Proceedings of the 3rd GCC International Conference on Industrial Engineering and Operations Management
Tabuk, Saudi Arabia, February 2-4, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20260316
Published: February 2, 2026

Assessment And Forecasting of Afforestation Efforts in Saudi Arabia Using Remote Sensing and Machine Learning

Mohammed Fayidh Alsharari, Hatem Awwad Almutairi, Muhannad Fahad Alhanaya, Talal Ali Alrashidi and Ahmad J. Alkhodair
University of Tabuk, Saudi Arabia
aalkhodair@ut.edu.sa

Abstract

In arid nations like Saudi Arabia, where leaves are vital to environmentally friendly operations and climate regulation, it is imperative to monitor afforestation efforts. This study tackles the drawbacks of manual vegetation tracking, which is frequently labor-intensive, slow, and unscalable, in support of national initiatives like the Saudi Green and Green the Saudi capital projects. In order to address these issues, we suggest a remote sensing method for evaluating vegetation health and coverage that combines machine learning techniques with Sentinel two and the combined Landsat 8 satellite imagery. The Normalized Difference Vegetation Index, or NDVI for short and the Enhanced Vegetation Index (EVI), two important vegetation indices, are used to assess the density and condition of trees in different parts of the Kingdom. Monitoring afforestation progress, measuring tree cover, examining seasonal vegetation trends, and projecting future growth using models like Random Forest (RF) and LSTM (long-short-term memory) networks are the four primary goals of the methodology, the findings show that spring is when vegetation reaches its peak health, with areas like Tabuk showing the highest NDVI and EVI values. On the other hand, because of the high temperatures, the summer season exhibits a notable decrease. Monitoring extensive planting operations is made more accurate and efficient by combining satellite imagery with cutting-edge machine learning. These results give environmental planners and policymakers important information that helps them develop data-driven plans for afforestation, environmental preservation, and long-term ecological success in Saudi Arabia.

Keywords
Remote Sensing, Machine Learning, Afforestation, NDVI, LSTM.

1. Introduction
1.1. Background and Climate Resilience
Vegetation maintains ecosystems, aids in climate regulation (Abdullah 2021), enhances the air's quality (Kumar et al. 2021), and lessens the effects of warmth islands in cities (Khan et al. 2020). The importance of precise and extensive vegetation monitoring has increased as a result of Saudi Arabia's increased emphasis on environmental projects like "Saudi Green" and "Green Riyadh" (Al-Qahtani 2021, Martinez et al. 2019). In addition, these efforts align directly with Saudi Vision 2030's goals to expand green areas and promote long-term environmental sustainability. Vegetation plays a vital role in sustaining ecosystems, helping to regulate climate (Khan et al. 2020), improve air quality (Abdullah 2021), and reduce the impact of urban heat islands (Kumar et al. 2021). The use of remote sensing technologies, specifically satellite imagery from Sentinel, also and Landsat 8 (Bosch 2022), in conjunction with vegetation indices such as the NDVI (Normalize Difference Vegetation Index) and the Enhanced Vegetation Index (Smith 2021), is the main focus of this study. By supporting the nation's afforestation objectives and promoting long-term environmental sustainability, these tools enable efficient monitoring of tree coverage and vegetation health (Li et al. 2021).

1.2. Limitations of field-based monitoring

Monitoring vegetation health and tracking afforestation efforts on a national scale presents several challenges. Surveying technologies, which provide scalable and effective ways to gather vegetation data over vast and frequently inaccessible areas, have been used in a number of studies to address these issues.

1.3. Brief intro to remote sensing and vegetation indices

Vegetation indices, such as the added vegetation index (EVI) and the standard deviation of the vegetation index (NDVI), which offer measurable measures of vegetation density and health, are among the most often utilized instruments in these investigations. These indices aid scientists in identifying plant stressors brought on by things like land degradation, temperature swings, and water scarcity. Furthermore, the capacity to forecast and model vegetation dynamics has been aided by recent developments in artificial intelligence, specifically machine learning. In order to produce high-accuracy forecasts and spot trends in vegetation change, algorithms like random forests, LSTM, also known as long connections, and XGBoost have been incorporated with satellite data more and more.

