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Remote Sensing-Based Crop Mapping in Tehran Province, Iran: Focus on Wheat and Barley for Efficient Agricultural Management

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INTRODUCTION & AIM

Agriculture is crucial in addressing global challenges such as population growth, increasing food demand, and climate change. Wheat and barley are among the most important crops worldwide, providing a significant portion of essential calories and nutrients. Accurate monitoring of these crops is key to ensuring food security, but traditional field-based methods are not practical for large-scale areas. Remote sensing technologies, combined with advanced machine learning algorithms, offer an efficient solution for large-scale, continuous monitoring. This study focuses on mapping wheat and barley in Tehran Province, Iran, through the analysis of Sentinel-1 and Sentinel-2 satellite images at key phenological growth stages—sowing, tillering, heading, and ripening—using Google Earth Engine. By leveraging various spectral indices and implementing a Random Forest classifier, the objective is to demonstrate the effectiveness of remote sensing and Google Earth Engine in providing precise and large-scale crop classification. This contributes to enhancing agricultural resource monitoring and decision-making processes for better crop management.

METHOD

This study aimed to classify wheat and barley in Tehran Province using remote sensing data. The study area is located in northeastern Tehran Province, encompassing selected regions within the cities of Rey, Varamin, Pakdasht, Pishva, and Qarchak. This region features diverse agricultural and semi-urban landscapes, offering a representative cross-section of the area's crop cultivation practices. Rey (35.5833° N, 51.4333° E) is situated to the southwest and includes a mix of industrial and agricultural lands. Varamin (35.3000° N, 51.5500° E) and Pakdasht (35.3833° N, 51.7833° E) are located to the southeast, characterized by extensive agricultural fields. Pishva (35.4333° N, 52.0667° E), positioned to the east, contains both agricultural and semi-urban areas. Qarchak (35.4167° N, 51.7167° E), to the south, features a combination of agricultural and residential zones.

