Assessing the Impact of MGNREGA on Cold Desert Agriculture Using Geospatial and Agro-Economic Indices: A Case Study of Saboo, Ladakh

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Abstract: The Union Territory of Ladakh, located in the Western Himalayan agro-climatic zone, represents an ecologically sensitive cold desert environment characterised by low precipitation, limited arable land, and a short growing season. Agricultural production in this region is highly dependent on efficient land and water resource management, primarily supported by glacial meltwater irrigation. In this context, the present study evaluates the role of the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in improving land-use efficiency, water resource management, and agricultural sustainability in Saboo Gram Panchayat, Leh district, using 2017 as the base year and 2024 as the assessment year. To carry out this study, a mixed-methods approach was adopted, integrating remote sensing, GIS analysis, and field-based agro-economic metrics. High-resolution satellite datasets, including Cartosat-3 and Resourcesat-2 (LISS-IV), were used to generate Land Cover/Land Use (LCLU) maps, while Sentinel-2 imagery was used to derive spectral indices such as the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Moisture Index (NDMI). These datasets were integrated with 317 geo-tagged MGNREGA interventions, including irrigation channels, farm ponds, and land development works. Agro-economic indicators such as the Cultivable Land Utilisation Index (CLUI) and Wheat Equivalent Yield (WEY), along with community survey data, were used to assess comprehensive spatio-temporal changes in the study area. The results show a significant improvement in the utilisation of land and water resources. Between 2017 and 2024, agricultural land increased by 15.22%, while water bodies expanded by 36.44%. Positive trends in NDVI and NDMI suggest improvements in vegetation health and soil moisture conditions in areas associated with MGNREGA interventions. The CLUI increased from 0.456 to 0.497, and WEY increased from 14.15 t/ha to 26.12 t/ha respectively, indicating enhanced cropping intensity and agricultural productivity by shifting towards high-value crops, like vegetables and hardwood species in horticulture produce. Community responses further support these findings, highlighting improved irrigation access, increased crop yields, and stronger participation in local planning processes; these reveal that MGNREGA benefits are both measurable and experienced at the community level. Overall, the study demonstrates that the integration of geospatial monitoring with community-driven rural developmental programmes such as MGNREGA can support sustainable agriculture in high-altitude, climate-sensitive environments. The findings provide a replicable framework for evidence-based rural development and natural resource management in similar ecosystems.

Keywords: Land Use Change; NDVI; Rural Development; Agricultural Productivity; High-Altitude Ecology; Natural Resource Management.

1. Introduction

The Union Territory of Ladakh, located in the Western Himalayan agro-climatic zone, represents a high-altitude cold desert environment characterised by low precipitation, limited cultivable land, and a short crop-growing season. Much of the region lies above 3,000 meters, where extreme climatic conditions significantly constrain agricultural productivity. In such environments, agriculture is heavily dependent on glacial meltwater for irrigation, and the efficient management of land and water resources is essential to sustain rural livelihoods.

Saboo Gram Panchayat, situated approximately 6 km from Leh town at elevations ranging from 3,500 to 3,745 meters, exemplifies these challenges. Agriculture in this region has traditionally relied on crops such as barley (grim), wheat, peas, and lucerne. The cultivable area is seen only in the valley region, along the terraced lining. Irrigation is primarily supported through traditional glacier-fed channels, locally known as kuhls or zings, reflecting a close interdependence between natural resource management and community-based practices (Singh, N., 1995, 1997; Tiwari et al., 2015; Michaud, 1991a). These indigenous systems have historically enabled communities to maintain a functional balance between agricultural production and environmental constraints.

In recent years, however, the agricultural landscape of Saboo has undergone notable changes driven by the presence of defence establishments, increasing integration with external markets, and the rapid growth of tourism, which have created new economic opportunities in the region. These developments have encouraged a transition toward mechanised farming practices and the cultivation of high-value crops, particularly vegetables and horticultural produce (Michaud, 1991b; Singh, H., 1997). While these changes have contributed to increased household incomes, they have also intensified pressure on limited irrigation resources and other natural systems. In

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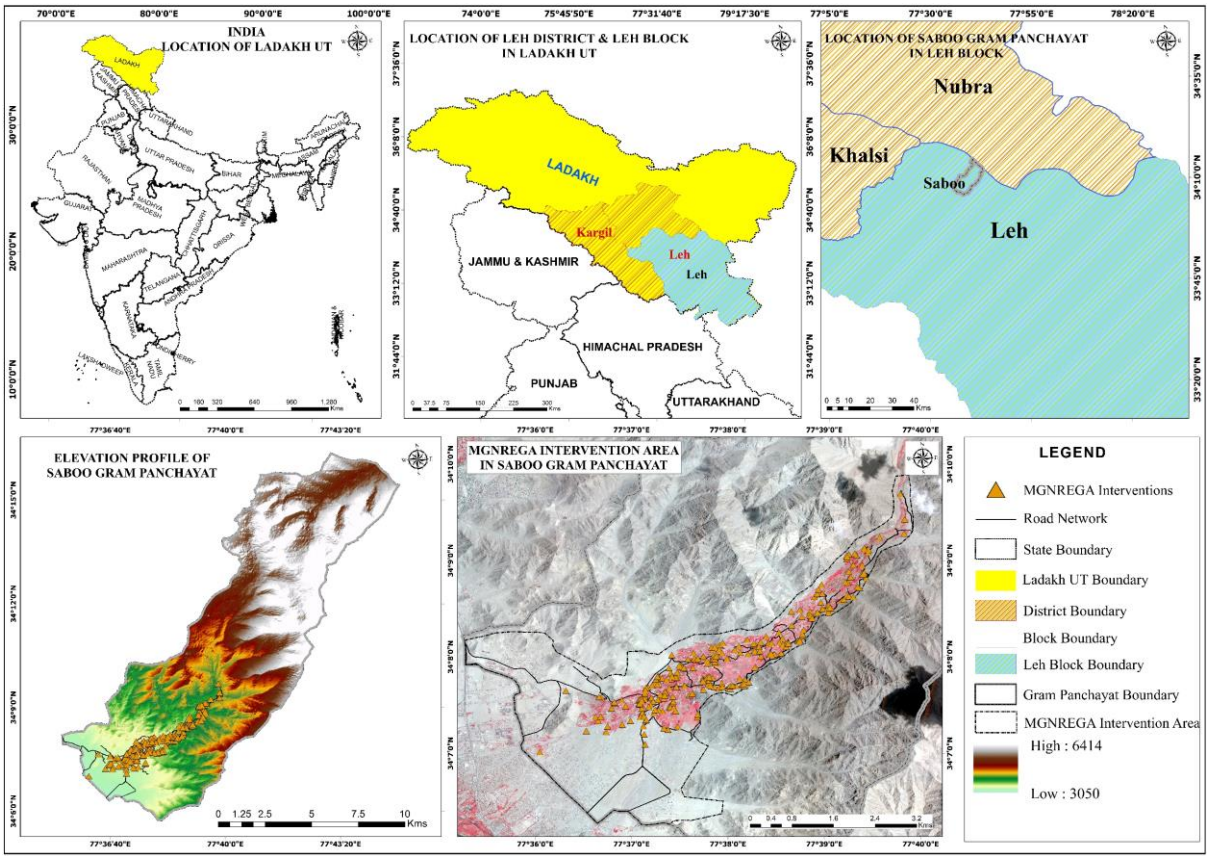


Figure 1: Study area map of Saboo Gram Panchayat in Leh District, Ladakh (UT)

this context, the growing demand for land and water resources underscores the need for sustainable land-use planning, improved water management, and ecologically informed development strategies in high-altitude environments.

