USING SENTINEL-2A DERIVED CMRI FOR MANGROVE COVER MAPPING OVER 7 YEARS (2016-2022) IN QUANG YEN, QUANG NINH PROVINCE

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SUMMARY

Mangrove forests are intertidal wetlands and found along tropical, subtropical, and warm-temperate coastlines. They have vital functions in preventing coastal erosion, mitigating effects of wave actions, and protecting coastal habitats. However, mangrove forests are more likely to be vulnerable as typhoons frequently hit and under driving human pressures. The study has constructed the spatial distribution of mangrove cover from 2016 to 2022 by using Sentinel-2A imageries. The Sentinel-2A data were used to detect changes in the extent of coastal mangrove forests using the visual interpretation approach in combination with the CMRI thresholds defined (CMRI > 0.47 for mangrove forests, -0.25 < CMRI ≤ 0.47 for non-mangrove forests, and CMRI ≤ -0.25 for areas covered water). The overall accuracy assessments of land covers in each selected year (2016, 2017, 2018, 2019, 2020, 2021, and 2022) are greater than 93.0% with Kappa coefficient more than 0.89, which have clearly confirmed using Sentinel-2A data for mapping temporal changes in mangrove forests are very reliable in along the coast of Quang Yen. The study also showed that mangrove cover in Quang Yen town decreased by 343.7 ha in 2022 (2,765.4 ha) compared to 2016 (3,109.1 ha). The development of aquaculture and shrimp farming, the expansion of agricultural production, and other land uses were defined as the main drivers for mangrove deforestation during the period of 2016-2022. The study highly suggests that using Sentinel-2A imagery should be applied to assess the changes of mangrove cover in Quang Yen town and expanded in other similar coastal areas in Quang Ninh province toward sustainable mangrove management.

Keywords: CMRI (Combined Mangrove Recognition Index), mangrove cover mapping, Quang Yen, Sentinel-2A, vegetation index.

1. INTRODUCTION

Mangrove forests are defined as a group of salt tolerant trees and shrubs that grow in the intertidal regions of the tropical and subtropical coastlines (Kathiresan and Bingham, 2001; Duke et al., 2007). They are considered as a rich ecosystem with many types of biodiversity and provision of the habitat for a wide variety of living things that can adapt, including aquatic and terrestrial insects, fish, reptilian, amphibian, and vertebrate species or plants that prefer wetlands and salts, typically sea grasses (Hogarth, 1999). Despite their well-perceived importance of mangrove forests, they are being globally degraded and deforested at the alarming rate (Duke et al., 2007; Hai-Hoa et al., 2014). The primary drivers of mangrove loss have been blamed for aquaculture expansion and conversion other land use (Valiela et al., 2001; Hai-Hoa et al., 2013; Hai-Hoa et al., 2022a).

In Vietnam, mangrove ecosystems are recently well-recognized as highly valuable resources for local people, who are living nearby the coastal regions (Hanh and Furukawa, 2007; Hai-Hoa et al., 2013; Hai-Hoa, 2014; Hai-Hoa et al., 2021). Mangrove ecosystems, which are diverse and rich in tree species and ecosystem values, and provide the shelter for highly economic values of marine species, have offered the local people with good opportunities and stable coastal livelihoods (Salem and Mercer, 2012). However, the extent of mangrove forests have experienced significant losses in recent decades under the economic development and the pressure from the growth of population to satisfy the major demand for aquaculture and fishing production (Kathiresan and Bingham, 2001; Valiela et al., 2001; Hai-Hoa, 2014).

Remote sensing has been commonly used to monitor and assess mangrove ecosystems and their dynamics for sustainable mangrove management over the last decades (Hai-Hoa et al., 2021; Hai-Hoa et al., 2022a). Although the global extensive application of remote sensing, GIS and techniques has been widely used to monitor and detect the mangrove deforestation and degradation, using these technologies for

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change detection in the extent of mangrove forests has been rarely well-documented in Vietnam or limited to monitor and evaluate the success of mangrove afforestation projects in Vietnam, including Quang Yen coast of Quang Ninh province (Hai-Hoa et al., 2022a and 2022b). In addition, although many efforts from national and international programs have been paid in mangrove restoration and rehabilitation in Quang Ninh province recently, some parts along the coast of Quang Yen are still experiencing a decline of mangrove extent as they are being under increasing threats from coastal high population growth, aquaculture expansion, timber cutting, and other human activities (Government of Vietnam, 2005; Hai-Hoa, 2014; Hai-Hoa et al., 2022a). Loss of mangrove resources might increase the threats to the local livelihoods by increased vulnerability of coastal communities to storm surges with large storms and typhoons (Duke et al., 2007; Hai-Hoa et al., 2018).

