetation health. For instance, regions like Upper Ganga and Narmada show clear upward trends in both variables. Notably, the Indira Gandhi Canal region shows a remarkable +75.7% increase in precipitation and a +42.26% rise in NDVI, indicating substantial greening in this arid zone. This could be attributed to effective canal irrigation and increased cropping intensity, though it also raises concerns about potential over-dependence on irrigation in water-scarce areas.

These variations suggest that canal command areas are experiencing non-uniform climatic shifts, impacting both supply-side (rainfall) and demand-side (vegetation/crop water needs) dynamics. Understanding these dual trends is vital for designing resilient irrigation strategies that respond to climate change while ensuring optimal water distribution across agricultural zones.

RESULTS

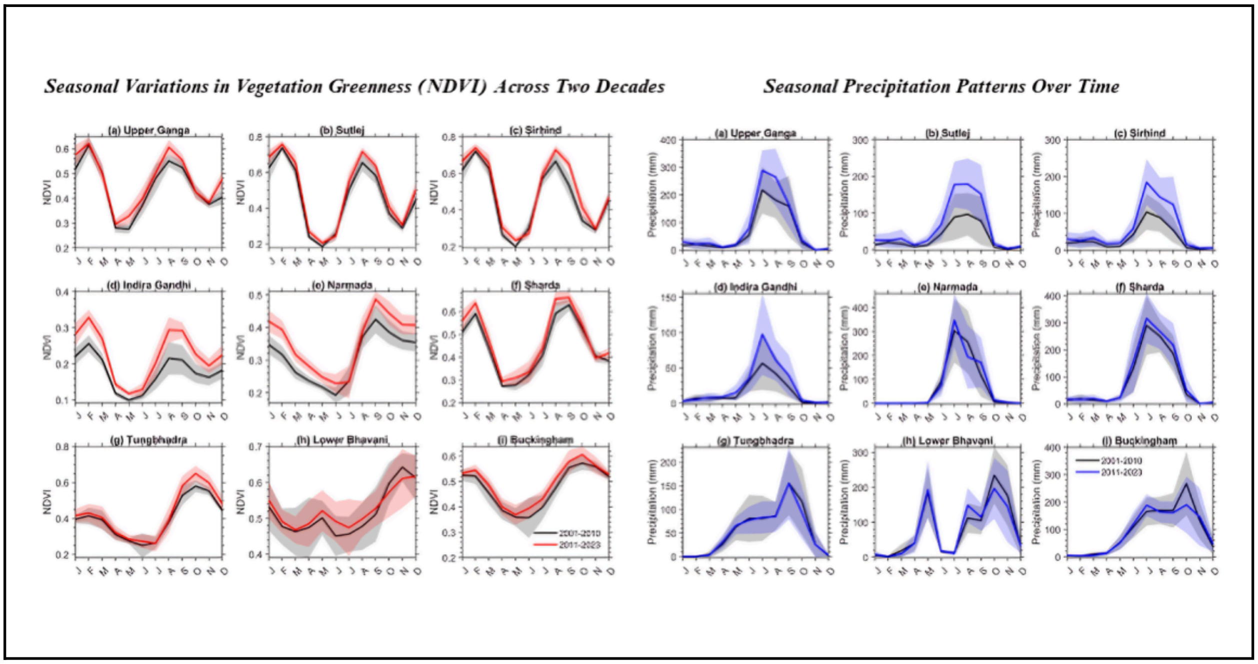


Figure 7:Seasonal Variations in Vegetation Greenness (NDVI) Across Two Decades and Seasonal Precipitation Patterns Over Time

The image clearly displays seasonal variations in vegetation greenness (NDVI) alongside precipitation patterns across nine different regions over two decades (2001-2010 and 2011-2020). The data reveals several important insights about regional vegetation dynamics and water utilization patterns.

Seasonal Vegetation Patterns and Rainfall Dependency:
The NDVI plots show distinct seasonal patterns with prominent peaks during the JJAS (June-July-August-September) months, directly correlating with the monsoon precipitation patterns 1. This confirms the expected relationship between rainfall and vegetation productivity during the monsoon season across all studied regions.