The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), introduced in 2005, has become increasingly important in this context. Although the programme was originally designed to provide up to 100 days of wage employment to rural households (MoRD, 2022), it has progressively contributed to the creation of durable natural resource management assets, including irrigation channels, water harvesting structures, land development works, and afforestation initiatives. In regions such as Ladakh, where ecological constraints are pronounced, these interventions have the potential to enhance agricultural productivity, strengthen climate resilience, and support sustainable livelihoods (Carswell et al., 2014; Ravindar, K., 2016). At the national level, these activities constitute a significant proportion of MGNREGA works, accounting for approximately 55-68% of total interventions in recent years (IEG, 2019; Patwardhan, 2023)

Previous studies across India have demonstrated the positive role of MGNREGA in improving natural resource management and rural livelihoods (Reddy, V. R., et al., 2017; Singh, R., & Gupta, 2020; Kumar et al., 2021). However, research on high-altitude cold deserts remains limited. These regions are ecologically distinct due to their short growing seasons, limited cultivable land, and high dependence on climate-sensitive water sources. Assessing development outcomes in such contexts requires an integrated approach that combines geospatial analysis, agro-economic indicators, and community-level insights.

Agro-economic indicators such as the Cultivable Land Utilisation Index (CLUI) (Maji et al., 2010a) and Wheat Equivalent Yield (WEY) (Choudhary et al., 2014) provide useful measures of land-use efficiency and agricultural productivity. These indicators are particularly relevant in regions with single cropping seasons, where maximising land utilisation is critical. At the same time, advances in geospatial technologies enable detailed monitoring of changes and ecological conditions. High-resolution satellite datasets from the Cartosat, Resourcesat, and Sentinel-2 platforms facilitate mapping of land cover/land use (LCLU) and the assessment of vegetation health and moisture dynamics using indices such as the Normalised Difference Vegetation Index (NDVI) and the Normalised Difference Moisture Index (NDMI).

Despite these advancements, there remains a lack of comprehensive studies that integrate geospatial data, agro-economic metrics, and field-based observations to evaluate the impacts of interventions taken up under MGNREGA in cold desert ecosystems. This gap limits our understanding of how rural employment programmes contribute to agricultural transformation and environmental sustainability in fragile mountain regions.

In this context, the present study aims to assess the impact of MGNREGA interventions in Saboo Gram Panchayat between 2017 and 2024 by integrating LCLU analysis, spectral indices (NDVI and NDMI), agro-economic indicators (CLUI and WEY), and community-level insights. By combining these approaches, the study

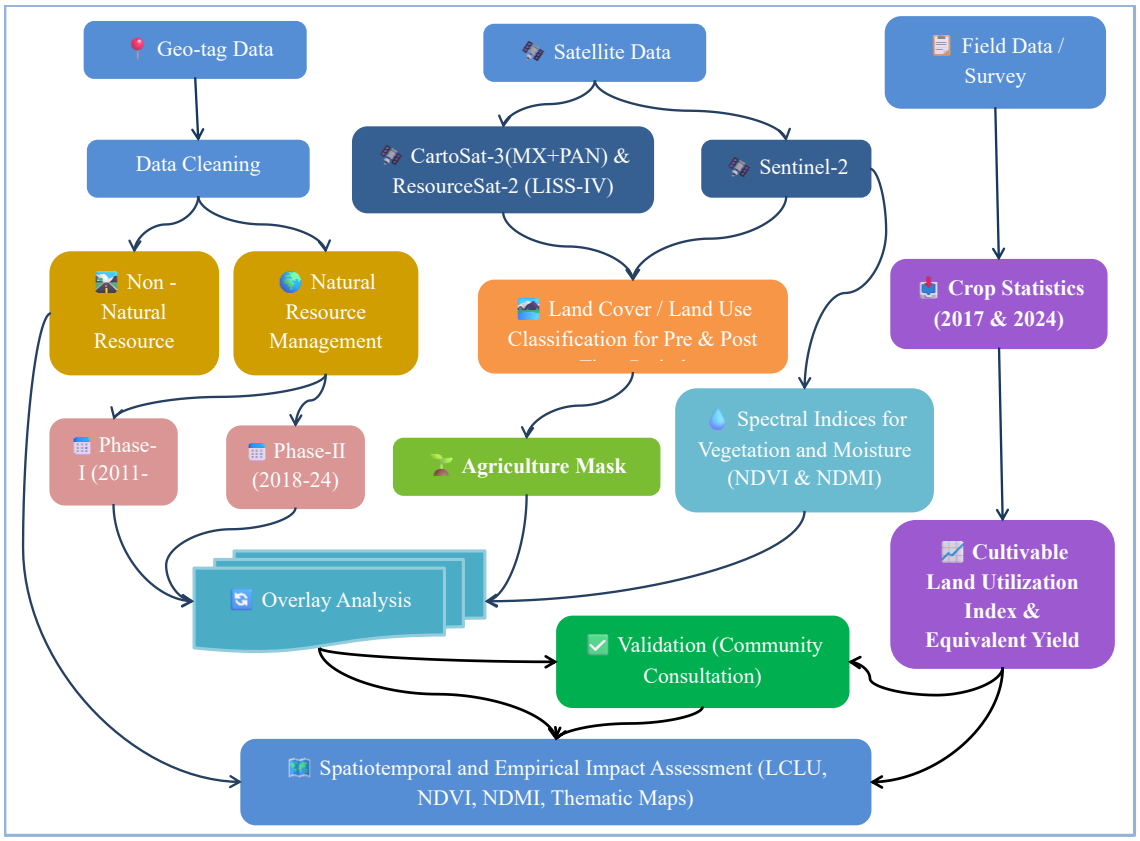


Figure 2: Methodology used in the study

provides a holistic assessment of changes in land use, water availability, and agricultural productivity.

This study contributes to the existing literature by offering an integrated framework that combines geospatial techniques, agro-economic analysis, and participatory data to evaluate rural development programmes in a cold desert environment. The findings aim to support evidence-based planning and provide insights for replicating similar interventions in other ecologically sensitive and climate-constrained regions.

2. Study Area

The Union Territory of Ladakh, located in the Western Himalayan agro-climatic zone, bounds the Saboo Gram Panchayat in Leh Block of Leh district, India. The study area lies between 34°05′30″N–34°06′30″N latitude and 77°35′30″E–77°45′20″E longitude (Figure 1). The administrative extent of the Gram Panchayat covers approximately 11,128 hectares (111.28 km²), of which only about 1,228 hectares (12.28 km²) are suitable for habitation and agriculture. The remaining area is largely characterised by rough terrain, snow-covered slopes, and high-altitude barren landscapes. Elevation in the region ranges from 3,305 to 5,543 meters above mean sea level.

The inhabited areas of Saboo are located at an average elevation of approximately 3,500 meters and experience a cold desert climate marked by low precipitation and extreme temperature variations. Temperatures range from about −18°C in winter (December) to around 14°C in summer (August), with an average annual rainfall of approximately 35 mm. The short crop-growing season, typically extending from April to October, imposes significant constraints on agricultural activities.