1.4. The Objectives of this study are as follows

1. Assess and quantify the spatial and temporal changes in vegetation cover across various regions of Saudi Arabia using satellite remote sensing data.
2. Develop and apply machine learning models to accurately forecast afforestation progress and evaluate vegetation health.
3. Examine the relationship between vegetation health indicators and key environmental factors such as temperature and rainfall.
4. Propose data-driven strategies to enhance vegetation resilience and support long-term environmental planning in response to climate challenges.

1.5. The contributions of this study are as follows

1. Development of a remote sensing method for vegetation health assessment using satellite imagery.
2. Application of machine learning models (Random Forest, LSTM) to forecast afforestation progress.
3. Analysis of seasonal vegetation trends to support long-term environmental planning.

2. Related Works

In Smith (2021) This paper explores the consistency between ground-measured NDVI and satellite-derived NDVI values. Comparative analysis of satellite and field-collected NDVI data to validate remote sensing methods. Tools: Sentinel-2 imagery, ground sensors, regression analysis. Gaps: Lacks implications for future vegetation prediction or policy application. (Smith 2021) In Ahmed (2020) This study developed a satellite-based system for detecting trees and mapping green cover. Spectral analysis of vegetation combined with classification techniques to map tree distribution. Tools: Sentinel-2 imagery, classification models, spectral indices. Gaps: Did not address time-based vegetation dynamics or machine learning predictions. In Kumar et al. (2021) A review paper that analyses how NDVI has been used over the years to monitor vegetation. The paper presents a literature review and comparative analysis of NDVI applications in various study contexts. Tools: NDVI, academic literature databases. Gaps: Does not compare NDVI with newer vegetation indices like EVI or apply it to current remote sensing technologies. The study Assiri et al. (2024) examines changes in water resources, vegetation, and land surface temperature in the Al-Asfar Lake region, Eastern Saudi Arabia, from 2013 to 2023. It uses satellite imagery to understand the impact of vegetation and water on climate change mitigation and analyses trends using linear regression. Tools: Landsat-8 OLI . satellite data, NDVI, NDWI, and LST datasets, ArcGIS and Google Earth Engine (GEE). Gaps: The study provides valuable observations but lacks predictive components such as machine learning models to forecast future trends. It also does not propose a comprehensive framework for managing water resources and vegetation cover in the region. Furthermore, while the study offers a detailed analysis of the past decade, it does not fully explore the impact of future climate scenarios. In Almalki et al. (2025) This study investigates the environmental impacts of dam construction in four basins located in southern Saudi Arabia: Hali, Baish, Yiba, and Reem. The study employs remote sensing, machine learning techniques, and a space-for-time substitution approach to analyze the effects of dams on vegetation, groundwater, soil salinity, and runoff. It aims to understand how changes in water flow caused by dams affect these environmental parameters in arid regions. The study uses a space-for-time substitution approach, combining remote sensing data with machine learning methods like Dynamic Time Warping (DTW) and regression-based models to assess temporal and spatiotemporal changes across the basins. The analysis includes NDVI (vegetation cover), soil salinity, groundwater, runoff, temperature, and precipitation from satellite data (MODIS, GPM, GRACE, etc.) between the periods 2003–2009 (predam) and 2010–2020 (post-dam). A four-fold cross-validation approach is used for model evaluation. Tools: MODIS satellite imagery (NDVI, NDSI), Machine learning techniques (DTW, regression models), Remote sensing tools (GRACE, GPM, AIRS, GLDAS, MERRA-2, Google Earth Engine), and MATLAB for data processing and analysis. Gaps: While the study provides valuable insights into the impacts of dams on the environment, it lacks direct field data validation for all variables, and further incorporation of local socio-economic factors could provide a more comprehensive assessment of dam impacts. Additionally, there is room for improvement in the prediction accuracy, especially for groundwater dynamics, which are influenced by complex hydrological changes. By combining remote sensing methods with machine learning models to forecast vegetation changes—a problem that was previously disregarded in studies that only used descriptive or comparative analysis—this study clearly closes a gap in the literature. In contrast to earlier studies that ignored the predictive and policy aspects, it presents a theoretical model for aquatic and vegetation management, links scientific discoveries with ecology planning and decision-making, and includes a continually changing time-frame analysis wrapping future trends (Figure 1)

4. Methodology

The study incorporates Sentinel-2 and Landsat 8 satellite imagery, as well as climate data from global sources such as NASA and NOAA.