Evidence of Irrigation Influence on Vegetation:
We observed NDVI peaks during non-monsoon months when precipitation is minimal. This trend is especially noticeable in the Indira Gandhi Canal and the Narmada. These out-of-season vegetation peaks clearly imply that irrigation is supported by groundwater extraction or canal irrigation.

Decadal Changes in Vegetation Patterns:
The comparison between the two decades (2001-2010 and 2011-2020) reveals significant changes in vegetation patterns:

- In the Indira Gandhi Canal region, there are visible differences in NDVI values between the two decades, with generally higher values in the more recent decade during certain seasons. This aligns with your observation about increased groundwater utilization in this region.
- The Narmada command area also shows temporal changes between decades, particularly in the intensity and timing of NDVI peaks. The pattern suggests a stronger relationship with canal water availability rather than precipitation alone.

Regional Differences in Water Source Utilization:
The contrasting patterns between regions highlight different water management approaches:

- The Indira Gandhi Canal area shows NDVI patterns that don't perfectly match precipitation curves, supporting your assessment that groundwater is the predominant source for vegetation support.
- In contrast, the Narmada region's NDVI patterns suggest a stronger dependency on canal irrigation, with vegetation patterns potentially following canal water release schedules rather than natural precipitation alone.

This analysis shows how NDVI data helps us understand the relationship between rainfall patterns and how people manage water – like through canals and irrigation – offering useful insights into how farming practices have changed and adapted over time in different regions.