Settlement patterns in Saboo vary from nucleated clusters to dispersed hamlets along valley floors, where relatively gentle slopes and access to water support habitation. Agriculture is primarily confined to these valley regions and is sustained through traditional glacier-fed irrigation systems. Cultivation is practised on terraced fields using gravity-fed channels (kuhls or zings), which represent long-standing community-managed water distribution systems.

The Saboo Gram Panchayat has a population of approximately 1,233 residents (609 males and 624 females) residing in 259 households, with a predominance of Scheduled Tribe communities. The cultivated area covers nearly 186 hectares and supports crops such as wheat, barley, pulses (including peas), and vegetables. In recent years, horticultural plantations have emerged as an economically viable alternative, contributing to the diversification of the local agricultural system.

The region has also witnessed the implementation of multiple activities under the MGNREGA program, including land development, water harvesting structures, and the renovation of irrigation channels. These interventions have contributed to improvements in irrigation infrastructure, expansion of cultivable land, and strengthening of rural infrastructure through the development of roads, pathways, and community assets.

3. Methodology

A mixed-method approach was adopted, integrating remote sensing, Geographic Information Systems (GIS), and field-based agro-economic metrics to assess land-use dynamics, agricultural performance, and the role of MGNREGA interventions in Saboo Gram Panchayat (Figure 2).

3.1 Data Collection and Pre-processing

Satellite Data: Multi-temporal satellite datasets from Cartosat-3 (MX+PAN; 0.6 m spatial resolution) and Resourcesat-2 (LISS-IV; 5.8 m spatial resolution) were acquired for the years 2017 and 2024 from the NRSC Bhoonidhi portal (https://bhoonidhi.nrsc.gov.in/bhoonidhi/index.html). These datasets were used for detailed Land Cover/Land Use (LCLU) mapping. Sentinel-2 multispectral data were obtained from the Copernicus Open Access Hub (https://www.copernicus.eu/en) for the peak cropping season (May–September) of 2017 and 2024 years to ensure temporal consistency in vegetation and moisture analysis.

Pre-processing steps included geometric correction, radiometric calibration, and layer stacking. False colour composites and image enhancement techniques were applied to improve visual interpretation and classification accuracy.

3.2 LCLU Classification and Accuracy Assessment

LCLU maps were generated using a combination of visual interpretation and supervised classification techniques. The classification followed the hierarchical scheme developed by the National Remote Sensing Centre, which enables multi-level categorisation for detailed mapping using high-resolution imagery (NRSC, 2019). The classification included categories such as agriculture, barren land, settlements, water bodies, and glacier/snow cover.

The NRSC classification framework is widely used in national-scale LCLU mapping and is based on hierarchical classification principles that allow detailed representation of land-use classes (Roy et al., 2015; Reddy et al., 2015).

Accuracy assessment was conducted using ground-truth data collected during field surveys and high-resolution reference imagery. A set of validation samples was used to generate a confusion matrix, resulting in an overall classification accuracy of 96%, indicating high reliability of the classification results.

3.3 Spectral Indices for Vegetation and Moisture Analysis

3.3.1 Normalised Difference Vegetation Index (NDVI)

The Normalised Difference Vegetation Index (NDVI) was used to assess vegetation health and greenness (Rouse et al., 1974). NDVI is calculated as:

$$NDVI = \frac{(NIR-R)}{(NIR+R)} \quad \text{Eq: 1}$$

Where:
NIR = Near Infrared (Sentinel-2 Band 8 - 842 nm)
R = Red Band (Sentinel-2 Band 4 - 665 nm)

NDVI is widely used as an indicator of vegetation dynamics across diverse ecosystems, including mountainous environments (Pettorelli et al., 2005).

3.3.2 Normalised Difference Moisture Index (NDMI)

To assess moisture conditions, the Normalised Difference Moisture Index (NDMI) was employed. NDMI is calculated using near-infrared (NIR) and shortwave infrared (SWIR) bands as:

$$NDMI = \frac{(NIR-SWIR)}{(NIR+SWIR)} \quad \text{Eq: 2}$$

Where:
NIR = Near Infrared (Sentinel-2 Band 8 - 842 nm)
SWIR = Short wave Infrared (Sentinel-2 Band 11 (1610 nm) or Band 12 (2190 nm))

Although several variants of the Normalised Difference Water Index (NDWI) exist (McFeeters, 1996; Xu, 2006), their performance in cold desert environments is often limited by spectral confusion among snow, barren land, and water bodies. In contrast, NDMI provides improved sensitivity to vegetation moisture and soil water content, making it more suitable for analysing agricultural water stress in high-altitude regions such as Ladakh (Gao, 1996).

3.4 Agro-Economic Indicators

3.4.1 Cultivable Land Utilisation Index (CLUI)

The Cultivable Land Utilisation Index (CLUI), proposed by Chuang (1973), was used to evaluate land utilisation efficiency. It is expressed as:

$$CLUI = \frac{\sum_{i=1}^{n}(A_i \times D_i)}{A_y \times 365} \quad \text{Eq: 3}$$

Where:
Ai = Area under the i-th crop in ha
Di = Duration of the i-th crop in days
Ay = Total cultivated area
365 = Total days in a year

CLUI provides an estimate of cropping intensity and the effective use of cultivable land.

3.4.2 Wheat Equivalent Yield (WEY)

The Wheat Equivalent Yield (WEY) was used to standardise crop productivity across different crop types based on their market price (Choudhary et al., 2014). It is calculated as:

$$WEY = \sum_{i=1}^{n}\left(\frac{Y_i \times P_i}{P_w}\right) \quad \text{Eq: 4}$$

Where:
Yi = yield of the i-th crop (t/ha)
Pi = price of the i-th crop (₹/t)
Pw = price of wheat (₹/t)

WEY enables comparison across diverse cropping systems and reflects overall agricultural productivity.