In this study, we aimed to quantify the spatial-temporal changes in the extent of mangrove forests along the coast of Quang Yen town, Quang Ninh province over 7 years (2016-2022) using Sentinel-2A-derived CMRI. The study would determine where the largest extent of mangrove forests has been changed over 7 years and what the main drivers have led to the spatial-temporal dynamics of mangrove forests along the coast of Quang Yen town. These findings would be used to inform coastal management authorities for approaching sustainable management of mangrove forests and livelihood improvements in Quang Yen town, Quang Ninh province.

2. RESEARCH METHODOLOGY

2.1. Study site

Quang Yen is a coastal town, located in the southwest of Quang Ninh province (Fig. 1). It is geographically situated away 40 km from Ha Long city to the southwest, 18 km from Uong Bi city to the southeast, and about 20 km from Hai Phong port city to the east. Terrestrial forests in Quang Yen occupy a small area and distribute mainly in the high mountainous area in the North bordering Hoanh Bo, but they play an important role in the economic development of the town, especially in regulating water resources of the Yen Lap reservoir. Furthermore, it offers diverse ecological landscapes for tourism development.

Significantly, Quang Yen town also has more than 30-km coastlines with many estuaries and tidal flats. The sea area with the enclosed bay is known as a home of many sea creatures, which are high economic values and provide a rich source of aquatic resources both in saltwater and brackish water. Mangrove forests along the coast of Quang Yen have been under great pressure from urbanization and economic development; land use/cover conversion; and shrimp farming activities (Hai-Hoa et al., 2022a; 2022b).

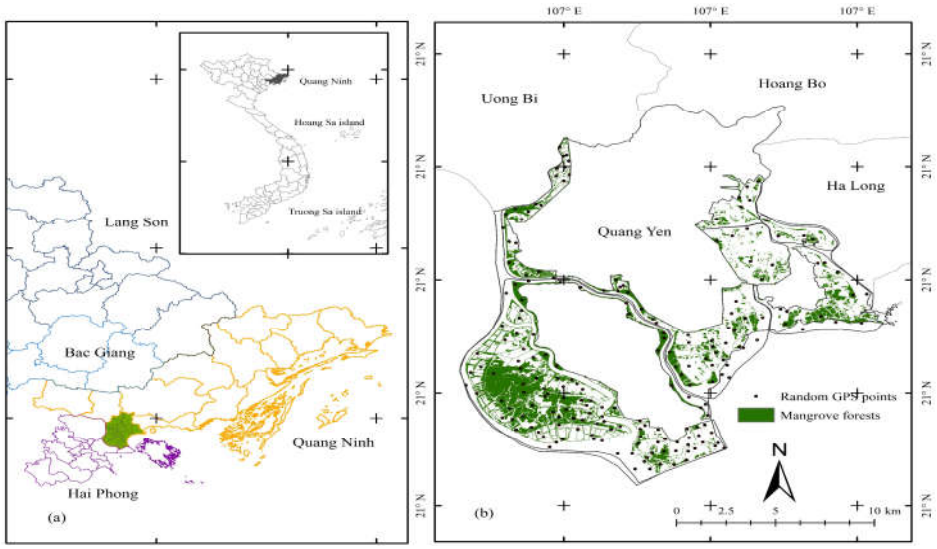

Fig. 1. Study site: (a) Geographical location of Quang Ninh province in Vietnam, (b) Mangrove forests distributing along the coast of Quang Yen town, Quang Ninh province

2.2. Remote sensing data collection

In this study, multiple-temporal Sentinel-2A images were used to classify the extent of mangrove forests in different periods (Table 1).