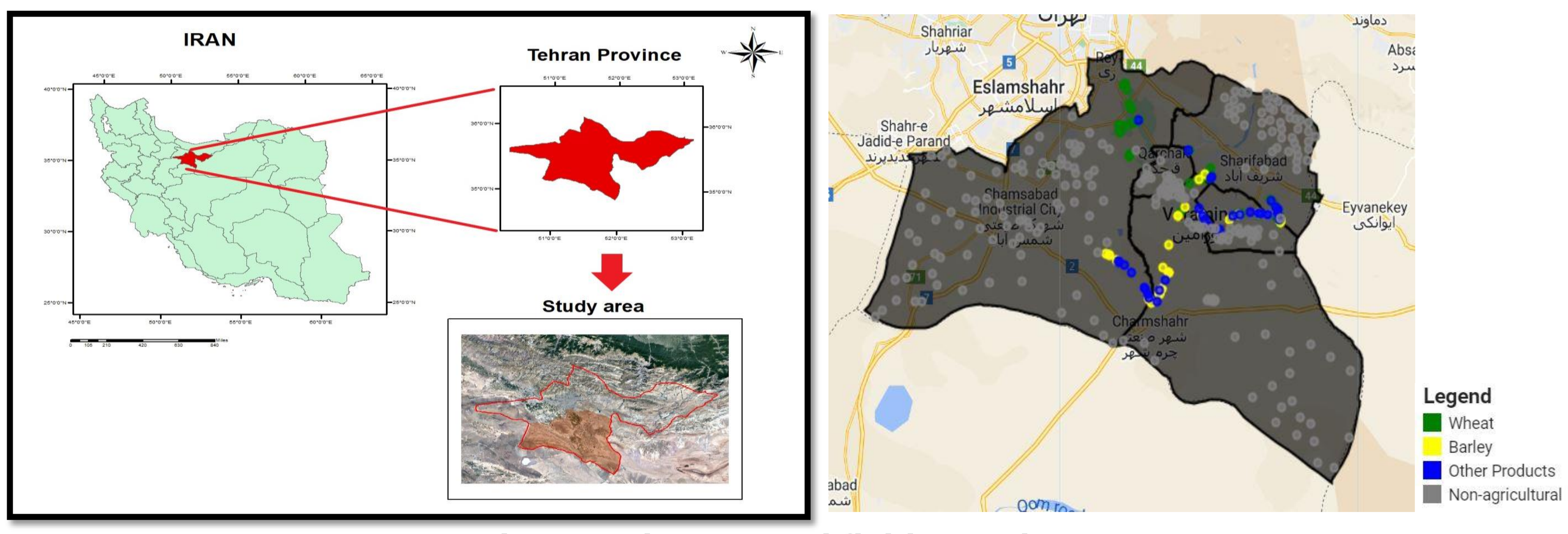


Fig 1 Study area and field samples

The primary satellite data utilized in this study were sourced from Sentinel-1 and Sentinel-2, processed via Google Earth Engine. The data cover the years 2022 and 2023 and are specific to four key periods in the agricultural calendar: sowing, tillering, heading, and ripening. Due to incomplete and imprecise dates in the agricultural calendar, spectral signatures were employed to approximate the dates for these critical agricultural periods. The field data consisted of 655 samples collected across four classes: wheat, barley, other agricultural products, and non-agricultural areas.
The proposed methodology consists of four distinct classification scenarios:

- ***Scenario 1**: This scenario utilized key vegetation indices extracted from Sentinel-2, including NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), LSWI (Land Surface Water Index), NDWI (Normalized Difference Water Index), GCVI (Green Chlorophyll Vegetation Index), NDREI (Normalized Difference Red Edge Index), and MTCI (Meris Terrestrial Chlorophyll Index) for identifying various land cover types.*
- ***Scenario 2**: This scenario employed only the multispectral bands of Sentinel-2 and the radar bands from Sentinel-1.*
- ***Scenario 3**: This scenario combined features derived from Sentinel-1 images with the aforementioned vegetation indices from Sentinel-2.*
- ***Scenario 4**: In the final scenario, all features tested in the previous scenarios were integrated and evaluated collectively.*

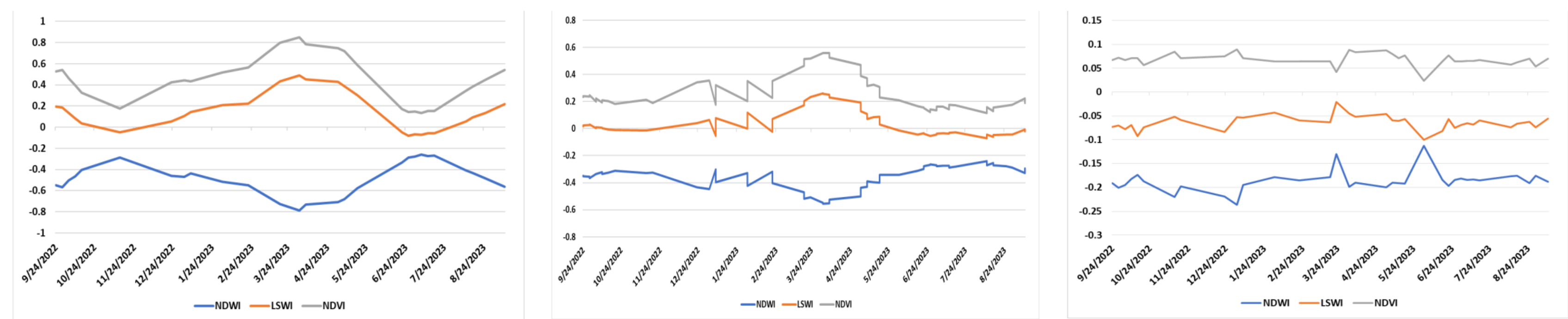
The aim of these four scenarios is to assess the impact of different combinations of spectral indices, multispectral bands, and radar data on the accuracy of crop classification. In the third stage, a Random Forest classification was applied to the prepared image stacks using field samples. Specifically, 70% of the samples were used for training, while the remaining 30% were reserved for accuracy assessment in the fourth stage of the study. Finally, all generated maps were evaluated for accuracy through confusion matrix analysis.