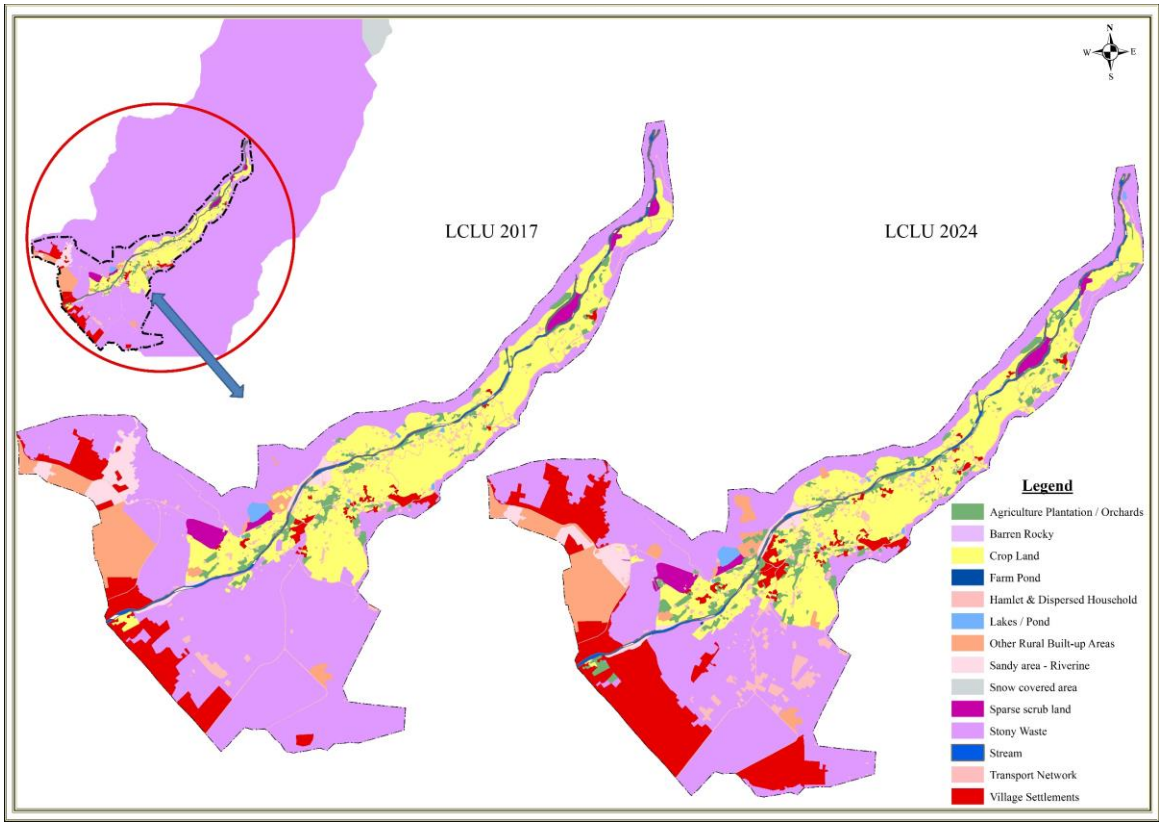


Figure 3: Land Cover / Land Use Map of 2017 & 2024

3.5 MGNREGA Intervention Mapping and Spatial Analysis

Geotagged data of MGNREGA interventions were obtained from the Bhuvan MGNREGA (https://bhuvan-app2.nrsc.gov.in/mgnrega/mgnrega_phase2.php) portal. A total of 317 assets, including irrigation channels, farm ponds, land development works, and water conservation structures, were mapped and integrated with LCLU and spectral datasets.

Spatial overlay analysis was performed to examine the association between the distribution of MGNREGA interventions and observed changes in land use, vegetation, and moisture conditions.

3.6 Socio-Economic Survey

A structured household survey was conducted using a 5-point Likert scale (Likert, 1932) to assess community perceptions of MGNREGA interventions. A total of 20 respondents were surveyed to evaluate programme awareness, employment generation, agricultural benefits, and participation in decision-making processes.

3.7 Integrated Analytical Framework

The study integrates LCLU analysis, spectral indices (NDVI and NDMI), agro-economic indicators (CLUI and WEY), and community-level insights to provide a comprehensive assessment of agricultural transformation. The relationships between MGNREGA interventions and observed changes are interpreted as spatial associations rather than direct causation, acknowledging the influence of multiple environmental and socio-economic factors.

4. Results

4.1 Land Cover/Land Use (LCLU) Changes (2017 – 2024)

The LCLU analysis of Saboo Gram Panchayat reveals notable changes between 2017 and 2024 (Figure 3; Table 1). High-resolution Cartosat-3 (MX+PAN) and Resourcesat-2 (LISS IV) datasets were interpreted according to NRSC Level-4 classification standards, resulting in an overall classification accuracy of 96%.

Agricultural land increased from 185.12 hectares in 2017 to 213.30 hectares in 2024, representing a 15.22% rise. This expansion indicates improved utilisation of cultivable land, particularly in valley regions with better irrigation access. In contrast, barren land decreased from 123.53 hectares to 113.23 hectares (−8.34%), suggesting a gradual conversion of underutilised land into productive use.

Table 1: LCLU Changes (2017 & 2024)

Land Use Type	2017 Area (Ha)	2024 Area (Ha)	Change (%) w.r.t base year
Agriculture	185.12	213.3	+15.22%
Barren	123.53	113.23	-8.34%
Glacier / Snow/Ice	44.25	42.31	-4.38%
Water Body	1.18	1.61	+36.44%
Settlements	3.78	5.22	+38.10%

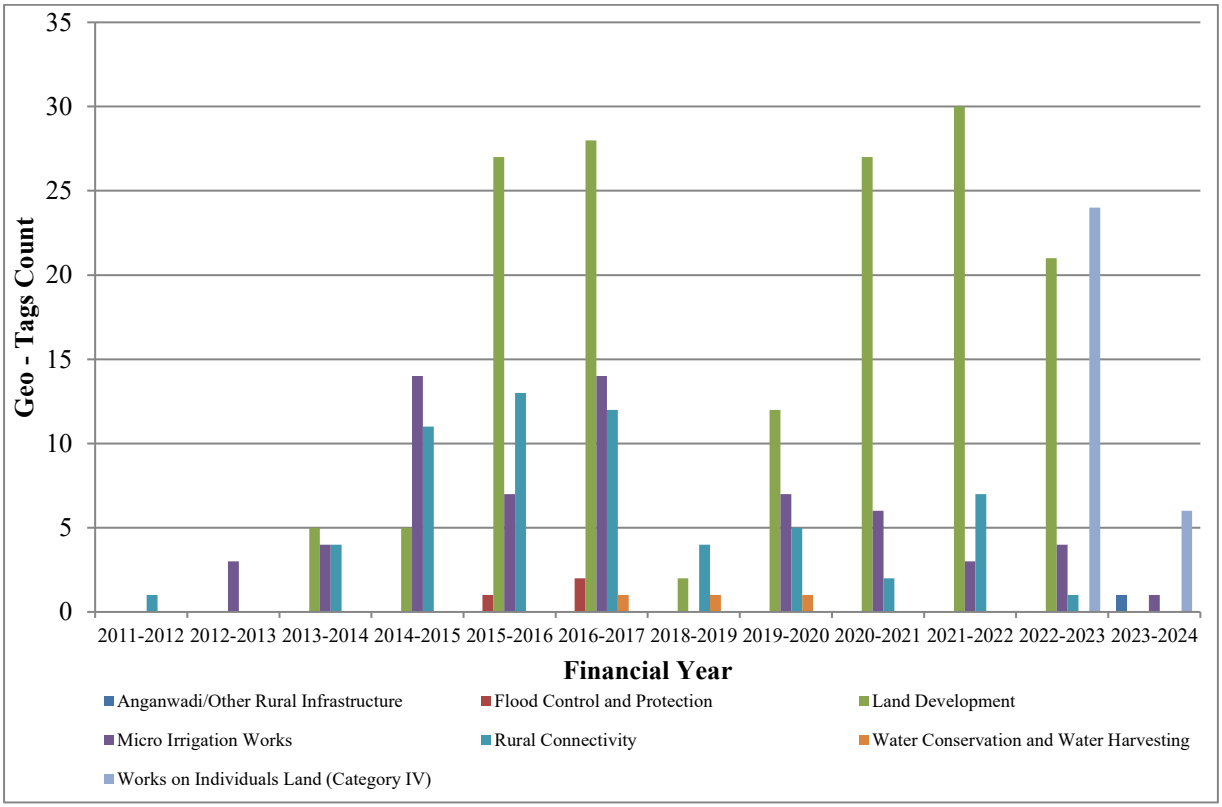


Figure 4: Category-wise MGNREGA Activities

A marginal decline in glacier/snow/ice cover was observed, from 44.25 hectares to 42.31 hectares (−4.38%). This change may be attributed to seasonal variability and broader climatic influences. Water bodies increased from 1.18 hectares to 1.61 hectares (+36.44%), reflecting enhanced water availability within the study area. Settlement areas also expanded from 3.78 hectares to 5.22 hectares (+38.10%), indicating gradual infrastructural growth and population-related expansion.

