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Assessing the Impact of Water Harvesting Structures on the Vegetation Dynamics of a Rural Area Using Geospatial Technologies

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Abstract

In the Molgi cluster of Nandurbar district, Maharashtra area prone to seasonal water scarcity-Jalkunds, small and cost-effective water harvesting structures, have been introduced to improve agricultural resilience. This study evaluates their impact on vegetation dynamics using geospatial technologies.

Landsat 8 satellite data were analysed using open-source geospatial technology, Google Earth Engine (GEE) to compute the Normalized Difference Vegetation Index (NDVI) for various seasonal phases of 2022. NDVI, a key indicator of vegetation health, showed distinct seasonal trends. During the pre-monsoon period (January to April), values ranged from 0.15 to 0.18, indicating moderate vegetation. In the early monsoon period (May to August), NDVI declined sharply from 0.18 to 0.02, reflecting acute water stress. This period aligns with peak summer, when vegetation typically depends on residual moisture. The presence of Jalkunds likely mitigated the impact, preventing complete vegetation collapse by providing localized moisture retention, as seen in the slight NDVI recovery in August.

Post-monsoon (September to December), NDVI improved significantly, ranging from 0.18 to 0.40, with peak greenness observed in September-October. The annual average NDVI was 0.18, reflecting moderate vegetation with strong seasonal variation.

1. Introduction

Water availability is a decisive factor influencing agricultural sustainability in semi-arid and hilly regions of India. In areas where rainfall is inconsistent and infrastructure for irrigation is limited, water stress directly impacts vegetation, food security, and rural livelihoods (Batchelor, 2003).

The Molgi cluster in Akkalkuwa Taluka, Nandurbar district, Maharashtra, located in the Satpuda ranges, exemplifies such a vulnerable ecosystem. This tribal-dominated region frequently faces seasonal water shortages, leading to low crop productivity and degraded land cover.

To address these challenges, Jalkunds small-scale, cost-effective water harvesting pits have been constructed across several villages under watershed development programs. These structures are designed to collect monsoon runoff, enhance soil moisture retention, and support vegetation during dry spells. However, despite widespread implementation, their ecological effectiveness, particularly in influencing vegetation dynamics, remains underexplored through quantitative, spatially explicit studies.

1.1 Research Context

With the advancement of remote sensing technologies, particularly the use of satellite-derived indices such as the NDVI (Tucker, 1979), it is now feasible to monitor and evaluate vegetative health with high temporal and spatial resolution. Platforms like GEE (Gorelick, 2017)enable efficient processing of satellite datasets, providing researchers and policymakers with a scalable tool to assess environmental interventions in near real-time.

1.2 Objectives of the Study

This study seeks to evaluate the impact of Jalkunds structures on vegetation health in the Molgi cluster using geospatial technologies. The specific objectives are:

1. To map and validate the spatial distribution of over 200 Jalkunds using field GPS data and satellite imagery.
2. To assess the influence of Jalkunds on vegetation dynamics by analyzing seasonal NDVI trends from Landsat 8 imagery for 2022 and comparing them with 2019 trends, when Jalkunds were absent.

3. To correlate vegetation response with the presence of Jalkunds, focusing on pre- and post-monsoon variations.
4. To establish a remote sensing–based assessment framework for evaluating localized water harvesting interventions in rural India.

1.3 Significance of the Study

This research provides a robust, data-driven assessment of how micro-level water harvesting strategies influence vegetation dynamics in drought-prone rural landscapes. It contributes methodologically by integrating field surveys, NDVI-based temporal analysis, and cloud-based geospatial processing. The findings offer actionable insights for policymakers and rural development agencies aiming to promote climate-resilient agriculture through nature-based solutions (Kumar, 2008) (FAO, 2019).

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2. Study Area and Methodology

The study area, in terms of its extent, and its characterization is explained and the methodology is presented in the sections.

