Evaluation of Sentinel-2 Deep Resolution 3.0 Data for Mapping Mangrove Forests in Iran

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Abstract

Recent developments in remote sensing, particularly deep learning-based Single Image Super-Resolution (SISR) techniques, have improved the spatial detail of satellite imagery, enabling more accurate mapping of land cover types such as mangrove forests. This study evaluates and compares the effectiveness of two datasets—standard Sentinel-2 imagery (10 m resolution) and super-resolved Sentinel-2 Deep Resolution 3 (S2DR3) data—in mapping mangrove forests across the Qeshm, Sirik, and Gwatar regions. Two widely used classification algorithms, Random Forest (RF) and Support Vector Machine (SVM), were applied to each dataset. The results showed that the RF algorithm applied to S2DR3 data achieved the highest classification accuracy (96%) for mangrove detection, outperforming RF–Sentinel-2 (86%), SVM–S2DR3 (90%), and SVM–Sentinel-2 (81%). In terms of area estimation, RF–S2DR3 mapped 8,147 ha of mangroves, while RF–Sentinel-2, SVM–S2DR3, and SVM–Sentinel-2 yielded 8,023, 9,227, and 9,984 ha, respectively. These results demonstrate that the higher spatial resolution of S2DR3 enhances the detection of smaller, fragmented mangrove patches, particularly along coastal fringes. Overall, the findings confirm the superiority of both S2DR3 imagery and the RF algorithm in accurately classifying and quantifying mangrove cover. This approach holds promise for improving the precision of ecosystem monitoring and supporting more effective conservation strategies in sensitive coastal environments.

1. Introduction

Remote sensing technology has recently become one of the most effective tools for monitoring and detailed analysis of natural ecosystems (Miandej et al., 2024). Continuous advancements in this field have enabled the extraction of more accurate information about the biological and physical characteristics of the environment (Chanev et al., 2025). Various satellite datasets with diverse spectral and spatial capabilities are utilized for this purpose. Among them, Sentinel-2 satellite data, due to its global coverage and high revisit frequency, is considered a key resource for land cover monitoring. These images are provided at three spatial resolutions of 10, 20, and 60 meters and have wide applications in environmental studies (Baloloy et al., 2020). Despite the importance of Sentinel-2 data in land cover monitoring, its 10-meter spatial resolution may pose limitations in some fine-grained applications, such as distinguishing intricate structures or accurately delineating vegetation boundaries (Cristille et al., 2024). Therefore, in recent years, advanced machine learning-based methods, particularly deep learning, have emerged to enhance the resolution of satellite images. One such approach is Single-Image Super-Resolution (SISR), which, by utilizing only a single input image, can significantly increase spatial resolution without requiring auxiliary data. This method, designed to reconstruct fine details in 10-meter Sentinel-2 images, is recognized as an effective solution to overcome spatial limitations in precise land cover monitoring applications (Michel et al., 2023). In this approach, a high-resolution image is predicted from a degraded low-resolution image—a process that presents a significant challenge in real-world scenarios due to the unknown and complex nature of image degradation (Chanev et al., 2025). The S2DR2 data, introduced in late 2022, is a highly effective Single-Image Super-Resolution (SISR) technique. Its primary objective was to enhance the spatial resolution of all spectral bands of Sentinel-2 images (originally at 10, 20, and 60 meters) to a target spatial resolution of 1 meter per pixel. Crucially, this model operates solely on a single Sentinel-2 image, without auxiliary high-resolution data, and successfully produces high-quality outputs that facilitate applications requiring high revisit rates (Akhtman, 2022). An improved version of this model, named S2DR3, was introduced in October 2023, focusing on increasing spectral resolution and reconstructing finer spatial details, demonstrating better performance than its predecessor (Akhtman, 2024). Both models are meticulously designed to preserve the precise spectral variability of soil and vegetation across all 10 Sentinel-2 bands. By leveraging advanced deep learning techniques, they significantly enhance not only image quality but also the richness and accuracy of the derived information. With the enhancement of the spatial resolution of Sentinel-2 images and the use of advanced super-resolution models such as S2DR3, more precise analysis and effective monitoring of sensitive ecosystems have become possible (Akhtman, 2024). One of these valuable and vulnerable ecosystems is the mangrove forest, which is highly productive in terms of biomass, with primary productivity comparable to tropical evergreen rainforests (Carugati et al., 2018; Bihamta Toosi et al., 2020). These forests provide vital ecological services such as carbon sequestration and storage and