Overall, the LCLU changes indicate a transition towards more intensive and productive land use, accompanied by improvements in water availability and settlement expansion.

4.2 MGNREGA Intervention Profile

Since 2011, MGNREGA interventions have been implemented in Saboo Gram Panchayat, playing a significant role in natural resource management and the development of rural infrastructure in the study area. A total of 317 works has been executed in a phased, demand-driven manner. The highest number of interventions was recorded in 2016 and 2023, with 57 and 53 works, respectively (Figure 4), indicating sustained and consistent implementation of community-driven development activities.

The interventions are categorised into four major groups:

- **Water Conservation (126 works):** Includes farm ponds, irrigation channels, and water-harvesting structures that improve water availability for agriculture.
- **Land Development (89 works):** Activities such as land levelling and bunding have enhanced the terrain's suitability for cultivation and improved soil moisture retention.
- **Drought-Proofing (57 works)**: Plantation and afforestation initiatives contribute to ecological stabilisation and improvements in micro-environments.
- **Rural Infrastructure (45 works):** Development of roads and access pathways has improved connectivity and access to markets and services.

These interventions collectively indicate a focus on strengthening natural resource management and rural infrastructure in the study area.

4.3 Satellite and Ground-Based Evidence of MGNREGA Intervention Impacts

High-resolution satellite data and ground photographs are highly useful for monitoring, visualising, and understanding the changes resulting from interventions under MGNREGA. Figure 5 presents satellite-based evidence of physiography-linked land-use changes observed during the pre-/mid-intervention and post-intervention periods under MGNREGA, while Figure 6 illustrates field photographs of selected interventions and the surrounding physiographic conditions. Together, these satellite and ground-based observations provide complementary temporal evidence aligned with the geospatial analysis of the interventions.

4.4 Spatial Association between LCLU and MGNREGA Interventions

Spatial overlay analysis of MGNREGA interventions with LCLU data reveals that areas with clusters of interventions correspond to zones with increased agricultural extent and water availability (Figure 7).

Pre / Mid Intervention, April - 2017	Post Intervention, June - 2024
	
Fallow Land (2017) transformed into Crop Land with Bund Plantation (2024)	
	
Under-construction Farm Pond (2017) converted into Completed Water-filled Farm Pond (2024)	
	
Under-construction Farm Pond in Scrub Land (2017) transformed into Completed Farm Pond with Block Plantation (2024)	

(Figure Continued on next page)

Clusters of land development and water conservation structures are predominantly located in valley regions where agricultural expansion has been observed. These spatial patterns suggest a strong association between the distribution of MGNREGA assets and localised changes in land use and resource availability. However, these relationships are interpreted as associative rather than strictly causal, as other environmental and socio-economic factors may also influence observed changes.

4.5 Agricultural Performance Based on Spectral and Agro-Economic Indicators

The integration of spectral indices (NDVI and NDMI) with agro-economic indicators (CLUI and WEY) provides a comprehensive assessment of agricultural performance.

4.5.1 Spectral Index Analysis (NDVI and NDMI)

The Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) were computed using Eqs. 1 and 2, respectively (Figure 8). The

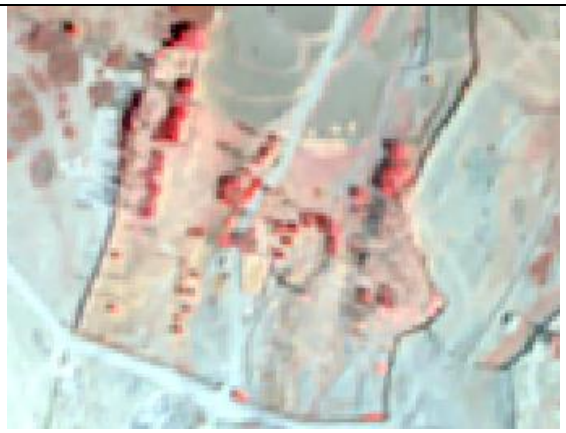
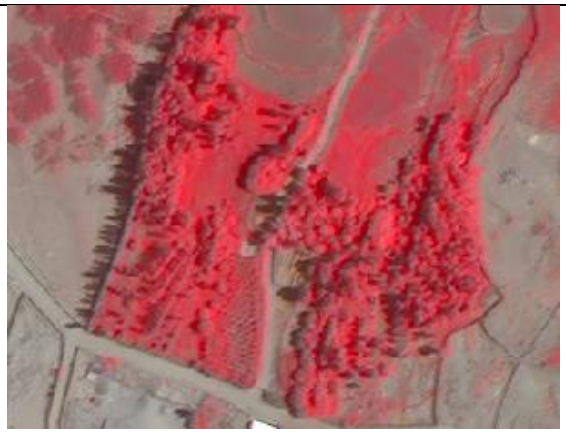
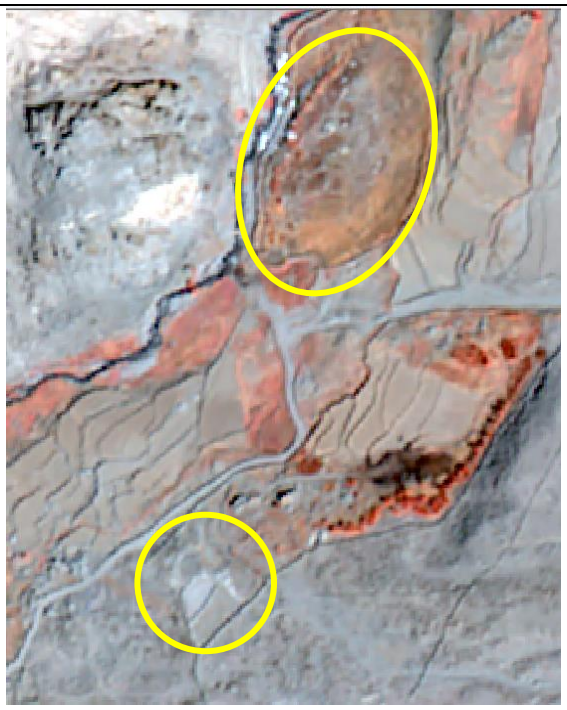
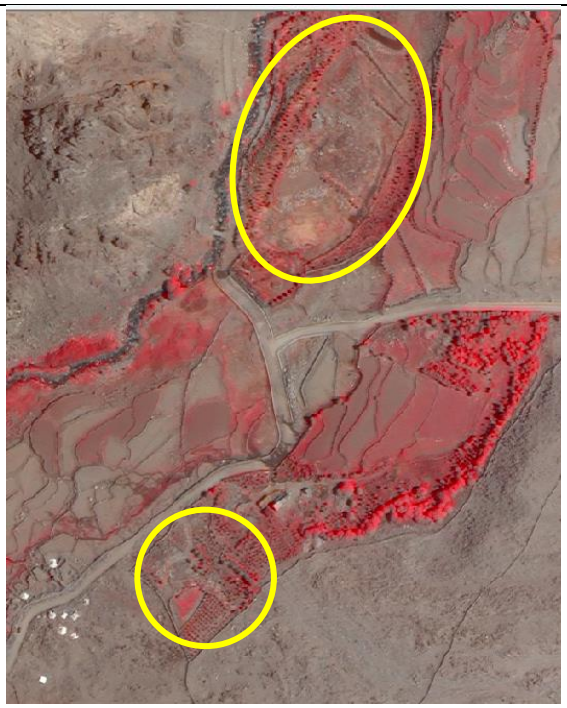
Pre / Mid Intervention, April - 2017	Post Intervention, June - 2024
	