2.1 Study Area:

As shown in Figure 1, the Molgi cluster is located in Akkalkuwa Taluka of Nandurbar district, in the northwestern region of Maharashtra near the Madhya Pradesh and Gujarat borders. Characterized by undulating terrain within the Satpuda range, the area faces frequent water scarcity due to erratic rainfall, adversely affecting agricultural productivity.

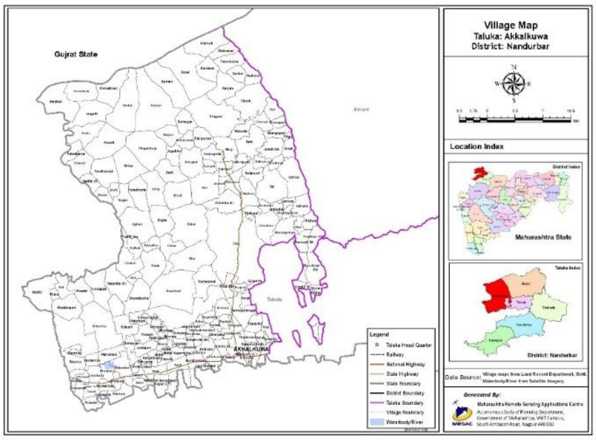

Figure 1. Geographic extent of the Molgi cluster in Akkalkuwa Taluka, Nandurbar district, showing terrain and administrative boundaries.

To address this, the project implemented low-cost rainwater harvesting structures, known as Jalkunds, across selected villages. These shallow excavations, shown in Figure 2, are designed to capture monsoonal runoff and enhance soil moisture retention during dry periods.

Figure 2. Field view of a Jalkund rainwater harvesting structure implemented in the Molgi cluster for localized moisture retention

2.2 Data Sources

To assess the health of the plants and their changes over time, the study utilized satellite images taken at various intervals and mapping software. Satellite imagery Landsat 8 Operational Land Imager (OLI) was used with a Spatial resolution 30meters with a timeframe of January to December 2022.

The Geospatial Tools used were Google Earth Engine (GEE) is a cloud-based platform for planetary-scale geospatial analysis. And QGIS is used for zonal, classification & map creation.

2.3 Vegetation Index Used: NDVI

The primary metric used to assess vegetation health was the Normalized Difference Vegetation Index (NDVI). The calculation of NDVI is as given:

$$NDVI = \frac{NIR-RED}{NIR+RED}, \tag{1}$$

where,
NIR = Near-Infrared Band (Band 5 for Landsat 8, Band 8 for Sentinel-2 & Band 17 for Sentinel-3),

RED = Red Band (Band 4 for Landsat 8, Band 4 for Sentinel-2 & Band 8 for Sentinel-3).

NDVI values range from –1 to +1. Values near 0 indicate bare soil or sparse vegetation, while values greater than 0.2 indicate moderate vegetation, and values greater than 0.4 represent dense and healthy vegetation.

Seasonal summary of NDVI values for the Molgi cluster during 2022, indicating minimum, maximum, and average vegetation indices across three climatic phases are shown in Table 1.

Time Period	NDVI Min	NDVI Max	NDVI Avg
Jan - April	0.15	0.185	0.168
May - Aug	0.013	0.224	0.119
Sep - Dec	0.158	0.392	0.275

Table 1 - Seasonal NDVI Summary for Molgi Cluster for the year 2022.

2.4 Geospatial Workflow and Data Preprocessing

The entire data processing workflow involved the use of open source geospatial technologies to derive NDVI for the entire region of interest, along with some level of analysis and visualization. The workflow is broken down in the following sections.

2.4.1 GPS Data Correction

The data set for the years 2022, 2023, and 2024, with a total having 211 locations for Jalkund, with each Jalkund having the details, such as, Farmer Name, Village Name, GPS Latitude, GPS Longitude

To enhance spatial accuracy, each Jalkund location was validated using 4–5 geotagged field photographs captured from multiple angles. GPS metadata from these images were extracted and cross-verified with the coordinates in the Excel database.

When multiple images were available, those taken from higher vantage points were prioritized, based on the assumption that water harvesting structures are typically situated on elevated or slope-intercepting sites to optimize runoff capture.

