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Land Restoration Effectiveness Assessed By Satellite-Based Remote Sensing Technologies As a New Monitoring Approach

THE RESEARCH

The Mediterranean region is under increasing pressure from climate change and land degradation, leading to declining tree growth and rising mortality. As these challenges intensify, there is an urgent need for innovative tools to monitor and guide restoration efforts. Since the launch of Sentinel satellite program, we now have more data which can be used to assess and monitor the restoration actions success.

This study focuses on leveraging Sentinel-2 and Sentinel-1 imagery to monitor restoration initiatives in Israel. Based on indices such as SAVI, NDII, and NDWI, Sentinel-2 enables detailed tracking of vegetation health. Meanwhile, Sentinel-1's radar capabilities provide insights into soil moisture and surface texture, making it possible to detect subtle changes in restored landscapes. To validate these tools, restored and non-restored areas were compared, revealing significant improvements in vegetation health, soil stability, and moisture retention in treated sites.

By combining cutting-edge satellite technology with restoration science, this research highlights the potential of remote sensing to transform land management. The findings not only demonstrate the effectiveness of restoration interventions but also emphasize the importance of monitoring systems in promoting sustainable practices in the face of a changing climate.

Study Area

The "Bethlehem of Galilee food forest" (32.704° N and 35.205° E) in Israel is leading significant project initiated in 2017 to address soil degradation and biodiversity loss stemming from conventional agricultural practices.

This food forest, located in a Mediterranean climate, seeks to restore natural ecosystems by implementing agroforestry principles. The project uses techniques like drip irrigation, rainwater harvesting, and mulching to improve water conservation and soil health, while fostering high species diversity and cultivating rare varieties of plants. By mimicking natural ecosystems, the food forest demonstrates the potential for sustainable food production, biodiversity enhancement, and livelihood creation, all while mitigating the harmful effects of traditional agriculture.

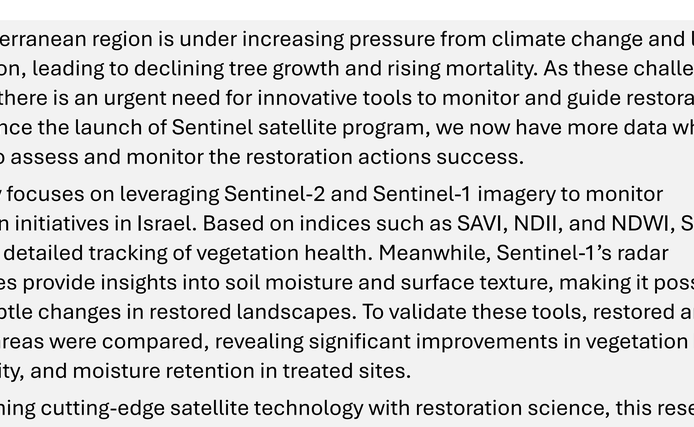


Figure 1. Food Forest, Bethlehem of Galilee, Northen District.

Alonei Abba Nature Reserve, located in northern Israel's Lower Galilee region, is a protected area renowned for its rich biodiversity and historical significance. Established in 1994, the reserve spans approximately 950 dunams (about 95 hectares) and serves as a remnant of the extensive oak forests that once covered the region.
The reserve is managed to preserve its unique ecosystem. Most of the area is open for experimental grazing by cattle from the moshav, which helps maintain the landscape and supports traditional agricultural practices. Wikipedia
Alonei Abba Nature Reserve offers a blend of natural beauty and historical depth, making it a noteworthy destination for visitors interested in Israel's natural and cultural heritage.

Figure 2. Alonie Abba, Natural Forest, Northen District.

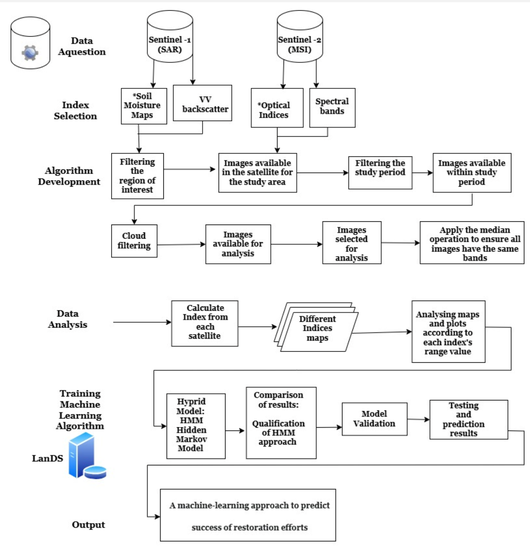
OBJECTIVES

The objective of this study is to explore methods for Sentinel- 1 and Sentinel- 2 data processing to monitor land restoration activities in the study area: the food forest and considering Alonie Abba natural reserve in the model as validation proof that the food forest is mitigating the natural forest characteristic while restoration actions are applied. as both are beside each other and situated in the Mediterranean region. These areas are part of a broader effort to combat desertification and land degradation driven by the region's climate.
The main goal is to assess the effectiveness of restoration actions and identify key indicators of success, such as changes in vegetation cover, soil moisture, and land use patterns by processing and analyzing the satellite data.
By leveraging Sentinel-1 and Sentinel- 2 capabilities, this study aims to detect areas where restoration efforts are progressing, as well as regions requiring further intervention.
This approach enhances decision-making processes and reduces the reliance on field-based assessments, providing a more efficient way to monitor and guide land restoration initiatives by predicting it's success in vulnerable Mediterranean ecosystems.