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water purification (Sahraei et al., 2023), and act as natural barriers against natural disasters like storms and tsunamis (Ibrahim et al., 2015). However, mangrove forests are rapidly declining, amounting to an overall 35 percent loss over the past 20 years (Carugati et al., 2018). Therefore, producing accurate and up-to-date maps of mangrove forests is essential for continuous monitoring and sustainable management of these ecosystems. Several techniques have been developed for classification and mapping of mangrove forests using medium to high-resolution remote sensing imagery (Wei et al., 2023; Wang et al., 2023). However, selecting appropriate data and products is crucial due to the diversity of species and forest structures in different mangrove regions (Ashournejad et al., 2019b). Machine learning algorithms such as Random Forest (RF) and Support Vector Machine (SVM) have been widely applied for classifying these ecosystems based on satellite data, demonstrating better performance compared to traditional approaches (Bihamta Toosi et al., 2020). Consequently, numerous studies have utilized these algorithms and remote sensing images for mapping, monitoring, and quantifying mangrove forests (Miandej et al., 2024; ErfaniFard et al., 2023; Soffianian et al., 2023). Today, SVM and RF algorithms are particularly recognized as reference tools in this field because of their high accuracy, automation capability, and efficiency (Xia et al., 2018; Wang et al., 2018). Despite significant advances in the use of remote sensing data for mapping mangrove forests, most studies have relied on medium spatial resolution data such as Landsat and Sentinel-2, and the effectiveness of enhanced high-resolution data has not been thoroughly evaluated (Qin et al; 2025). This study utilizes standard 10-meter resolution Sentinel-2 images and enhanced 1-meter spatial resolution Sentinel-2DR3 images to map mangrove forests in the sensitive regions of Qeshm, Sirik, and Gwatar using Random Forest and Support Vector Machine classification algorithms. The aim of this research is to assess the accuracy and efficiency of the Sentinel-2 Deep Resolution 3 (S2DR3) data and to evaluate the feasibility of using these images for monitoring sensitive coastal ecosystems. The results of this study could provide a novel perspective for leveraging deep learning technologies in the field of remote sensing and coastal ecosystem management.

2. Materials and methods

2.1 Study area

The mangrove forests of Iran are scattered along the northern coasts of the Persian Gulf and the Gulf of Oman, occurring either as continuous stands or fragmented patches. These forests are typically located along estuaries, bays, and waterways, with their distribution extending up to the maximum tidal influence (Safiari, 2017). According to Miandej et al. (2024), the regions of Qeshm, Sirik, and Gwatar host the most extensive mangrove areas along these coasts (Figure 1).