Village	Jalkund Locations	
	GPS Lat	GPS Long
Athyabari	21.72886	74.021862
Konbipada	21.726479	74.020801
Chivalutar	21.69448	74.05807

Table 2- Raw latitude and longitude data for Jalkund sites before elevation-based correction.

After this verification, the GPS latitudes and longitudes were corrected to improve spatial precision. These tables, Table 2 and Table3, illustrate the coordinate adjustments made during the validation phase, ensuring spatial accuracy for subsequent geospatial analysis and shapefile creation.

Village	Jalkund Locations	
	GPS Lat	GPS Long
Athyabari	21.728681	74.021741
Konbipada	21.721897	74.022373
Chivalutar	21.694384	74.028086

Table 3 - GPS coordinates corrected using elevation filtering to improve positional accuracy.

2.4.2 Combining Yearly Datasets

Following data validation, the subsequent step involved integrating spatial datasets from multiple years into a unified geospatial database. For this purpose, corrected location data pertaining to Jalkund structures were organized across three separate data sheets corresponding to the years 2022, 2023, and 2024. Each dataset included essential attribute information such as farmer names, village identifiers, and GPS coordinates. Then these three data sheets were combined into one consolidated spreadsheet, thus creating a spatial database of 211 Jalkund locations.

During the data consolidation process, duplicate records were identified and removed, and field structures were standardized to ensure consistency across entries. The resulting dataset was geometrically refined and served as the input for subsequent geospatial operations, including shapefile generation and spatial filtering in QGIS and Google Earth Engine.

2.4.3 Shapefile Creation

The consolidated dataset containing corrected GPS coordinates for 211 Jalkund sites was imported into QGIS with latitude and longitude fields appropriately labeled. Georeferencing was performed using the WGS 84 coordinate system (EPSG:4326), and the data points were rendered as spatial features. The layer was subsequently exported as an ESRI Shapefile (.shp), retaining all attribute information such as farmer names and village identifiers. This shapefile served as the spatial input for satellite image filtering and zonal NDVI analysis in GEE).

2.4.4 Data Calling & NDVI Generation in Google Earth Engine.

The spatial shapefile, generated in QGIS, was uploaded to GEE for the extraction of satellite data and the computation of the NDVI. Thereafter, the study area was filtered spatially in the GEE code editor through the shapefile for the extraction of satellite images.

The kind of imagery that was taken is Landsat 8 Surface Reflectance Tier 1, which was chosen because of its suitability for the vegetation analysis.

A period of analysis corresponding to the 2022 calendar year was covered in the research. The year of study was further divided into three seasonal segments, each lasting for four months, to collect temporal changes in vegetation: January to April – Pre-Monsoon Phase, May to August – Monsoon Phase, September to December – Post-Monsoon Phase

The GEE script was created for the sake of having a raster map of NDVI for each season, as well as a time-series chart that shows the variability of NDVI throughout the year, every month.This result was the basis for the following spatial and temporal analysis of the vegetation dynamics in the area of study.

2.4.5 NDVI Calculation

After generating the raster image from the Google Earth Engine, the images were further downloaded in GeoTIFF format for analysis. Then the image was imported into QGIS for refinement & visual classification.

In QGIS, with the help of the Raster Calculator tool, the NDVI calculation is done & the formula is mentioned in section 2.3. After the NDVI calculation, the NDVI classification and mapping was done. The map layout underwent precise adjustments to highlight how vegetation spread throughout the Molgi cluster. The cartographic process enabled a clear presentation of spatial vegetation patterns, which were influenced by fluctuations in water availability and seasonal variation, as shown in Figure 3.