Table 1. Remotely sensed data used for mangrove cover mapping over 7 years

ID	Image codes	Date	Spatial resolution (m)	Remarks
1	S2A_MSIL1C_20161202T110044	02/12/2016	10	T48QXJ
2	S2A_MSIL1C_20171217T032131	17/12/2017	10	T48QXJ
3	S2A_MSIL1C_20181102T031901	02/11/2018	10	T48QXJ
4	S2A_MSIL1C_20191107T031931	07/11/2019	10	T48QXJ
5	S2A_MSIL1C_20200902T031541	02/09/2020	10	T48QXJ
6	S2A_MSIL1C_20210619T031541	19/06/2021	10	T48QXJ
7	S2A_MSIL1C_20220224T031731	24/02/2022	10	T48QXJ

Source: http://earthexplorer.usgs.gov

2.3. Study methods

To quantity spatial-temporal extent of mangrove forests and detect its changes, three main steps were proceeded in this study: (1) Data pre-processing steps included atmospheric corrections, band combination and subset of the potential of mangrove extent along the coast of Quang Yen; (2) Mangrove cover interpretation and classification consisted of using the thresholds of Sentinel-2A derived CMRI to identify mangrove forests, non-mangrove forests and areas covered by water known as the class of 'water bodies', accuracy assessments of mangrove forest mapping with the assistance of the field data survey and other referenced data; (3) Finally, post-classification process was conducted to examine multi-temporal changes in mangrove cover along the coast of Quang Yen town.

Sentinel-2A pre-processing: In this study, the available time series of Sentinel-2A data (2016, 2017, 2018, 2019, 2020, 2021, 2022), covering the whole coast of Quang Yen town with cloud-free cover selected in Quang Ninh province, were freely downloaded from the United States Geological Survey (USGS) as shown in Table 1. They were then used to quantify the spatial-temporal changes in mangrove forests along the coast of Quang Yen town during the period of 2016-2022. Prior to the interpretation and classification of land covers and mangrove forests, the semi-automatic classification plugin (SCP) in QGIS Version 3.16 (Congedo, 2020), which both allows to download the time series of Sentinel-2A datasets, but also provides a full suite of processing tools that facilitate the pre-processing phases for image classification. The acquired Level-1C orthorectified, top-of-atmosphere optical Sentinel-2A data were atmospherically corrected and further processed to Level-2A product to obtain bottom-of-atmosphere corrected reflectance image (Castillo et al., 2017; Hai- Hoa and Hien, 2021).

Visual Interpretation: This study also used the visual interpretation approach to separate the extent of mangrove cover from other land covers using a band combination (Hai-Hoa et al., 2020a; 2020b). The visual interpretation was based on either the true color image (RED, BLUE and GREEN) or other band combination, such as (RED, GREEN, and NIR) (Pavlovic et al., 1997; Ye et al., 2021). In this study, visual image interpretation was adopted to observe the presence or absence of mangrove forests (Asrat et al., 2018).

Mangrove extraction: Vegetation indices, including the Normalized Difference Vegetation index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), are effective for assessing vegetation status and quantifying vegetation attributes (Huang et al., 2020). Under the natural condition, mangrove forests distribute nearby water areas or between vegetation and water, there should be a spectral distinction by using Normalized Difference Water Index (NDWI) (Yang et al., 2017). This NDWI is also useful to delineate open water features (McFeeters, 1996). It has also been developed to discriminate the mangrove cover, which has higher water content (Teng et al., 2021).

Therefore, the combination of the two vegetation indices (NDVI and NDWI) would be very effective to classify mangrove cover from non-mangrove covers and water bodies along the coast of Quang Yen town (Veettil and Quang, 2019; Hai-Hoa et al., 2022a). This combination is created the CMRI (Combined Mangrove Recognition Index), which has been widely used in recent years (Gupta et al, 2018; Hai-Hoa et al., 2022a) for distinguishing mangrove covers from other features. This CMRI has been considered as a useful tool and selected to determine the presence of mangrove forests (Baloloy et al., 2020; Yancho et al., 2020). The calculation of NDVI, NDWI and CMRI was summarized in Table 2.