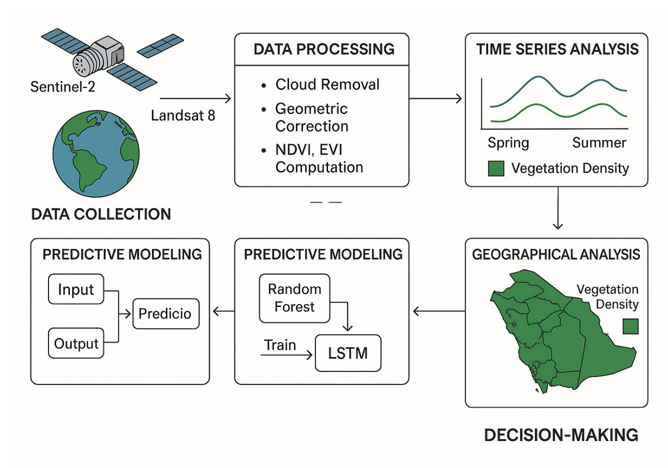

Figure 1. outlines the methodology used in this study, focusing on the use of remote sensing data, vegetation indices, and machine learning models to monitor afforestation efforts within the Saudi Green Initiative.

3.1 Data Collection

To ensure the accuracy and reliability of vegetation monitoring, this study relies on multiple data sources:

- **Satellite Imagery:** Sentinal-2 (Copernicus) and Landsat 8 (USGS) are utilized for capturing High-resolution vegetation images, following methodologies applied in previous studies on remote sensing-based vegetation analysis. MODIS data is incorporated for long-term vegetation monitoring at a broader scale.

- **Climate Data:** Environmental factors such as temperature, precipitation, and humidity are obtained from NASA, NOAA, and ECMWF databases, which are commonly used for assessing vegetation-climate in interactions.

3.2 Data Preprocessing

The raw satellite images undergo several preprocessing steps to enhance accuracy and usability:

- **Cloud and Shadow Removal:** Sentinel-2 images are processed using the Scene Classification Layer (SCL) to eliminate cloud-contaminated pixels, following best practices in satellite data correction.

- **Georeferencing and Alignment:** Image datasets from different sources are standardized to maintain spatial consistency across all time periods.

- **Calculation of Vegetation Indices:** NDVI and EVI are computed to measure vegetation density, as widely used in afforestation and ecosystem monitoring projects.

- **Region of Interest (ROI) Selection:** Areas with significant vegetation coverage are selected for further analysis, as recommended in previous studies focusing on targeted afforestation monitoring.

3.3 Analytical Approach
To assess tree coverage and track vegetation changes, the following analytical techniques are applied:

- **Vegetation Index Analysis:** NDVI and EVI values are evaluated across different seasons to identify growth trends and stress factors affecting vegetation.

- **Time-Series Monitoring:** Seasonal and annual vegetation patterns are analyzed to detect long-term environmental trends.

- **GIS-Based Spatial Analysis:** ArcGIS and QGIS are used to visualize tree distribution and identify potential gaps in afforestation efforts.

3.4 Machine Learning and Modeling Tools
This study employs several machine learning techniques to analyze vegetation dynamics, including:

1. **Random Forest (RF)** for classifying vegetation health levels based on climate and satellite data.

2. **Long Short-Term Memory (LSTM)** networks for forecasting future vegetation trends over time.

3. **XGBoost** for enhancing prediction accuracy by modeling vegetation-climate relationships.

3.5 Tools and Technologies
A combination of software and programming tools is used to process and analyze the data:

- **Programming Languages:** Python is used for data processing and machine learning implementation, leveraging libraries such as NumPy, Pandas, and Scikit-learn.

- **GIS Software:** ArcGIS and QGIS facilitate spatial analysis and visualization of afforestation data.

- **High-Performance Computing:** Cloud-based processing is used to manage large-scale satellite datasets, improving computational efficiency.