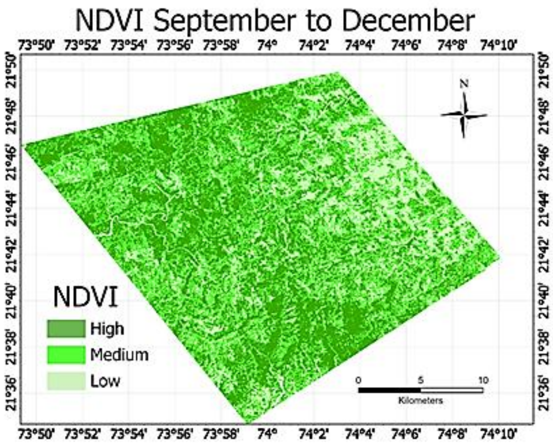

Figure 3. NDVI classification map of Molgi cluster. Light green shows low vegetation density, while dark green indicates healthy

2.5 Seasonal Classification

To evaluate the impact of rainfall and temperature on vegetation dynamics, the year 2022 was categorized into three climatic phases based on the typical seasonal pattern of semi-arid regions in Maharashtra.

2.5.1 Pre-Monsoon (January–April)

During this period, NDVI values ranged from 0.150 to 0.185, indicating moderate vegetation sustained by residual soil moisture from the previous monsoon. Extreme temperatures, reaching up to 57.42°C and falling to 25.9°C, contributed to significant heat stress. The complete absence of rainfall and high evapotranspiration rates resulted in gradual vegetation decline, particularly in elevated and exposed areas. This phase provides a baseline to assess vegetation response in subsequent seasons.

2.5.2 Monsoon (May–August)

In 2022, Dhule district received an annual rainfall total of approximately 819.9 mm, concentrated primarily in the monsoon months (June–October). This is substantially above (excess of roughly 21.7%) the long-period average (LPA) for the district, which is ~ 674 mm per year.

The NDVI values ranged from 0.013 to 0.224, indicating limited and uneven vegetation growth. Most areas exhibited delayed greening due to insufficient soil moisture recharge. Overall, vegetation stress persisted, with slight improvement in areas benefiting from micro-level water retention structures like Jalkunds.

2.5.3 Post-Monsoon (September–December)

This period showed the strongest vegetation recovery, with NDVI values increasing to a range of 0.158–0.392. The combination of residual soil moisture and water harvesting interventions supported significant vegetation enhancement. Temperatures reached to a maximum of 39.5°C, remaining generally favorable for plant growth.

Vegetation resilience in this phase underscores the importance of post-monsoon monitoring for assessing delayed greening and moisture retention effectiveness.

Figures 4 and 5 illustrate the seasonal NDVI response in relation to temperature and rainfall, respectively, highlighting the sensitivity of vegetation to climatic variability in the Molgi Cluster.

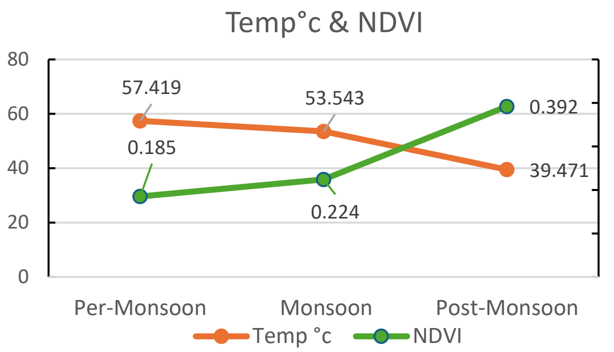

Figure 4. Monthly NDVI variation vs. maximum temperature in the Molgi Cluster (2022).

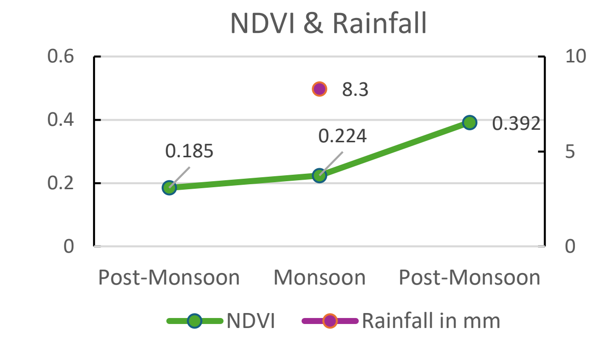

Figure 5. Seasonal NDVI variation and rainfall in the Molgi Cluster (2022).