Figure 3. Study areas on the map

METHODS

- Image Processing: Used Google Earth Engine (GEE) to filter cloud-free satellite images (2015–2024) for defined regions and timeframes.
- Data Analysis: Applied cloud masking, seasonal labeling, and index calculations. Exported results as TIFF and CSV files.
- Hidden Markov Models (HMMs): Analyzed restoration success (2015–2024) by modeling environmental changes and predicting indices states.
- Validation: Validated with a natural forest beside it to prove the behavior of sustainable forest.



RESULTS AND DISCUSSION

This section presents the findings from the analysis of soil and vegetation health using remote sensing indicators derived from Sentinel- 1 and Sentinel- 2 satellite data.
The analyzed satellites images spans from 2015- 2024. The averaged seasonal variations and long-term trends in both restored and control areas were proceed in this study. The indicators used in this analysis include:

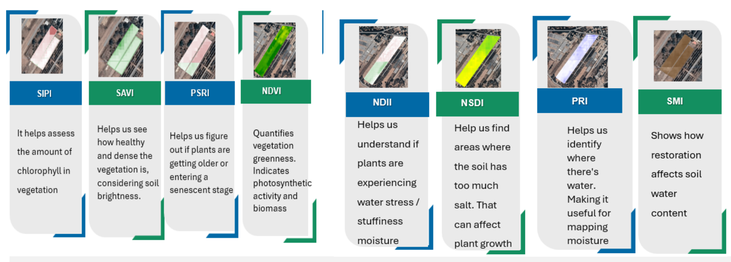


Figure 5. Indicators usage and showing a layer from the different satellites images .

A comparative methodology was employed on Food Forest area, where the restored area was matched with a reference area without any restoration interventions, traditional agriculture were applied as usual. This approach minimized environmental variables and provided a robust baseline for assessing the effectiveness of restoration efforts.

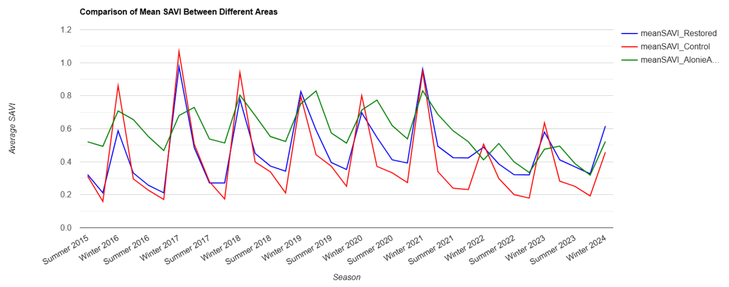


Figure 6. In FF*, the analysis of the Soil-Adjusted Vegetation Index (SAVI) that employs the Near Infrared **(NIR) and Red bands** to assess vegetation health by accounting for soil brightness, revealed notable seasonal trends. Both the restored and control areas showed higher SAVI values during the winter and spring months, indicating robust vegetation health, while lower values were recorded in the summer and autumn, suggesting a decline in vegetation vitality. Initially, the control area exhibited higher SAVI values than the restored area. However, as time progressed, the SAVI values for both areas began to align, with the restored area showing slightly elevated SAVI values during wetter seasons. This trend indicates that the restoration **stability and resilience in the RESTORED area**, which experienced few efforts have had a beneficial impact on vegetation health, **contributing to enhanced** er significant drops in SAVI values compared to the control area.

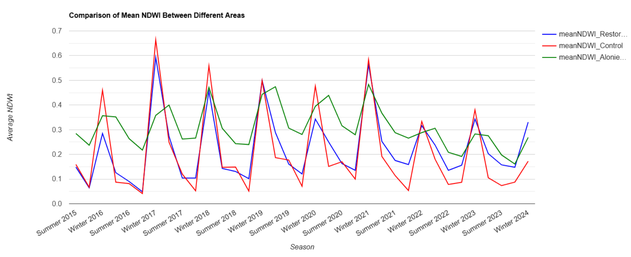


Figure 7. The analysis of the Normalized Difference Water Index (NDWI) that uses the Near Infrared **(NIR)** and Shortwave Infrared **(SWIR) bands** to evaluate vegetation water content. The FF* shows significant seasonal variations, with higher values in winter and spring. Over time, the restored area has converged towards the control area, indicating enhanced water retention and resilience. Comparing those finding with the natural forest- Alonie Aba reveals that the FF* restored area is beginning to mimic natural ecosystems by fostering self-facilitation, suggesting successful restoration and potential self-sustainability which enhance biodiversity and ecological processes.

Term 1. : FF- Food Forest

CONCLUSIONS

The study shows that remote sensing effectively assesses long-term land restoration, revealing that restoration efforts significantly improve vegetation health and water retention, enhance ecosystem resilience, and highlight the importance of ongoing monitoring for sustainable land management.

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