4. Results
4.1 Seasonal Vegetation Dynamics
The analysis of Sentinel-2 Satellite images across four seasons revealed clear patterns in vegetation health:

- **Spring:** Recorded the highest NDVI and EVI values, indicating peak vegetation density and optimal tree health due to favourable weather conditions and increased rainfall.

Summer: Noted a significant decrease in vegetation indices, reflecting the impact of extreme temperatures and limited precipitation on tree health.

- **Autumn and Winter:** Displayed moderate vegetation density, with gradual recovery after the summer decline but lower than spring levels.

4.2 Regional Variations
Three Regions of Interest (ROIs) within Riyadh were analysed to compare vegetation density. The results showed noticeable differences in tree coverage between areas:

- Some region maintained consistently higher NDVI values, suggesting successful afforestation efforts.

- Other regions exhibited lower vegetation indices, highlighting areas requiring additional efforts.

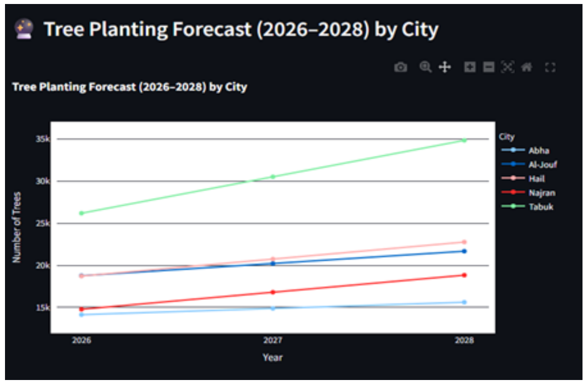

Figure 2. Tree planting forecast

Figure 2, the graph shows the projections of the number of trees that will be planted in five Saudi cities during the period from 2026 to 2028. Data shows that Tabuk will continue to lead with a clear increase of more than 35,000 trees by 2028, while other cities such as Al-Jawf, Najran and Hail will continue to achieve moderate and steady growth. Abha is growing slower than other cities. These projections reflect the results of predictive models based on historical data and satellite imagery, and are an important tool for decision makers to prioritize target areas for afforestation in the coming years.

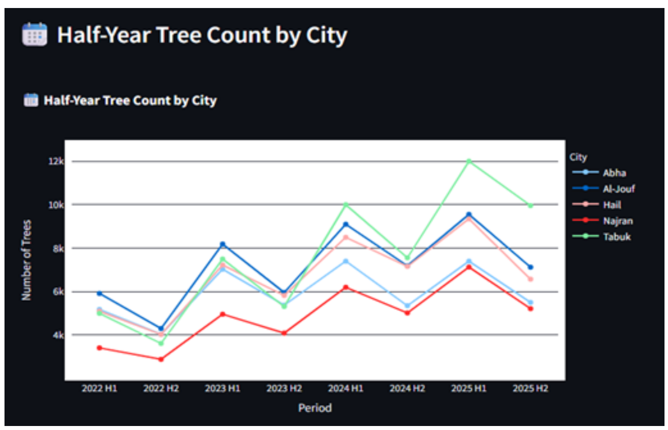

Figure 3. Half-year Tree count by city

As shown in Figure 3 presents the number of trees planted in five Saudi cities—Abha, Al-Jouf, Jazan, Riyadh, and Tabuk—over half-year intervals from the first half of 2021 to the second half of 2023. The x-axis represents the time periods, while the y-axis shows the number of planted trees.Riyadh consistently recorded the highest tree Distribution, with a notable peak in the first half of 2023. Abha, Al-Jouf, and Tabuk followed similar patterns with some fluctuations, whereas Jazan had the lowest tree Distribution but showed gradual improvement over time. Overall, Figure 3 highlights the variation in afforestation efforts among the cities and how these efforts progressed during the observed period.