Scrub/Fallow Land (2017) converted into Crop Land with Plantation Activity (2024)	
	
Scrub/Waste Land (2017) transformed into Crop Land with Bund and Block Plantation (2024)	

Figure 5: Temporal Land Use Transformation and Impact of MGNREGA Interventions between Pre/Mid Implementation (2017) and Post Implementation (2024)

NDVI results indicate an overall improvement in vegetation health between 2017 and 2024 (Figure 8). Areas with low vegetation cover decreased from 894.93 hectares (71.84%) to 868.10 hectares (69.68%), while areas with high NDVI values increased from 126.94 hectares (10.19%) to 166.23 hectares (13.34%).

Similarly, NDMI analysis shows an increase in moisture availability across the study area. Low moisture zones decreased from 902.15 hectares (72.42%) to 829.40 hectares (66.58%), while areas with high moisture content increased from 105.59 hectares (8.48%) to 169.76 hectares (13.63%).

These trends indicate improvements in vegetation condition and soil moisture status, particularly in agriculturally active zones (Yadav et al., 2023).

4.5.2 Cropping Pattern and Agricultural Productivity

Between 2017 and 2024, the study area experienced an expansion in cultivated land and diversification of cropping patterns. Horticultural crops showed the highest increase in area (approximately 50%), while wheat, vegetables, and barley also recorded notable gains.

The Cultivable Land Utilisation Index (CLUI) increased from 0.456 in 2017 to 0.497 in 2024, indicating improved cropping intensity and more efficient use of available land (Table 2). The Wheat Equivalent Yield (WEY) also increased substantially from 14.15 t/ha to 26.12 t/ha, reflecting enhanced agricultural productivity (Table 3).

This improvement corresponds with the expansion of irrigation infrastructure and a shift toward high-value crops such as vegetables and horticultural produce.



Bund Plantation



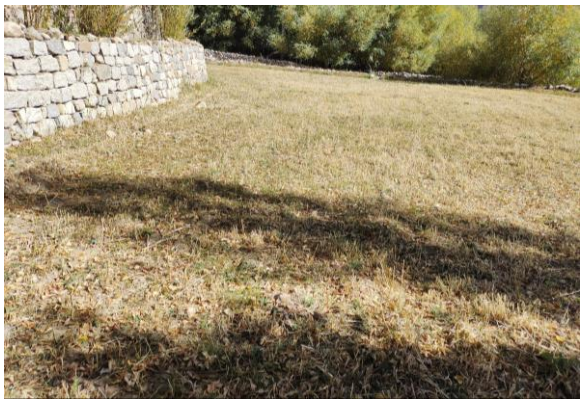
Land Development & Vegetable Crop



Irrigation Channel



Irrigation Channel



Land Development



Land Development



Farm Pond



Farm Pond

Figure 6: Photographs illustrating different types of MGNREGA interventions sourced from the field visit.

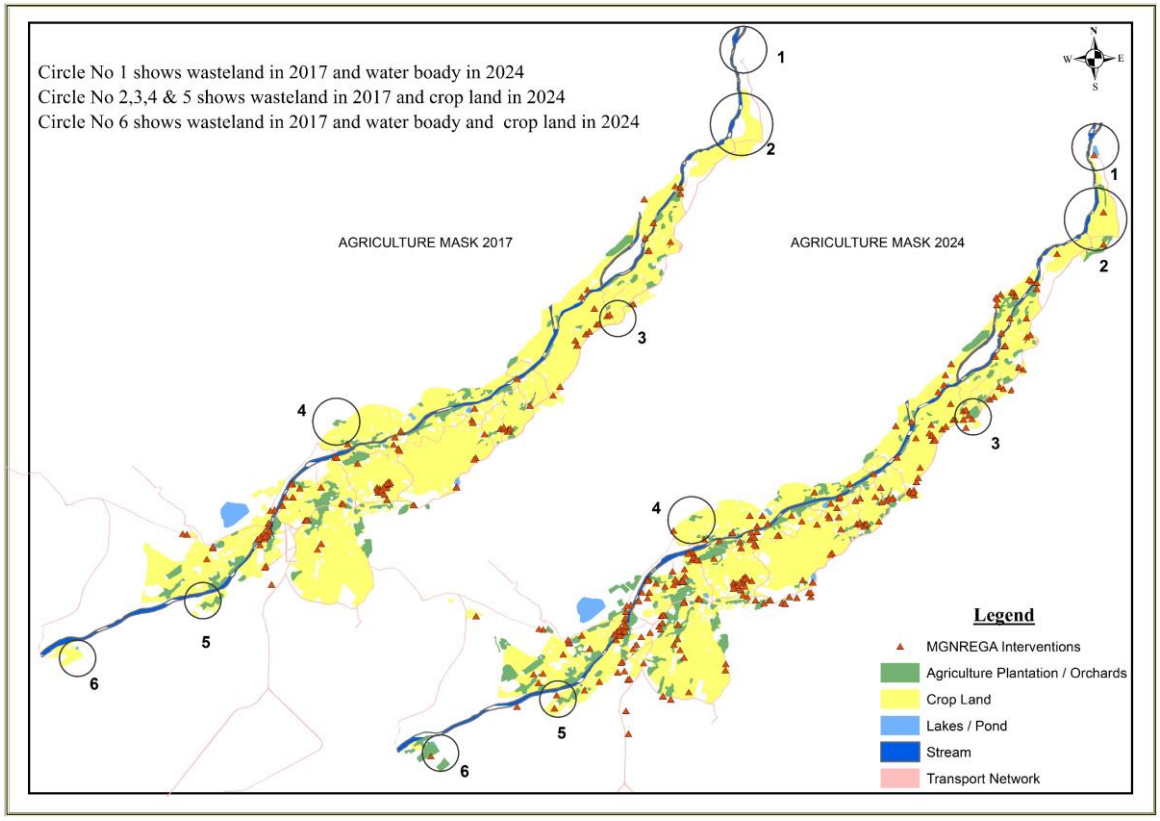


Figure 7: Spatial Distribution of MGNREGA Interventions on Agriculture Mask

Table 2: Cultivation Land Utilisation Index (2017 & 2024)

Crop	Area (ha)	Area (ha)	Duration	Area × Duration	Area × Duration
	2017	2024		2017	2024
Wheat	68	75	140	9520	10500
Barley	12	14	125	1500	1750
Pulses	2	2	105	210	210
Vegetables	20	23	95	1900	2185
Fodder	32	27	100	3200	2700
Horticulture	30	45	365	10950	16425
Total	164	186		27,280	33,770

Source: Office of Agriculture, Leh.

$$CLUI_{2017} = \frac{27280}{164 \times 365} = \frac{27280}{59860} = \mathbf{0.456} \quad \text{Eq: 5}$$

$$CLUI_{2024} = \frac{33770}{186 \times 365} = \frac{33770}{67890} = \mathbf{0.497} \quad \text{Eq: 6}$$

4.6 Community Perceptions and Programme Outcomes

A mixed-methods approach was adopted to evaluate the effectiveness of MGNREGA interventions, integrating quantitative data from a 5-point Likert scale (Likert, 1932) with qualitative field observations. The survey, conducted among 20 respondents, assessed programme performance, community impact, beneficiary satisfaction, and scope for improvement in Saboo Gram Panchayat (Figure 9).