Table 2. Equations of vegetation indices used for mangrove cover mapping

Vegetation indices	Equations	References
NDVI Normalized Difference Vegetation Index	$(Band_{NIR}–Band_{RED})/(Band_{NIR}+Band_{RED})$	Rouse et al., (1974); Thu and Populus, (2007)
NDWI Normalized Difference Water Index	$(Band_{GREEN}–Band_{NIR})/(Band_{GREEN}+Band_{NIR})$	Du et al., (2016); Kaplan and Avdan, (2017)
CMRI Combined Mangrove Recognition Index	(NDVI– NDWI)	Gupta et al., (2018); Jamaluddin et al., (2021)

Where: $Band_{NIR}$ is Near Infrared Band (Band 8 in Sentinel-2A); $Band_{RED}$ is RED Band (Band 4 in Sentinel-2A); $Band_{GREEN}$ is GREEN Band (Band 3 in Sentinel-2A).

The wavelength of the Near Infrared Band ranges from 0.7 to 1.0μm, while the wavelength of the RED Band ranges from 0.4 to 0.7μm. The Sentinel–2A data were used to produce the CMRI land -cover map, including the mangrove cover along the coast of Quang Yen town. This study adopted the thresholds of Sentinel-2A-derived CMRI from the study of Hai-Hoa et al., (2022a) for distinguishing mangrove cover from other land covers. The thresholds for mangrove cover are greater than 0.47 (CMRI> 0.47), while areas with frequent presence of water surface are defined with a threshold of less than -0.25 (CMRI< -0.25), a range from -0.25 to 0.47 (-0.25< CMRI≤ 0.47) is identified as non-mangrove covers (Hai-Hoa et al., 2022a). These thresholds were then used to construct a thematic land covers/mangrove cover map for each selected year (2016, 2017, 2018, 2019, 2020, 2021, and 2022).

Accuracy assessments of classified images: Thematic mangrove cover map derived from Sentinel-2A-based CMRI was required to assess the accuracy of classified images (Ghorbanian et al, 2021). Therefore, both visual interpretation and statistical approaches were performed to assess the classification accuracies of the final mangrove cover map each year. For accuracy assessments, this study used high-resolution satellite images offered by Google Earth images (2016, 2017, 2018, 2019, 2020, and 2021) in combination with GPS points collected from the field investigation in 2020 and 2022 to assess the accuracy of classified images. The quantitative validation was then performed to evaluate the classification accuracies of land-covers/mangrove cover derived from CMRI values and referenced data. A total of 200 GPS sampling points (including 100 GPS points for mangrove cover; 60 points for non-mangrove covers, 40 points for water bodies) selected for each single year of Sentinel-2A data. These random points were used for accuracy assessments of each thematic mangrove cover map.

For statistical accuracy assessments, independent test samples were combined to create a computational matrix. The classification and control matrices were constructed to cross-tabulate the observed data with the reference data using the Kappa coefficient (Congalton, 1991). The Kappa coefficient is a measure of the consistency between two maps, considering all the elements of the error matrix (Stehman, 1997). A Kappa with value of 0 is inconsistent; from 0.41 to 0.6

refers as moderately consistent; 0.61–0.8 is remarkably homogeneous; and 0.81–1.0 is almost perfect homogeneity (Conchedda et al, 2008; Dat and Yoshino, 2016). To use the data correctly, this study considered the minimum level of the overall interpretation accuracy in coastal land covers, mangrove cover maps would be at least 85.0% as suggested by previous studies of Foody (2002).

Post-classification of classified images: In post-classification process, the filtering process was applied to remove isolated pixels or noise or the "salt-and-pepper" effects in the land cover map. The filtered classified image was then used as the final forest cover map each year.

3. RESULTS AND DISCUSSION

The results of this study include the accuracy assessments, assessment of mangrove cover change, drivers of changes in mangrove forests, and policy implications for sustainable management of mangrove forests.

3.1. Multi-temporal coastal land use and land cover in Quang Yen town

Accuracy assessments of land cover and mangrove cover mapping:

All the Sentinel-2A images were used to produce the CMRI-based land cover classification maps for the whole coast of Quang Yen. The error matrices indicated that accuracy assessments of each selected year (from 2016 to 2022) have high accuracies with user's accuracies, as follow: mangrove cover (from 94.0% to 98.0%), non-mangrove covers (from 90.0% to 96.7%), and water bodies (from 90.0% to 92.5%), giving overall accuracies of 93.0%, 94.0%, 95.0%, 94.5%, 94.0%, 94.5% and 93.5% in 2016, 2017, 2018, 2019, 2020, 2021 and 2022, respectively (Table 3).