2.6 Tools and Platforms Used

A combination of cloud-based, desktop, and spreadsheet applications was employed for spatial analysis, image processing, and map generation. GEE served as the primary platform for processing and analyzing Landsat 8 satellite imagery, with NDVI values computed using JavaScript in GEE's Code Editor. The platform's cloud computing and multi-temporal capabilities enabled efficient handling of large-scale datasets.

QGIS (version 3.22 or newer) was used for geospatial data processing and visualization, supporting tasks such as CSV-to-shapefile conversion, NDVI-based raster classification, and final cartographic layout design, including legends, scale bars, and north arrows. Figure 6 illustrates the Landsat imagery processed in GEE. Figure 7 shows NDVI classification and raster operations performed in QGIS.

Microsoft Excel was used for preparing and correcting spatially referenced worksheets (2022–2024) and organizing and analyzing non-spatial attribute data for integration into GIS workflows.

Figure 6 – Landsat 8 surface reflectance image of Molgi Cluster from GEE, used for NDVI computation.

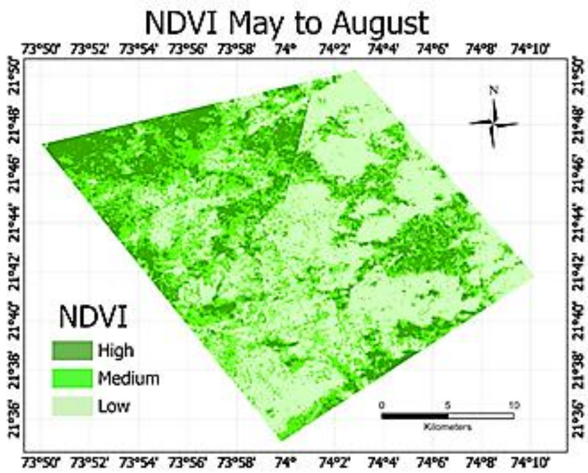

Figure 7 – NDVI classification map from Landsat raster, showing vegetation health from low (light green) to high (dark green).

3. Result

Temporal analysis of NDVI for the year 2022 was carried out across pre-monsoon, monsoon, and post-monsoon phases to assess vegetation dynamics in response to seasonal climatic variations and water availability, in relation to temperature and rainfall patterns. For validation and comparative assessment, the NDVI results of 2022 were further evaluated against those of 2019, a reference year when Jalkunds were absent.

3.1 Pre-Monsoon Period (January to April)

During the pre-monsoon period (January–April 2022), vegetation primarily depended on residual soil moisture from the preceding monsoon. NDVI values ranged between 0.156 and 0.183, reflecting moderate vegetation growth under moisture stress conditions. The maximum NDVI (0.185) was observed on January 12, while the minimum (0.150) occurred on April 11, 2022. Daytime temperatures remained high (25.9°C–57.4°C), intensifying heat stress, and no rainfall was recorded, consistent with the semi-arid climate of the Molgi Cluster. Figures 8 and 9 present the NDVI time-series and classification maps for this period.

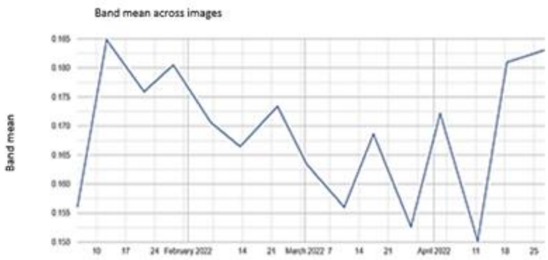

Figure 8. NDVI time series (Jan–Apr 2022) for Molgi Cluster, showing monthly variation and pre-monsoon vegetation stress.