Greening Trends Across Major Irrigation Command Areas

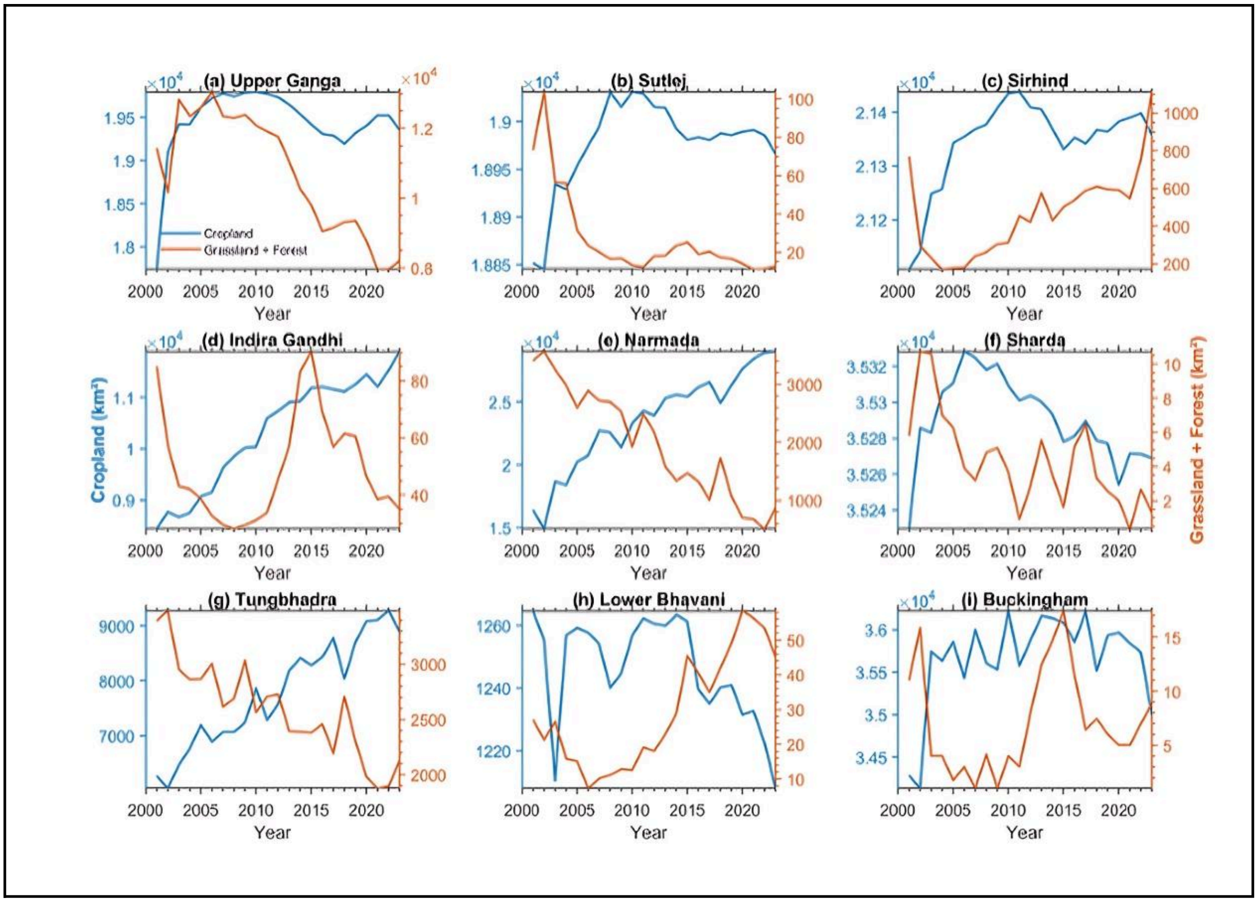


Figure 8:Analysis of forest cover and cropland extent reveals land use changes contributing to increased vegetation (greening) across regions.

Figure 8 shows land use dynamics in nine canal command areas, highlighting the trends in cropland (blue) and grassland + forest areas (orange) from 2000 to 2022. In many regions, an increase in cropland area is accompanied by a corresponding decrease in grasslands and forests, suggesting possible conversion of natural land covers to agricultural land, likely enabled by the expansion of canal irrigation. For example, in the Narmada region, a clear decline in grassland and forest cover alongside a sharp increase in cropland area aligns with the development of the Narmada Canal system, indicating direct land use change due to improved irrigation access.

However, not all regions follow this pattern. In some cases, cropland and grassland/forest areas both show increasing trends, which could imply that irrigation expansion was supported by existing canals, groundwater extraction, or diversified water sources, rather than converting forested areas. Such patterns may indicate more balanced land use expansion, or effective water management practices in those regions.

These contrasting trends reflect the varied impacts of canal development across regions, influenced by local geography, pre-existing land use, and reliance on different water sources. A deeper analysis combining satellite data and ground-level irrigation records would help better understand these land use transitions.

CONCLUSION

The transformative impact of canal irrigation on agricultural command areas across India. Through geospatial and remote sensing analysis using satellite-derived datasets (NDVI, LAI, LULC, and CHIRPS rainfall), we assessed vegetation dynamics, land use changes, and water availability patterns in nine major canal systems.

Our findings indicate that canal irrigation significantly enhances vegetation cover, especially in arid and semi-arid regions like those under the Indira Gandhi and Narmada Canals. Notable increases in NDVI and cropland extent across several command areas reflect the effectiveness of these systems in sustaining agricultural productivity.

However, the analysis also reveals regional disparities in rainfall trends, suggesting that some regions, while experiencing greening, may be becoming more dependent on canal and groundwater resources – raising concerns about long-term water sustainability. For example, areas like the Indira Gandhi Canal region showed increased NDVI despite declining rainfall, highlighting potential over-reliance on supplemental irrigation.

Additionally, urban expansion near canal - fed regions is placing additional pressure on water resources, demanding better allocation strategies to balance agricultural, domestic, and industrial needs.

In conclusion, while canal irrigation continues to be a cornerstone of India's agricultural strategy, its future success will depend on sustainable water management, climate-resilient planning, and adaptive land use policies. Integrating satellite monitoring tools with irrigation planning can play a vital role in ensuring food security, resource sustainability, and ecological balance across India's diverse agro-climatic zones.