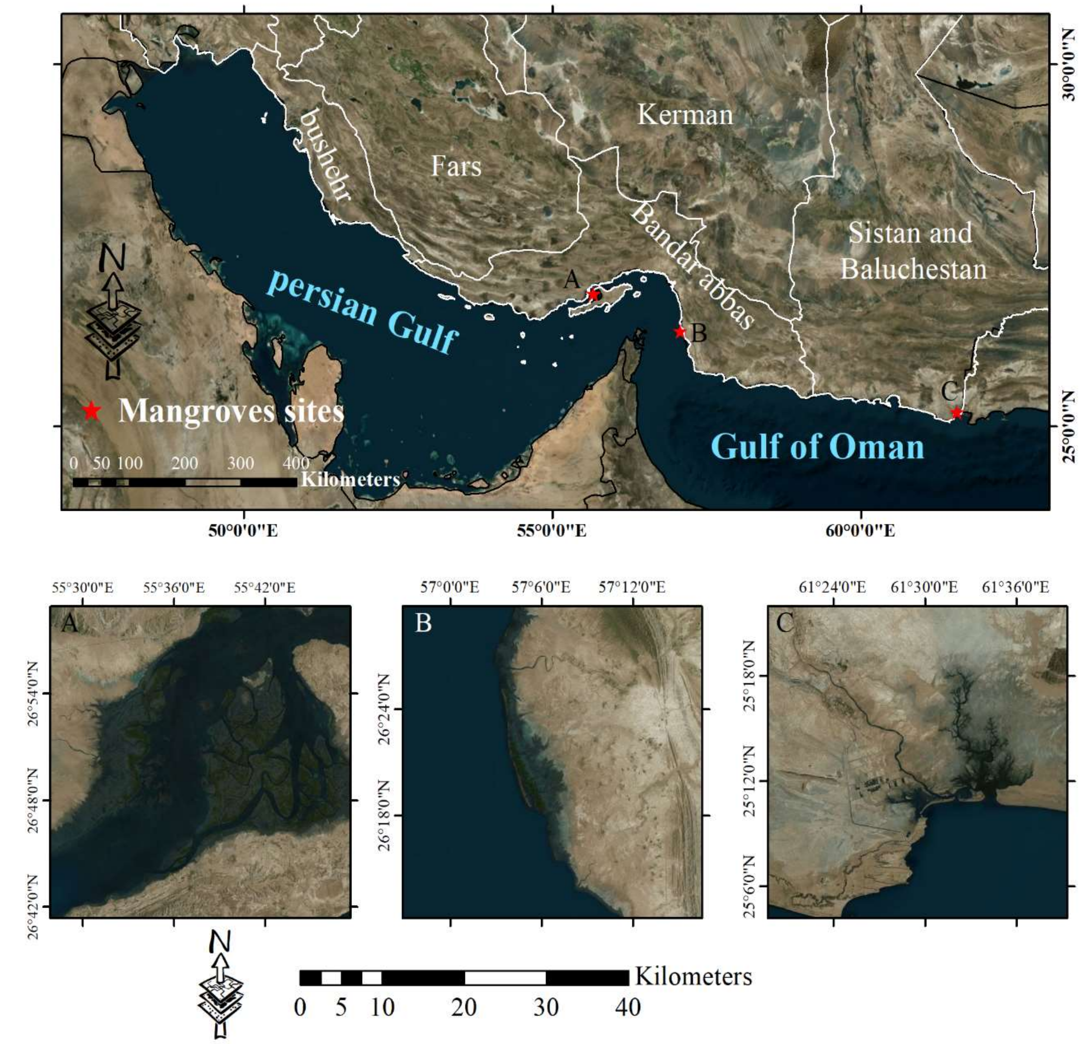

Figure 1. Map of the study area: Qeshm Island (A), Sirik (B), and Gwatar (C).

2.2 Methods

In this study, two types of Sentinel-2 satellite imagery were used for mangrove forest mapping: standard images with a spatial resolution of 10 meters and enhanced images with a spatial resolution of 1 meter (S2DR3). To distinguish mangrove cover from other land cover types, two machine learning algorithms—RF and SVM—were employed (Figure 2).

Since mangrove cover is affected by seawater during high tide, making its detection more difficult, selecting satellite images captured during low tide is of great importance (Erfanifard et al., 2022; Baloloy et al., 2020). Accordingly, three satellite images representing low tide conditions and covering the entire study area were selected (Table 1). These images were obtained using archived tidal data from the Tides4Fishing website, and the times corresponding to maximum seawater retreat were identified and chosen for analysis.

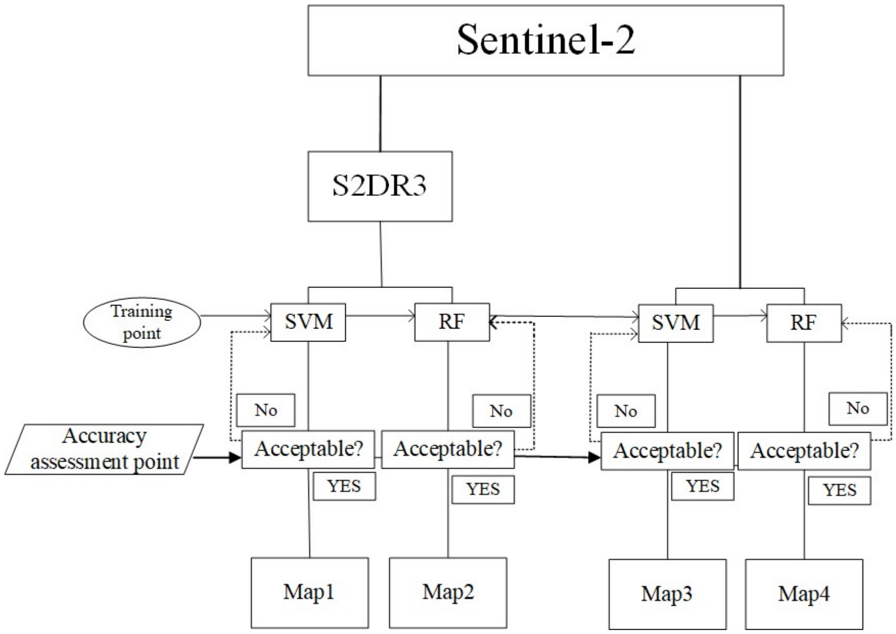

Figure 2. Conceptual model of the mangrove forest mapping process in the study areas.

Image	Satellite/Sensor	Image ID	Date	Coordinate System
1	Sentinel2A/MSI	T40RCQ	07/07/2023	WGS84/UTM/40N
2	Sentinel2A/MSI	T40RDQ	07/27/2023	WGS84/UTM/40N
3	Sentinel2A/MSI	T41RLH	06/01/2023	WGS84/UTM/41N

Table 1. Specifications of the images used in this study

2.2.1 Classification

The mangrove forest classification in this study was performed using two algorithms: RF and SVM. To ensure complete coverage of the study areas, both standard Sentinel-2 (S2) imagery and its enhanced version (S2DR3) were utilized. The input data consisted of ten Sentinel-2 bands: B2, B3, B4, B5, B6, B7, B8, B8A, B11, and B12. A total of 1,680 training samples were collected through visual interpretation of high-resolution Google Earth imagery, ensuring representation of the diverse land cover types present in the study area. The use of high-accuracy reference sources such as Google Earth for labeling is a common practice in evaluating the performance of satellite image classifications (Garshasbi et al., 2025). For the RF algorithm, 30 decision trees were empirically selected to achieve an optimal trade-off between classification accuracy and overfitting. The SVM algorithm, grounded in statistical learning theory, defines decision boundaries by maximizing the margin between classes (Vidhya et al., 2014), thereby enhancing generalization capability. For multi-class classification with SVM, the One-vs-One strategy was employed. The outputs from both RF and SVM algorithms—typically in the form of decision scores for each pixel—were subsequently converted into class membership probabilities for the final analysis.