4.3 Average Vegetation Index Values

The calculated average NDVI and EVI values for each ROI and season confirmed the visual observations. The highest averages were found in spring, while the lowest were observed in summer. These findings validate the importance of continuous seasonal monitoring to understand the health and development of vegetation (Table 1)

Table 1. Model Performance Comparison

Model	**Metric**	**Value**	**Data Used**	**Region**	**Study**
SVM	Afforestation detection	94.5 %	MODIS	Arid Lands (Africa / Middle East)	Afforestation Mapping (SVM)
SVM	Vegetation index enhancement	99.01 %	Sentinel-2 + MCARI, NDI45, GNDVI	Serbia	Improved Vegetation Detection (SVM)
Random Forest	Track vegetation recovery	90.0 %	Landsat (1984–2020)	Italy	Long-Term Vegetation Restoration (RF)
Random Forest	Evaluate national afforestation	90.0 %	Multispectral Satellite Imagery	Pakistan	Pakistan Billion Tree Project Evaluation (RF)
Random Forest	**Afforestation assessment & prediction**	**99.92 %**	**Sentinel-2 + NDVI + EVI + B2, B4, B8**	**Saudi Arabia**	**Current Work**

4.4. Comparison with Previous Studies
The results of this are consistent with earlier studies on vegetation monitoring in arid regions. For instance:

- Study conducted on the Al-Ahsa Oasis and other Saudi cities also identified spring as the peak season for vegetation health using NDVI analysis.
- Studies focusing on urban greening strategies confirmed the effectiveness of remote sensing technologies in identifying vegetation density and supporting large-scale afforestation monitoring.

However, this study builds upon previous work by expanding the monitoring to cover multiple regions and integrating time-series analysis to track vegetation changes over different periods, which addresses key gaps identified in the literature.

4.5. Implications of the Findings
These results provide valuable insights for supporting the Saudi Green Initiative:
- Identifying areas with low vegetation density enables better resource allocation and targeted interventions.
- The established framework can serve as a scalable solution for nationwide monitoring of tree coverage, offering long-term support for environmental sustainability efforts.

5. Discussion
5.1. Interpretation of Results
The seasonal variations in vegetation health align with expected environmental conditions in Saudi Arabia. The harsh summer climate negatively impacts vegetation, while the milder spring season promotes growth. These findings emphasize the importance of planning afforestation activities in alignment with seasonal weather patterns to maximize survival rates and growth.

6. Conclusion and Future Work
Summary of Findings
This study focused on monitoring tree coverage and vegetation health in support of the Saudi Green Initiative, using satellite imagery and vegetation indices (NDVI) and (EVI). By analysing seasonal and regional variations, the study identified clear patterns in vegetation dynamics, with spring emerging as the period of highest vegetation density, while

summer posed significant challenges due to extreme temperatures. The study successfully demonstrated the effectiveness of remote sensing technologies and machine learning models in tracking afforestation progress and providing reliable, large-scale data for environmental management.

Achieving the study Objectives

The study has effectively addressed its key objectives:

- It expanded vegetation monitoring across different regions of Saudi Arabia offering insights into afforestation initiatives on a national scale.
- It utilized remote sensing technologies to accurately assess tree coverage and monitor seasonal changes in vegetation health.
- It established correlations between environmental factors, such as temperature and rainfall, and vegetation dynamics.
- Predictive models were designed to support future vegetation monitoring and enhance planning for afforestation programs.

Future Work

While this study provided valuable insights, there are several areas that could benefit from further study:

- Expanding the geographic scope to cover additional regions of the Kingdom and assess different ecosystems.
- Incorporating high-resolution satellite imagery to improve accuracy in Afforestation Monitoring and vegetation analysis.
- Enhancing machine learning models to predict long-term vegetation trends under various climate change scenarios.
- Integrating socio-economic factors to evaluate the broader impacts of afforestation on urban environments and communities.

In conclusion, this study contributes a practical, scalable framework for vegetation monitoring in Saudi Arabia, supporting national sustainability goals and advancing methods for environmental analysis in arid regions.

References

Abdullah, N., Exploring pattern of green spaces and their impact on climatic change mitigation and adaptation strategies: Evidence from a Saudi Arabian city. *Urban Climate*, 36, 100–111.2021.

Ahmed, S., An application for tree detection using satellite imagery and vegetation data. *Geospatial Journal*, 28(2), 150–162.2020.

Almalki, R., Khaki, M., Saco, P. M., & Rodriguez, J. F., Remote sensing assessment of dam impact on arid basins in southern Saudi Arabia: A machine learning and space-for-time approach. *Journal of Hydrology: Regional Studies*, 58, 102221. 2025.