The socio-economic assessment covered key dimensions, including programme awareness, employment generation, agricultural benefits, participation in decision-making, inclusion of women and Scheduled Tribe households (Ravindar, M., 2016), implementation challenges, and alignment of interventions with local needs. It also evaluated perceived contributions to overall socio-economic development.

Survey results indicate that MGNREGA interventions are associated with improved irrigation access, enhanced agricultural productivity, and increased employment opportunities. Respondents also reported greater participation in local decision-making processes, suggesting strengthened community engagement and inclusivity.

When integrated with geospatial analysis, areas with a higher concentration of MGNREGA interventions-particularly land development and micro-irrigation works-correspond to zones exhibiting increased crop area and productivity. These patterns indicate a strong spatial association between intervention density and improvements in agricultural and socio-economic conditions. Farmers' perceptions of increased productivity and a shift toward high-value crops further support the quantitative findings.

Despite these positive outcomes, sustaining long-term benefits will require stronger institutional convergence, particularly with agriculture and horticulture departments, to ensure access to inputs, technical guidance, and climate-resilient practices.

Overall, the combined evidence from geospatial analysis, agro-economic indicators, and community feedback

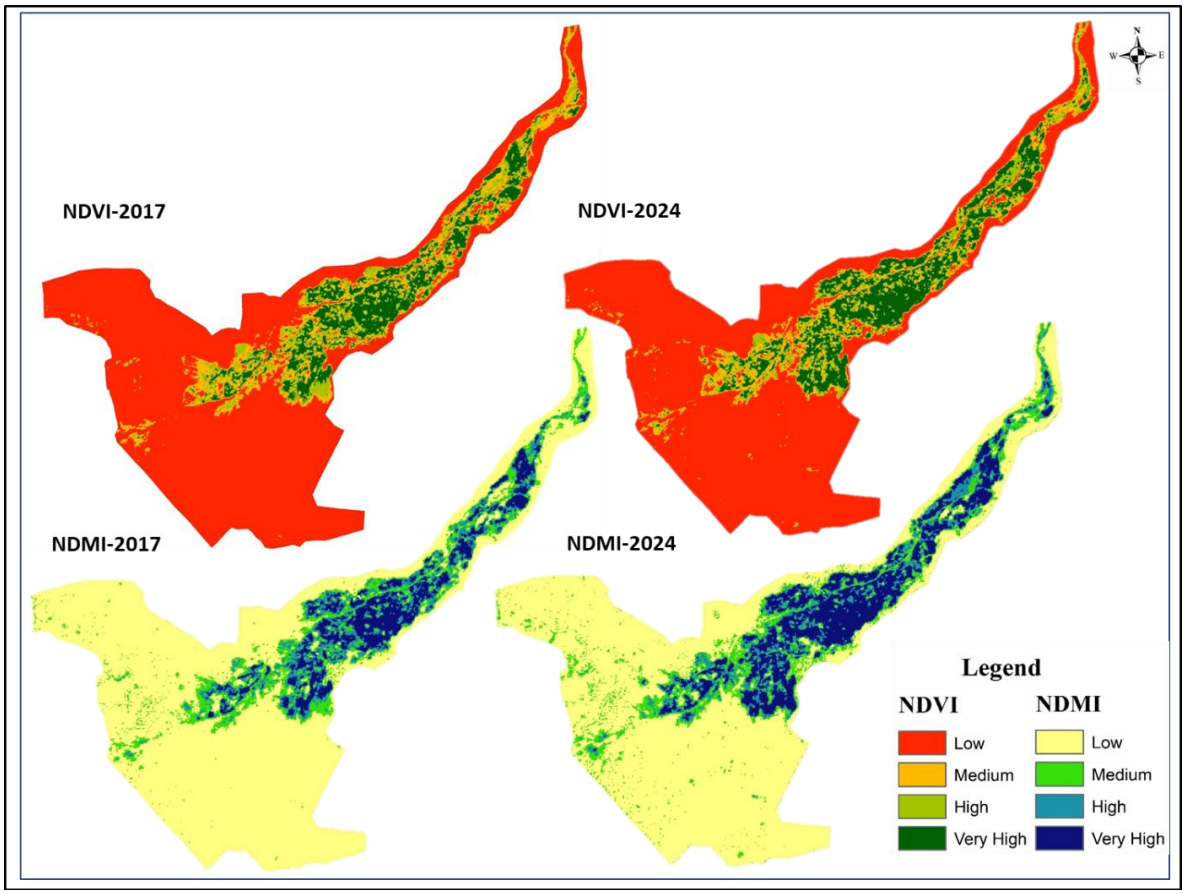


Figure 8: Spectral Indices (NDVI & NDMI) for 2017 and 2024

indicates improved land-use efficiency, water availability, and livelihood outcomes. These findings highlight the potential of community-driven interventions under MGNREGA to support sustainable agricultural development in ecologically sensitive, high-altitude regions.

5. Discussion

This study provides a comprehensive assessment of land-use transformation and agricultural change in a high-altitude cold desert environment, highlighting the role of MGNREGA interventions in shaping these dynamics. The observed increase in agricultural land (+15.22%), reduction in barren land (-8.33%), and expansion of water bodies (+36.44%) between 2017 and 2024 indicate a broader trend of improved utilisation of land and water resources. These changes are spatially associated with areas where MGNREGA interventions, particularly irrigation channels, land development works, and water harvesting structures, are concentrated.

5.1 Land-Use Intensification in Cold Desert Environments

The conversion of barren land into cultivable land reflects a gradual intensification of land use in response to improved resource availability (Maji et al., 2010a). Similar trends have been observed in Himalayan regions such as Himachal Pradesh and Uttarakhand, where watershed development and employment-linked natural resource management programmes have contributed to the reclamation of degraded lands and expansion of cultivable area (Ravindar, K., 2016; Sharma et al., 2019).

In Ladakh, where cultivable land is inherently limited, even modest increases in productive land have significant implications for local food security. The observed increase in the Cultivable Land Utilisation Index (CLUI) from 0.456 to 0.497 further supports this trend, indicating more efficient use of available agricultural land. These findings suggest that community-driven land development interventions can enhance land productivity in ecologically constrained mountain environments.

5.2 Water Availability and Vegetation Response

The observed increase in high NDVI and NDMI zones suggests improved vegetation health and soil moisture conditions. Similar studies in Himalayan agro-ecosystems have demonstrated that small-scale water-harvesting structures and irrigation interventions can significantly increase cropping intensity and vegetation cover (Bhattacharya & Kumar, 2020; Choudhary et al., 2014; Chaurasia et al., 2022). In Ladakh, however, the dependence on seasonal glacial melt introduces additional uncertainty, as water availability is closely linked to climatic variability (IPCC., 2022; FAO., 2020). Therefore, while improved water infrastructure enhances agricultural potential, long-term sustainability will depend on adaptive water management strategies that account for changing climate conditions.