2.2.2 Accuracy Assessment

In this study, the classification accuracy of mangrove forests for maps produced using the RF and SVM algorithms was evaluated using 900 reference points extracted from Google Earth imagery. A confusion matrix was employed as the primary evaluation tool. This matrix is a standard and widely accepted method for assessing classification performance by comparing the classification results with reference data (Congalton, 1991). This approach quantifies the proportion of pixels identified by the model as mangrove forest that actually correspond to the ground truth (Miandej et al., 2024).

3. Results

The results indicate that S2DR3 data demonstrate superior accuracy in detecting smaller and more fragmented mangrove areas compared to standard Sentinel-2 data. This improvement in classification accuracy is primarily attributed to the higher spatial resolution of S2DR3, which allows for more precise delineation of vegetation boundaries in heterogeneous environments. In the model evaluation, the RF algorithm outperformed SVM (Figure 3). Specifically, the overall accuracy of mangrove classification using RF with S2DR3 data reached 94%, 96%, and 97% for the Qeshm, Sirik, and Gwatar regions, respectively, whereas the same algorithm using standard Sentinel-2 data achieved accuracies of 84%, 87%, and 86%. In contrast, the SVM algorithm combined with S2DR3 data also produced relatively favorable classification results, with accuracies of 90%, 92%, and 91% for the studied regions. These figures represent a significant improvement over the results obtained using standard Sentinel-2 imagery. The accuracies for the same regions were 80%, 81%, and 91%, respectively (Table 2).

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Site Name		Qeshm	Sirik	Gwatar	Overall
RF(1m)	**OA**	94%	96%	97%	96%
	Kappa	89%	93%	93%	92%
	Area(ha)	6903.94	764.82	478.35	8147.11
RF(10m)	**OA**	84%	87%	86%	86%
	Kappa	68%	75%	72%	72%
	Area(ha)	6735.29	783.4	505.2	8023.89
SVM(1m)	**OA**	90%	92%	91%	90%
	Kappa	80%	86	82%	79%
	Area(ha)	7870.24	822.08%	535.24	9227.56
SVM(10m)	**OA**	80%	81%	82%	81%
	Kappa	64%	62%	64%	63%
	Area(ha)	8414.7	891.27	678.57	9984.54

Table2. Evaluation results of the performance of RF and SVM classification algorithms for mangrove forest classification using Sentinel-2 and S2DR3 data.

From the perspective of mangrove forest area estimation, the classification results using the RF algorithm, based on Sentinel-2 data, showed estimated mangrove cover of 6,735.29, 783.40, and 505.20 hectares in Qeshm, Sirik, and Gwatar regions, respectively. Conversely, estimates derived from S2DR3 data for these regions were slightly different, yielding 6,903, 764.82, and 478.35 hectares. When the SVM algorithm was applied to Sentinel-2 imagery, it estimated larger areas—8,414.70, 891.20, and 678.50 hectares for the same regions. However, utilizing S2DR3 data with SVM resulted in lower estimates of 7,870, 822.08, and 535.20 hectares, respectively (Figure 4). Further analysis of the classification outputs through visual comparison strongly suggests that the 1-meter resolution data (S2DR3) offers a more detailed and precise delineation of mangrove forest distribution compared to the coarser 10-meter resolution. Furthermore, the Random Forest algorithm consistently demonstrated superior performance in identifying and delineating mangrove boundaries, particularly within heterogeneous landscapes, when compared to the SVM classifier (Figure 5).