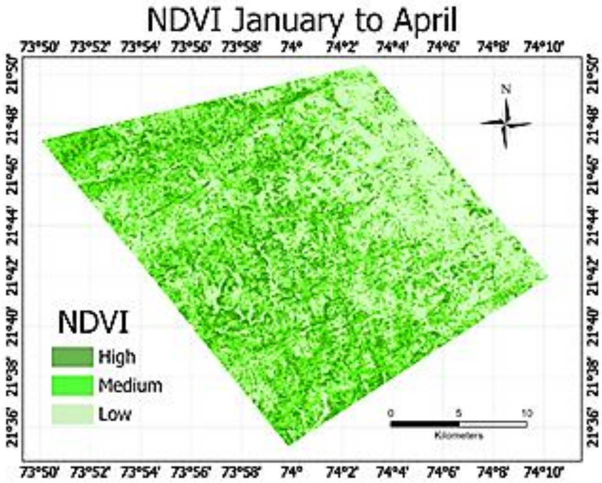

Figure 9. NDVI classification map (Jan–Apr 2022) showing vegetation health from low (light green) to high (dark green).

In contrast, the pre-monsoon NDVI values in 2019, when Jalkunds were absent, were lower, ranging from 0.118 to 0.164, under comparable temperature conditions (25.9°C–56.9°C). The higher NDVI values in 2022 indicate that the presence of Jalkunds contributed to improved vegetation condition during the dry pre-monsoon season by enhancing soil moisture availability and mitigating moisture stress.. Figures 8 and 9 depict the time series chart and NDVI classification map for this period.

3.2 Monsoon Period (May to August)

During the monsoon period (May–August 2022), which generally represents the peak wet season, rainfall was exceptionally low at only 8.3 mm. NDVI values fluctuated between 0.013 and 0.224, reflecting severe vegetation stress caused by inadequate early-season precipitation. The minimum NDVI (0.013) was recorded on June 30, while the maximum (0.224) occurred on August 24, indicating partial vegetation recovery from sporadic late rainfall events. Daytime temperatures reached as high as 53.54°C, further exacerbating heat and moisture stress.

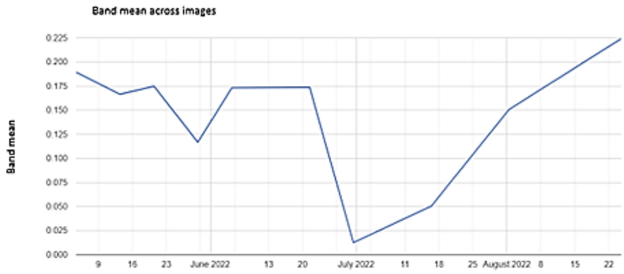

Figure 10. NDVI time series (May–Aug 2022) showing monthly vegetation stress in the Molgi Cluster.

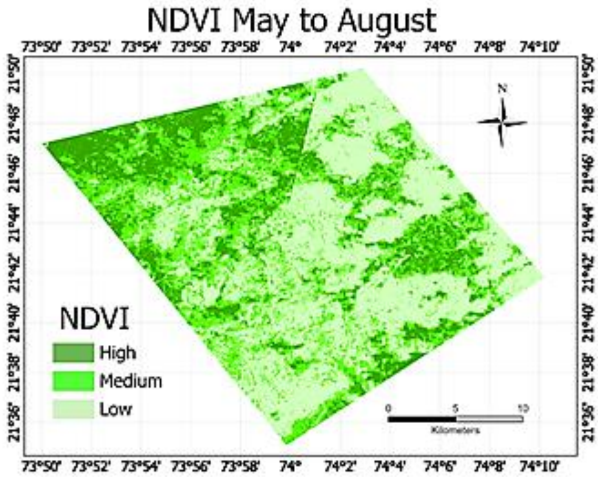

Figure 11. NDVI classification map (May–Aug. 2022) showing vegetation health from low (light green) to high (dark green).

In comparison, NDVI values during the 2019 monsoon season, when Jalkunds were absent, ranged from 0.063 to 0.209 under relatively milder maximum daytime temperatures (34°C).