The increase in water spread area and improved NDMI values indicate enhanced moisture availability across the study area. This is particularly important in cold desert ecosystems, where agriculture relies heavily on glacier-fed irrigation systems.



Figure 9: Social perspectives on MGNREGA

5.3 Crop Diversification and Agricultural Productivity

The substantial increase in Wheat Equivalent Yield (WEY), from 14.15 t/ha to 26.12 t/ha, indicates a notable improvement in agricultural productivity. This increase is accompanied by a shift toward high-value crops, particularly horticulture and vegetables, which expanded significantly during the study period.

Crop diversification has been widely recognised as a key adaptation strategy in Himalayan agriculture, enabling farmers to enhance income while reducing vulnerability to climatic and market risks (FAO, 2019; Singh, S. P., et al., 2020). Similar transitions toward horticulture-based systems have been reported in regions such as Lahaul-Spiti and Nubra Valley, where improved irrigation and institutional support have facilitated diversification and increased farm income (Tewari et al., 2015; Kumar & Joshi, 2016; Norboo et al., 2023).

The findings of this study align with these regional trends, suggesting that MGNREGA-supported interventions may help enable such transitions by improving land and water infrastructure.

Table 3: Wheat Equivalent Yield (2017 &2024)

Crop	Yield (t/ha) 2017	Yield (t/ha) 2024	Crop Production (t)		Price (₹/t)		WEY = (Yield × Price of Crop / Price of Wheat)	
	2017	2024	2017	2024	2017	2024	2017	2024
Wheat	2.2	2.5	149.6	187.5	₹ 16,250	₹ 22,750	149.60	187.50
Barley	1.8	2	21.6	28	₹ 13,250	₹ 18,500	17.61	22.77
Pulses	1.5	1.6	3	3.2	₹ 39,000	₹ 42,370	7.20	5.96
Vegetables	15	18	300	414	₹ 15,000	₹ 50,000	276.92	909.89
Fodder	3.8	4	121.6	108	₹ 3,000	₹ 5,000	22.45	23.74
Horticulture	125	125	3750	5625	₹ 8,000	₹ 15,000	1846.15	3708.79
Total Production			4345.8	6365.7	Total WEY (t)		2319.94	4858.65

Source: Author computed with the field data.

5.4 Role of Geospatial Monitoring in Evaluating Rural Development

The integration of geospatial datasets, agro-economic indicators, and field-based observations provides a robust framework for evaluating rural development interventions. The use of high-resolution satellite data allows for objective monitoring of LCLU changes, vegetation dynamics, and moisture conditions over time.

Recent studies have highlighted the growing role of Earth Observation (EO) technologies in assessing the effectiveness of rural development programmes, particularly in geographically remote and ecologically sensitive regions (NRSC, 2019; Deshmukh & Rao, 2021; Jain et al., 2018; Mandal et al., 2020; Singh, P., et al., 2020). The approach adopted in this study demonstrates how geospatial analysis can be combined with socio-economic data to provide a more comprehensive understanding of development outcomes.

5.5 Community Outcomes and Participatory Development

The findings from the community survey indicate that MGNREGA interventions are associated with improved access to irrigation, increased agricultural productivity, and enhanced participation in local decision-making processes. These outcomes are consistent with studies from other parts of India, where MGNREGA has strengthened local governance and promoted inclusive development (Reddy & Galab, 2017; Reddy, V. R., et al., 2017; Carswell & De Neve, 2014).

The emphasis on community participation in planning and implementation is particularly important in fragile mountain environments, where local knowledge is critical to resource management. Strengthening community capacity for maintenance and management of assets can further enhance the long-term sustainability of these interventions.

5.6 Implications for Policy and Practice

The findings of this study highlight the potential of MGNREGA to function beyond a wage-employment programme and serve as a strategic tool for climate-resilient rural development. The clustering of interventions, integration with geospatial monitoring, and convergence with agricultural and horticultural programmes can enhance the effectiveness of such initiatives.

For cold desert regions like Ladakh, policy focus should include:

- Strengthening water management through adaptive irrigation planning
- Promoting crop diversification toward high-value and climate-resilient crops
- Enhancing convergence between MGNREGA and Line departments
- Supporting community-based maintenance of assets

These measures can help ensure that MGNREGA interventions are both environmentally sustainable and economically beneficial.

5.7 Contribution and Novelty of the Study

This study contributes to the existing body of knowledge by providing an integrated framework that combines geospatial analysis, agro-economic indicators, and community-level insights to assess rural development interventions in a cold desert ecosystem. While previous studies have examined the impacts of MGNREGA or land-use changes independently, this study brings together multiple dimensions to provide a holistic understanding of agricultural transformation in a high-altitude environment.

The approach presented here offers a replicable model for evaluating similar interventions in other ecologically sensitive and climate-constrained regions.

6. Limitations

This study has certain limitations. The analysis is based on two temporal snapshots (2017 and 2024), which may not fully capture inter-annual variability in climatic conditions and agricultural practices. Although efforts were made to ensure seasonal consistency in satellite data acquisition, minor variations in acquisition timing may influence spectral index interpretation.

The relationship between MGNREGA interventions and observed changes is primarily associative, as multiple external factors, such as climate variability, market dynamics, and policy convergence, may also contribute to the observed outcomes. Additionally, the absence of long-term climatic datasets limits a deeper understanding of climate–agriculture interactions in the study area.

Future research may incorporate multi-year time series data and advanced modelling approaches to better isolate the effects of developmental interventions and climatic factors.

7. Conclusion

This study demonstrates that integrated geospatial analysis combined with agro-economic indicators and community-based assessment provides a robust framework for evaluating rural development interventions in ecologically sensitive regions. In the case of Saboo Gram Panchayat, notable improvements in land use, water availability, and agricultural performance were observed between 2017 and 2024.

The Land Cover/Land Use (LCLU) analysis indicates an expansion of agricultural land (+15.22%) and water bodies (+36.44%), accompanied by a reduction in barren land. Spectral indices, particularly NDVI and NDMI, reveal improved vegetation health and moisture conditions, especially in areas where MGNREGA interventions are concentrated. Agro-economic indicators further support these findings, with increases in CLUI (0.456 to 0.497) and WEY (14.15 t/ha to 26.12 t/ha), reflecting enhanced land-use efficiency and agricultural productivity.

The integration of geospatial analysis with field observations and community perceptions indicates that these improvements are associated with the implementation of MGNREGA interventions, including irrigation infrastructure, land development works, and water conservation measures. Additionally, the study highlights a transition toward crop diversification, particularly the expansion of horticulture and high-value crops, contributing to improved livelihood outcomes.

From a policy perspective, the findings emphasise the importance of clustering MGNREGA interventions, strengthening convergence with agriculture and horticulture departments, and incorporating geospatial monitoring into routine planning and evaluation processes. Such measures can enhance the effectiveness and sustainability of rural development programmes in climate-sensitive regions.

This study contributes to the growing body of literature by presenting an integrated, multi-dimensional approach to assessing development interventions in a cold desert ecosystem. The framework developed here is replicable and can be applied to other mountainous and environmentally fragile regions to support evidence-based planning and sustainable resource management.

Future research should focus on incorporating long-term climatic datasets, multi-temporal analysis, and advanced modelling techniques to better understand the interactions between developmental interventions, environmental changes, and agricultural systems in high-altitude regions.

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Ethical Statement
We confirm that this research is original and has not been previously published, nor is it under consideration for publication in any other academic journal.

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