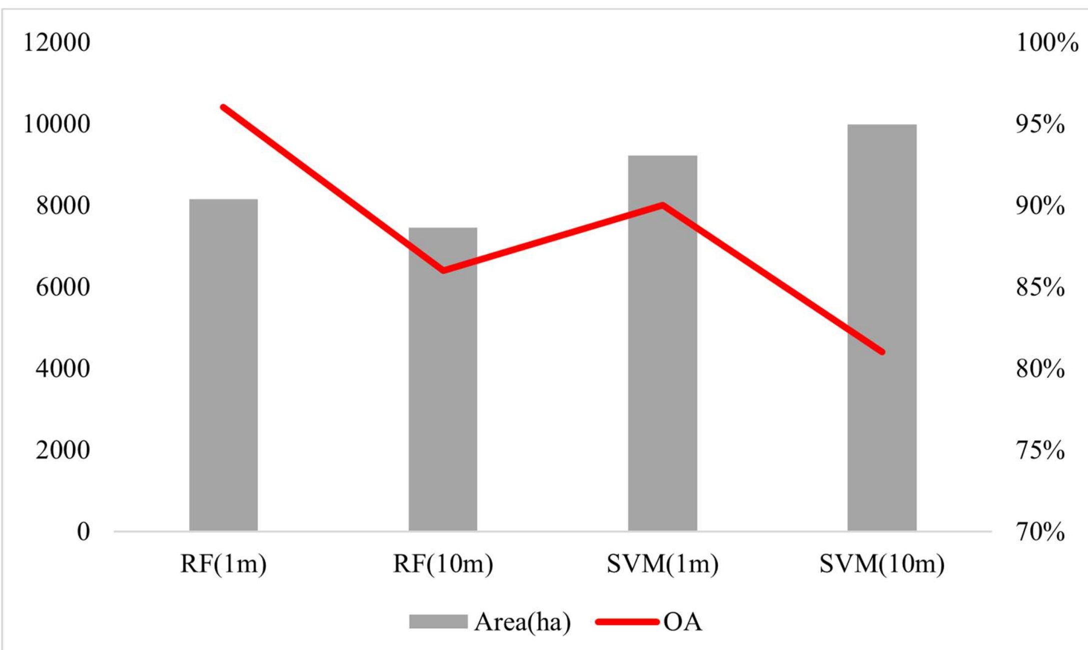

Figure 3. Comparison of the performance of RF and SVM classification algorithms for mangrove forest mapping using Sentinel-2 and S2DR3 data.