In 2019, Dhule district received approximately 971.8 mm of rainfall, amounting to about 144% of the long-period average (674.0 mm), which likely supported better vegetation growth even in the absence of jalkunds, thus underscoring the added value of such structures under lower rainfall scenarios.

Despite the less rainfall (819.9mm) in 2022, NDVI values were generally higher than in 2019, particularly during the late monsoon phase. This suggests that the presence of Jalkunds improved soil moisture retention and provided localized water availability, thereby enhancing vegetation resilience and supporting better greenness even under suboptimal monsoon conditions.

3.3 Post-Monsoon (September through December)

During the post-monsoon season (September–December 2022), vegetation exhibited marked recovery, with NDVI values ranging from 0.158 to 0.392. The maximum NDVI (0.392) was recorded on October 4, reflecting vigorous vegetation growth supported by residual soil moisture from the preceding monsoon.

By December 14, NDVI had declined to 0.158, signaling the onset of seasonal drying. Daytime temperatures remained moderate, reaching a maximum of 39.5°C. Despite cooler and progressively drier conditions, relatively high NDVI values were sustained, attributable to effective soil moisture retention facilitated by local water harvesting structures such as Jalkunds.Figures 12 and 13 present the NDVI time series and spatial distribution for the post-monsoon period, respectively.

Figure 12. NDVI time series (Sept.–Dec. 2022) showing monthly variation.

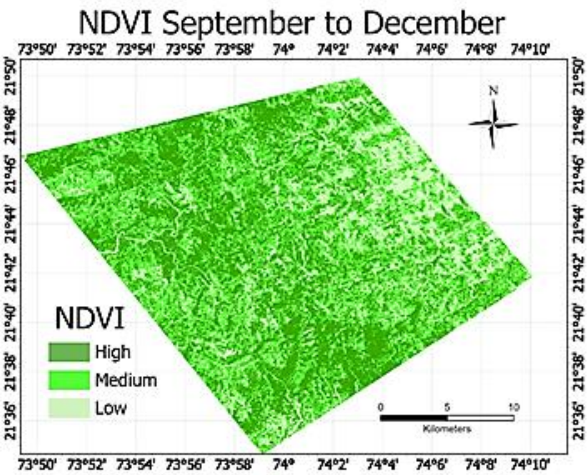

Figure 13. NDVI classification map (Sept.–Dec. 2022) showing vegetation health from low (light green) to high (dark green).

In comparison, post-monsoon NDVI values in 2019, prior to the introduction of Jalkunds, ranged from 0.060 to 0.381 under similar climatic conditions (maximum temperature ~30°C). The higher baseline NDVI observed in 2022 indicates that Jalkunds enhanced soil water availability beyond the immediate monsoon period, thereby supporting prolonged vegetation greenness and delaying seasonal senescence.

4. Conclusion

This study underscores the pivotal role of Jalkunds in strengthening vegetation resilience across critical agricultural phases in semi-arid regions. Comparative NDVI analysis between 2019 (pre-Jalkund) and 2022 (post-Jalkund) revealed consistent improvements in vegetation health across pre-monsoon, monsoon, and post-monsoon periods. During the pre-monsoon season, Jalkunds mitigated early-season moisture stress, sustaining higher NDVI values despite extreme temperatures and lack of rainfall. In the monsoon season, even under severe rainfall deficits, areas supported by Jalkunds demonstrated greater vegetation greenness and resilience relative to 2019. Post-monsoon observations further confirmed the prolonged availability of soil moisture, as evidenced by sustained high NDVI values and delayed onset of seasonal senescence.

Beyond the biophysical results, this study highlights the effectiveness of integrating geospatial technologies such as Google Earth Engine and QGIS for scalable, cost-efficient vegetation monitoring. By linking NDVI time-series with climatic drivers, the analysis provides quantitative evidence that localized water harvesting interventions significantly reduce vegetation stress in drought-prone landscapes. The synergy between geospatial monitoring and traditional water conservation practices offers a robust framework to enhance agricultural productivity, ecological resilience, and climate adaptation in semi-arid regions.

Acknowledgments

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