RESULTS & DISCUSSION

In this section, the results derived from the proposed methodology are detailed, with a focus on the effectiveness of different approaches to mapping wheat and barley in Tehran Province, Iran.

- ***Data Preparation and Feature Extraction***

To initiate the analysis, satellite data were collected for four key time points within the agricultural calendar, specifically during the phenological stages of sowing, tillering, heading, and ripening. The spectral variation between each time plays a crucial role in distinguishing vegetation cover from other land uses and aids in differentiating between various crops.
The spectral analysis led to the selection of the NDVI, EVI, and LSWI for graphical representation. The below figure presents these indices for three land uses: wheat, barley, and non-agricultural areas, throughout the study period. The choice of these three indices was made to prevent overcrowding in the results while ensuring sufficient data for effective analysis. The graphs demonstrate distinct behaviors for each land use from planting to harvest, highlighting the potential of spectral behavior analysis in identifying and differentiating various land uses.



(a) (b) (c)

Fig 2 NDVI, LSWI and NDWI indices diagrams; a) Wheat, b) Barley, c) Non-agricultural.

While the spectral responses of wheat and barley may appear somewhat similar at certain time points, a closer examination of the y-axis in the graphs reveals more pronounced differences. This emphasizes the importance of utilizing multiple time periods, or leveraging the phenological behavior of the crops, to enhance the feature extraction process and improve the performance of the classification algorithm.

- ***Map Generation and Evaluations***

The mapping of wheat and barley was conducted using machine learning algorithms available in Google Earth Engine. After thorough evaluations, the Random Forest algorithm, utilizing 100 trees, was identified as the most accurate and effective method for delivering results. The outcomes of the algorithm across all four scenarios are summarized here, providing insight into the performance of various data combinations.
***Scenario 1** relied solely on features extracted from Sentinel-2 images, yielding an overall accuracy of 76.9% with an Omission Error of 27.92% and a Commission Error of 28.32%. While these results indicate a need for improved class identification, the F1 Score stood at 71.85%.*
***Scenario 2** which integrated bands from both Sentinel-1 and Sentinel-2, exhibited a marked reduction in Omission Error to 16.55% and a Commission Error of 27.65%, resulting in an overall accuracy of 86.1% and an F1 Score of 74.88%. This significant enhancement underscores the advantage of combining data from multiple satellites for crop mapping.*
*In **Scenario 3**, which considered features extracted from both Sentinel-1 and Sentinel-2, the overall accuracy was recorded at 81.25%; however, this scenario faced an increase in Omission Error to 35.67%, indicating challenges in classifying certain crop types effectively. The F1 Score was 65.35%, with a Kappa coefficient of 61.4%, suggesting a less favorable performance compared to Scenario 2.*
*Finally, **Scenario 4**, which combined both features and bands from Sentinel-1 and Sentinel-2, provided the best results among the evaluated scenarios. It achieved an Omission Error of 29.72% and a Commission Error of 21.32%, resulting in an overall accuracy of 83.5% and an F1 Score of 72.2%. This scenario indicated significant improvements in class identification and overall performance.*
In conclusion, Scenario 2 demonstrated the best performance regarding overall accuracy and Omission Error reduction, while the combination of features and bands in Scenario 4 also yielded promising results, indicating substantial potential for improved crop identification accuracy.

CONCLUSION

This research highlights the vital role of remote sensing technologies in accurately mapping wheat and barley crops, crucial for global food security and agricultural management. By utilizing data from Sentinel-1 and Sentinel-2 and applying advanced machine learning algorithms, the study successfully categorized agricultural land. The results indicate that combining both satellite data enhances mapping accuracy, with optimal performance achieved through integrating features and bands. Future improvements in feature selection, algorithm optimization, and the inclusion of ground truth data can further enhance classification precision, supporting better agricultural planning and future research in remote sensing-based crop monitoring.

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