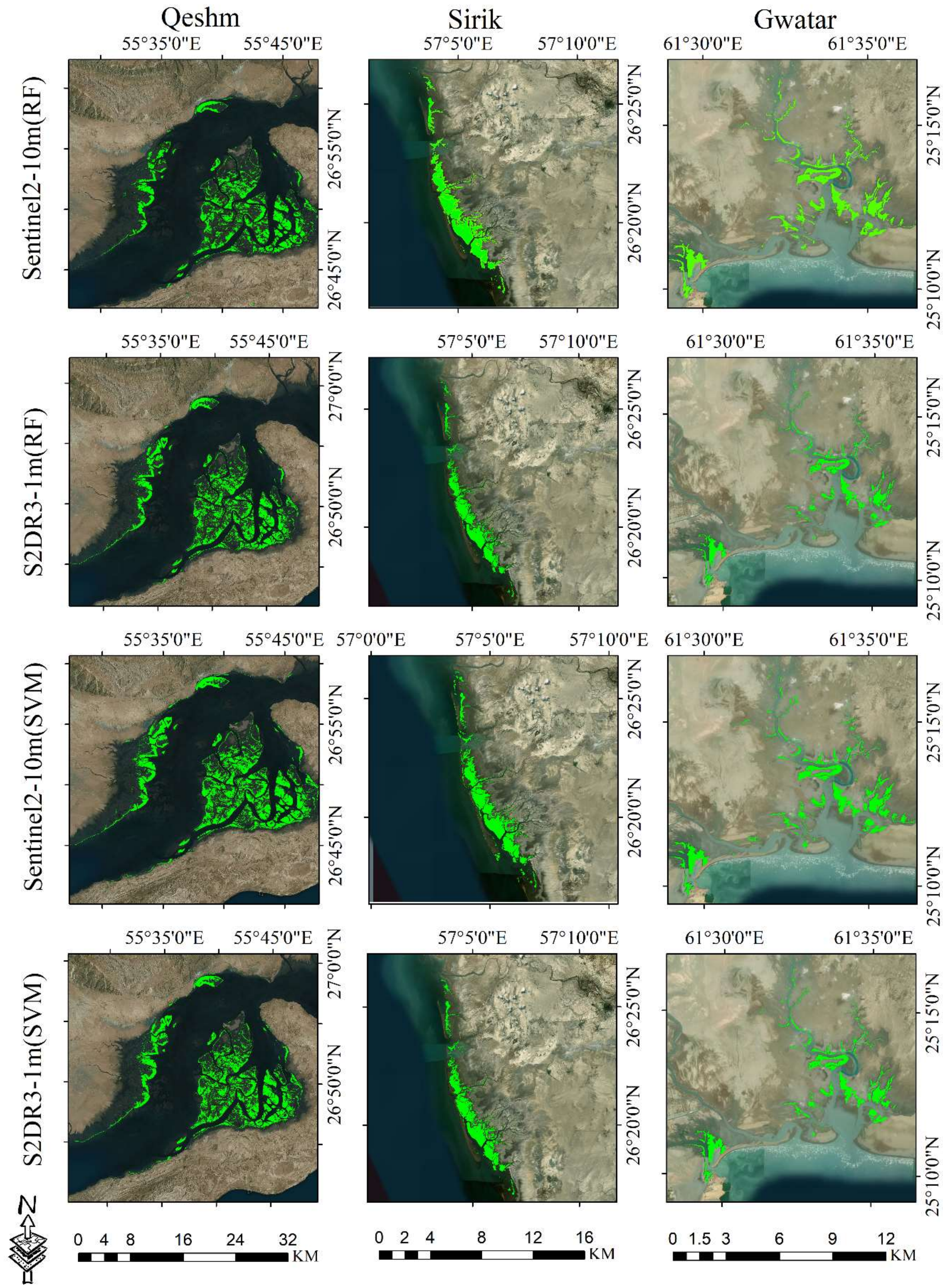

Figure 4. Spatial distribution of mangrove forests in the study areas

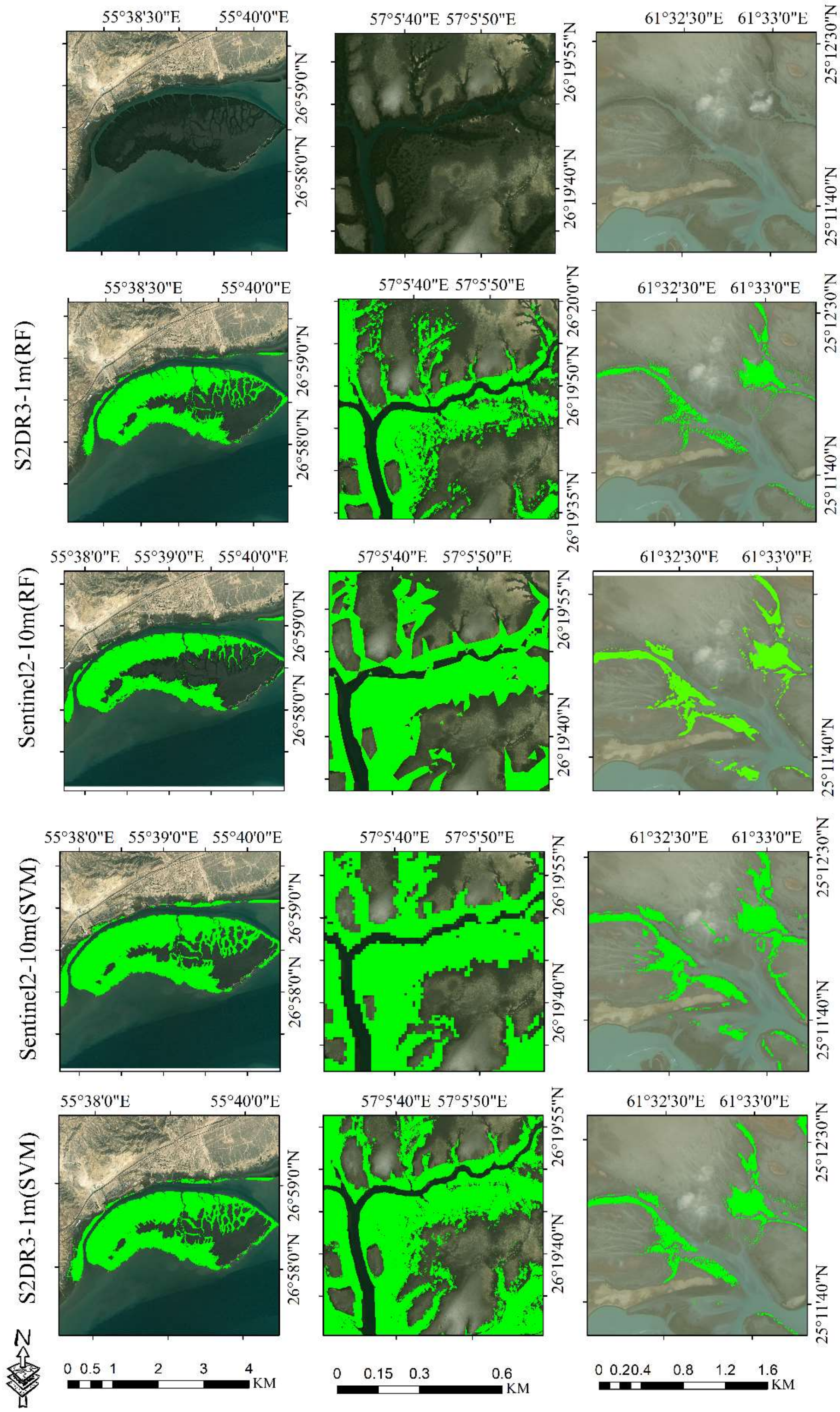

Figure 5. Visual assessment of mangrove cover based on classification algorithms

4. Discussion

The present study aims to assess the impact of enhanced spatial resolution on classification accuracy and to compare the results with those obtained from medium-resolution imagery. Unlike previous research (Miandej et al., 2024; Gupta et al., 2018), which primarily employed medium-resolution data for mangrove forest mapping, this study utilizes high-resolution imagery to evaluate potential improvements. The findings indicate that higher spatial resolution enables more accurate delineation of small and heterogeneous mangrove structures, particularly in areas with sparse or fragmented vegetation cover. The results further show that using enhanced S2DR3 data not only increases overall classification accuracy but also significantly improves the reliability of mapping outputs for the management and conservation of these sensitive ecosystems—findings that are consistent with those reported by Wang et al. (2018). The superior performance of S2DR3 data is largely attributed to its enhanced ability to differentiate mangroves from spectrally similar land cover classes, such as water bodies and wet soils. These classes often exhibit spectral overlap in standard Sentinel-2 imagery at 10-meter spatial resolution, a challenge also highlighted in prior studies, including Chen et al. (2023), which emphasize that classification accuracy in heterogeneous coastal zones is highly dependent on the spatial resolution of the input imagery. A comparative analysis of the RF and SVM algorithms revealed that the choice of classification algorithm plays a critical role in final accuracy, depending on the characteristics of the input data. Specifically, the RF algorithm exhibited superior performance across both high- and medium-resolution datasets, in agreement with the findings of Bihamta Toosi et al. (2019) and Cherian et al. (2023).

5. Conclusion

The spatial resolution of remote sensing data plays a critical role in accurately estimating area and identifying sensitive ecosystems such as mangrove forests. A key objective of this study was to assess the impact of spatial resolution on mangrove area estimation. The S2DR3 data produced different area estimates than standard Sentinel-2 imagery, highlighting its enhanced capability to detect smaller and more fragmented mangrove patches. This distinction is particularly important in extensive regions such as Qeshm Island, which exhibits heterogeneous vegetation structures and complex spatial patterns. Improved accuracy in area estimation not only enhances coastal ecosystem monitoring but also supports more informed and effective