Al-Qahtani, A., Irrigation water demand management-based innovative strategy: Model application on the Green Riyadh Initiative, Saudi Arabia. *Water Resources Management*, 35(3), 789–802. 2021.

Assiri, M. E., Ali, M. A., Siddiqui, M. H., AlZahrani, A., Alamri, L., Alqahtani, A. M., & Ghulam, A. S. , Remote sensing assessment of water resources, vegetation, and land surface temperature in eastern Saudi Arabia: Identification, variability, and trends. *Remote Sensing Applications*. 2024.

Bosch, M. M. , *DetecTree: Tree detection from aerial imagery in Python*.2022.

Khan, S., et al, Role of urban greening strategies for environmental sustainability: A review and assessment in the context of Saudi Arabian megacities. *Environmental Science Reports*, 12(4), 233–245. 2022.

Kumar, P., et al. , A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Remote Sensing Applications: Society and Environment*, 23, 100–113.2020.

Li, H., et al, Large-scale date palm tree segmentation from multiscale UAV-based and aerial images using deep vision transformers. *Computers and Electronics in Agriculture*, 191, 106–118. 2021.

Martinez, F., et al. Mapping shrub coverage in Xilin Gol Grassland with multi-temporal Sentinel-2 imagery. *Remote Sensing*, 11(9), 1052–1068. 2019.

Smith, J., The retrieval of ground NDVI data consistent with remote-sensing observations. *International Journal of Remote Sensing*, 42(8), 2984–3001. 2021.

Biographies

Mohammed Fayidh Alsharari is currently pursuing a Master of Science degree in Data Science after completing his undergraduate studies in Computer Science at Al-Jouf University, Saudi Arabia. His advanced academic focus lies in applying deep learning and predictive analytics to complex spatio-temporal datasets. He specializes in leveraging remote sensing and machine learning (e.g., LSTM, Random Forest) for environmental forecasting, specifically contributing to the algorithmic and modeling aspects of this research on afforestation efforts. His aim is to develop scalable data-driven solutions for national sustainability challenges.

Hatem Awwad Almutairi is a Master's student in Data Science at the University of Tabuk, Saudi Arabia, holding a strong academic background in Mathematics. His graduate research centers on the statistical validation and interpretation of big data, with an emphasis on time-series analysis for climate and ecological modeling. He is interested in the intersection of mathematical theory and practical data science applications, contributing deep analytical rigor to the assessment of vegetation health and afforestation efforts within this study.

Muhannad Fahad Alhanaya is currently enrolled in the Master of Science program in Data Science at Al-Qassim University, Saudi Arabia, building upon his quantitative skills acquired during his undergraduate studies in Mathematics. His research focuses on advanced machine learning techniques and the implementation of robust methodological frameworks for geospatial analysis. He contributed to the rigorous comparative study of vegetation indices (NDVI/EVI) and the development of high-accuracy forecasting models used to inform regional planning in Saudi Arabia.

Talal Ali Alrashidi is a Master's student in Data Science at the University of Tabuk, Saudi Arabia, with an undergraduate foundation in Mathematics. His graduate work is concentrated on the practical use of advanced analytical tools, particularly Geographical Information Systems (GIS) and cloud computing platforms for managing large environmental datasets. He specialized in the spatial visualization, data engineering, and policy implication aspects of this afforestation project, ensuring the research findings are actionable for environmental decision-makers.

Dr. Ahmad Alkhodair rreceived the B.Sc. degree in Computer Engineering from Fahd Bin Sultan University, Tabuk, Saudi Arabia, in 2012 (with honors); the M.Sc. degree in Computer Engineering from the University of Denver, USA, in 2017, and the Ph.D. degree in Computer Engineering from the University of North Texas, USA, in 2023. Since 2012, he has been with the University of Tabuk, where he is currently an assistant professor in computer engineering. He has been involved in several institutional roles related to risk and business continuity and leads a technical initiative on AI-driven resilience analytics. His research interests include cyber-physical and resilient systems, distributed-ledger technologies and their applications, AI for smart cities, and governance–risk–compliance frameworks for digital transformation.