management decisions. However, higher spatial resolution comes with trade-offs, including increased computational demands and larger data volumes, which may pose limitations for large-scale or long-term studies. Therefore, balancing the desired mapping precision with operational feasibility is essential for practical applications. Future research should consider integrating multi-source data with varying spatial resolutions and sensitivities to harness both the detailed insight of high-resolution imagery and the scalability of conventional datasets.

References

Akhtman, Y. (2022, Dec 16). *Sentinel-2 Deep Resolution 2.0*. Medium. https://medium.com/@ya_71389/sentinel-2-deep-resolution-2-0-c3d530d9bdf8

Akhtman, Y. Sentinel-2 Deep Resolution. Available online: https://medium.com/@ya_71389/sentinel-2-deep-resolution-3-0-c7 1a601a2253 (accessed on 23 January 2024).

Ashournejad, Q., Amiraslani, F., Kiavarz Moghadam, M., Toomanian, A., 2019b**.** Assessing the changes of mangrove ecosystem services value in the Pars Special Economic Energy Zone. *Ocean & Coastal Management*, 179, 104838. https://doi.org/10.1016/j.ocecoaman.2019.104838

Baloloy, A. B., Blanco, A. C., Ana, R. R. C. S., Nadaoka, K. 2020. Development and application of a new mangrove vegetation index (MVI) for rapid and accurate mangrove mapping. *ISPRS Journal of Photogrammetry and Remote Sensing,* 166, 95–117. https://doi.org/10.1016/j.isprsjprs.2020.06.001

Bihamta Toosi, N., Soffianian, A. R., Fakheran, S., Pourmanafi, S., Ginzler, C., Waser, L. T. 2020. Land cover classification in mangrove ecosystems based on VHR satellite data and machine learning—an upscaling approach. *Remote Sensing,* 12(17), 2684. https://doi.org/10.3390/rs12172684

Chanev, M., Kamenova, I., Dimitrov, P., Filchev, L. 2025. Evaluation of Sentinel-2 Deep Resolution 3.0 Data for Winter Crop Identification and Organic Barley Yield Prediction. *Remote Sensing*, 17(6), 957. https://doi.org/10.3390/rs17060957

Carugati, L., Gatto, B., Rastelli, E., et al. 2018. Impact of mangrove forests degradation on biodiversity and ecosystem functioning. *Scientific Reports,* 8, 13298. https://doi.org/10.1038/s41598-018-31683-0

Chen, R., Zhang, R., Zhao, C., Wang, Z., Jia, M. 2023. High-Resolution Mapping of Mangrove Species Height in Fujian Zhangjiangkou National Mangrove Nature Reserve Combined GF-2, GF-3, and UAV-LiDAR. *Remote Sensing,* 15(24), 5645. https://doi.org/10.3390/rs15245645

Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37(1), 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Cristille, P.-L., Bernhard, E., Cox, N. L. J., Bernard-Salas, J., Mangin, A. 2024. Earth Observation Multi-Spectral Image Fusion with Transformers for Sentinel-2 and Sentinel-3 Using Synthetic Training Data. *Remote Sensing*, 16(16), 3107. https://doi.org/10.3390/rs16163107

Erfanifard, Y., Lotfi Nasirabad, M. 2023. Mapping mangrove forest extent in Iran using Sentinel-2 imagery. *Iranian Journal of Forest and Poplar Research*, 31(2), 98–112. https://doi.org/10.22092/IJFPR.2023.360820.2081

Erfanifard, Y., Lotfi Nasirabad, M., Stereńczak, K. 2022. Assessment of Iran's mangrove forest dynamics (1990–2020) using Landsat time series. *Remote Sensing,* 14(19), 4912. https://doi.org/10.3390/rs14194912

Garshasbi, F., Ashournejad, Q., Ghalenoei, N. 2025. A comparative assessment of remote sensing based land cover products for economic valuation of ecosystem services of

Hyrcanian forests. *Advances in Space Research*, *75*(6), 4552-4574. https://doi.org/10.1016/j.asr.2024.12.064

Gupta, K., Mukhopadhyay, A., Giri, S., Chanda, A., Majumdar, S. D., Samanta, S., ... Hazra, S. 2018. An index for discrimination of mangroves from non-mangroves using LANDSAT 8 OLI imagery. *MethodsX,* 5, 1129–1139. https://doi.org/10.1016/j.mex.2018.09.011

Miandej, M., Ashournejad, Q., Garshasbi, F. 2024. Assessment of Remote Sensing Images and Products in Mapping Mangrove Forests of Iran (Northern Coasts of the Persian Gulf and the Gulf of Oman). *Desert,* 29(2), 283–302. https://doi.org/10.22059/jdesert.2024.100718

Michel, J., Vinasco-Salinas, J., Inglada, J., Hagolle, O. 2022. SEN2VENµS, a Dataset for the Training of Sentinel-2 Super-Resolution Algorithms. *Data*, 7(7), 96. https://doi.org/10.3390/data7070096

Cherian, S. M., K, R. (2024). Random forest and support vector machine classifiers for coastal wetland characterization using the combination of features derived from optical data and synthetic aperture radar dataset. *Journal of Water and Climate Change*, 15(1), 29-49. https://doi.org/10.2166/wcc.2023.238

Qin, Q., Dai, W., Wang, X. (2025). Super Resolution for Mangrove UAV Remote Sensing Images. *Symmetry*, 17(8), 1250. https://doi.org/10.3390/sym17081250

Sahraei, R., Ghorbanian, A., Kanani-Sadat, Y., Jamali, S., & Homayouni, S. 2023. Identifying suitable locations for mangrove plantation using geospatial information system and remote sensing. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 10*, 669–675. https://doi.org/10.5194/isprs-annals-X-4-W1-2022-669-2023

Safiari, S. (2017). Mangrove forests in Iran. *Iran nature*, 2(2), 49-57. https://doi.org/10.22092/irn.2017.111425

Soffianian, A. R., Toosi, N. B., Asgarian, A., Regnauld, H., Fakheran, S., Waser, L. T. 2023. Evaluating resampled and fused Sentinel-2 data and machine-learning algorithms for mangrove mapping in the northern coast of Qeshm island, Iran. *Nature Conservation,* 52, 22. https://doi.org/10.3897/natureconservation.52.89639

Vidhya, R., Vijayasekaran, D., Farook, M. A., Jai, S., Rohini, M., Sinduja, A. 2014. Improved classification of mangroves health status using hyperspectral remote sensing data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-8*, 667–670. https://doi.org/10.5194/isprsarchives-XL-8-667-2014

Wang, D., Wan, B., Qiu, P., Su, Y., Guo, Q., Wang, R., ... Wu, X. 2018. Evaluating the performance of Sentinel-2, Landsat 8 and Pléiades-1 in mapping mangrove extent and species. *Remote Sensing,* 10(9), 1468. https://doi.org/10.3390/rs10091468

Wang, X., Tan, L., Fan, J. 2023. Performance Evaluation of Mangrove Species Classification Based on Multi-Source Remote Sensing Data Using Extremely Randomized Trees in Fucheng Town, Leizhou City, Guangdong Province. *Remote Sensing*, 15(5), 1386. https://doi.org/10.3390/rs15051386

Wei, Y., Cheng, Y., Yin, X., Xu, Q., Ke, J., Li, X. 2023. Deep Learning-Based Classification of High-Resolution Satellite Images for Mangrove Mapping. *Applied Sciences*, 13(14), 8526. https://doi.org/10.3390/app13148526

Xia, Q., Qin, C.-Z., Li, H., Huang, C., Su, F.-Z. 2018. Mapping Mangrove Forests Based on Multi-Tidal High-Resolution Satellite Imagery. *Remote Sensing*, 10(9), 1343. https://doi.org/10.3390/rs10091343