Table 3. **Summary of accuracy assessments of land covers/mangrove cover in Quang Yen**

Reference data in 2022 (Data collected from field survey)

Classified image-based CMRI		**Man**	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
	Man	**95**	4	1	100	95.4
	Non-	0	**55**	5	60	91.7
	Water	0	3	**37**	40	92.5
	Total	*95*	*62*	*43*	200	
	Producer's Accuracy (%)	100.0	88.7	86.0	Overall Accuracy: 93.5% Kappa coefficient = 0.90	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

Reference data in 2021 (Data collected from field survey)

Classified image-based CMRI		**Man**	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
	Man	**97**	3	0	100	97.0
	Non-	2	**55**	3	60	91.7
	Water	1	2	**37**	40	92.5
	Total	*100*	*60*	*40*	200	
	Producer's Accuracy (%)	97.0	91.7	92.5	Overall Accuracy: 94.5% Kappa coefficient = 0.91	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

Reference data in 2020 (Data collected from field survey)

Classified image-based CMRI		**Man**	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
	Man	**97**	3	0	100	97.0
	Non-	3	**54**	3	60	90.0
	Water	0	3	**37**	40	92.5
	Total	*100*	*60*	*40*	200	
	Producer's Accuracy (%)	97.0	90.0	92.5	Overall Accuracy: 94.0% Kappa coefficient = 0.90	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

		Reference data in 2019 (Data collected from field survey)				
		Man	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
Classified image-based CMRI	Man	**94**	4	2	100	94.0
	Non-	2	**58**	0	60	96.7
	Water	0	3	**37**	40	92.5
	Total	*96*	*65*	*39*	200	
	Producer's Accuracy (%)	97.9	89.2	94.9	Overall Accuracy: 94.5% Kappa coefficient = 0.91	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

		Reference data in 2018 (Data collected from field survey)				
		Man	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
Classified image-based CMRI	Man	**96**	2	2	100	96.0
	Non-	2	**58**	0	60	96.7
	Water	1	3	**36**	40	90.0
	Total	*99*	*63*	*38*	200	
	Producer's Accuracy (%)	97.9	92.1	94.7	Overall Accuracy: 95.0% Kappa coefficient = 0.92	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

		Reference data in 2017 (Data collected from field survey)				
		Man	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
Classified image-based CMRI	Man	**97**	3	0	100	97.0
	Non-	2	**54**	4	60	90.0
	Water	0	3	**37**	40	92.5
	Total	*99*	*60*	*41*	200	
	Producer's Accuracy (%)	98.0	90.0	90.2	Overall Accuracy: 94.0% Kappa coefficient = 0.90	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

		Reference data in 2016 (Data collected from field survey)				
		Man	**Non-**	**Water**	**Total**	**User's Accuracy (%)**
Classified image-based CMRI	Man	**98**	2	0	100	98.0
	Non-	5	**52**	3	60	86.7
	Water	2	2	**36**	40	90.0
	Total	*105*	*56*	*39*	200	
	Producer's Accuracy (%)	93.3	92.9	92.3	Overall Accuracy: 93.0% Kappa coefficient = 0.89	

Man (Mangrove forests); Non- (Non-Mangrove forests); Water (Water bodies)

Accuracy assessment results from verified data show that the CMRI index is a good classifier with overall classification accuracy (>93.0%) and Kappa coefficient (>0.89). This confirms that using CMRI for mangrove cover mapping is reliable with Sentinel-2A data, which offers the spatial resolution of 10 m. The kappa coefficients also indicate that there are very high agreements between the classified maps and the reference data, thus implying that the Sentinel-2A-derived CMRI has a great potential for mangrove monitoring and mapping in the study area.

Coastal land use and land cover mapping:

As the thresholds have been determined for classifying mangrove forests, non-mangrove forests, and water bodies, the thematic maps of coastal land covers/mangrove cover are then constructed as indicated in Fig. 2.

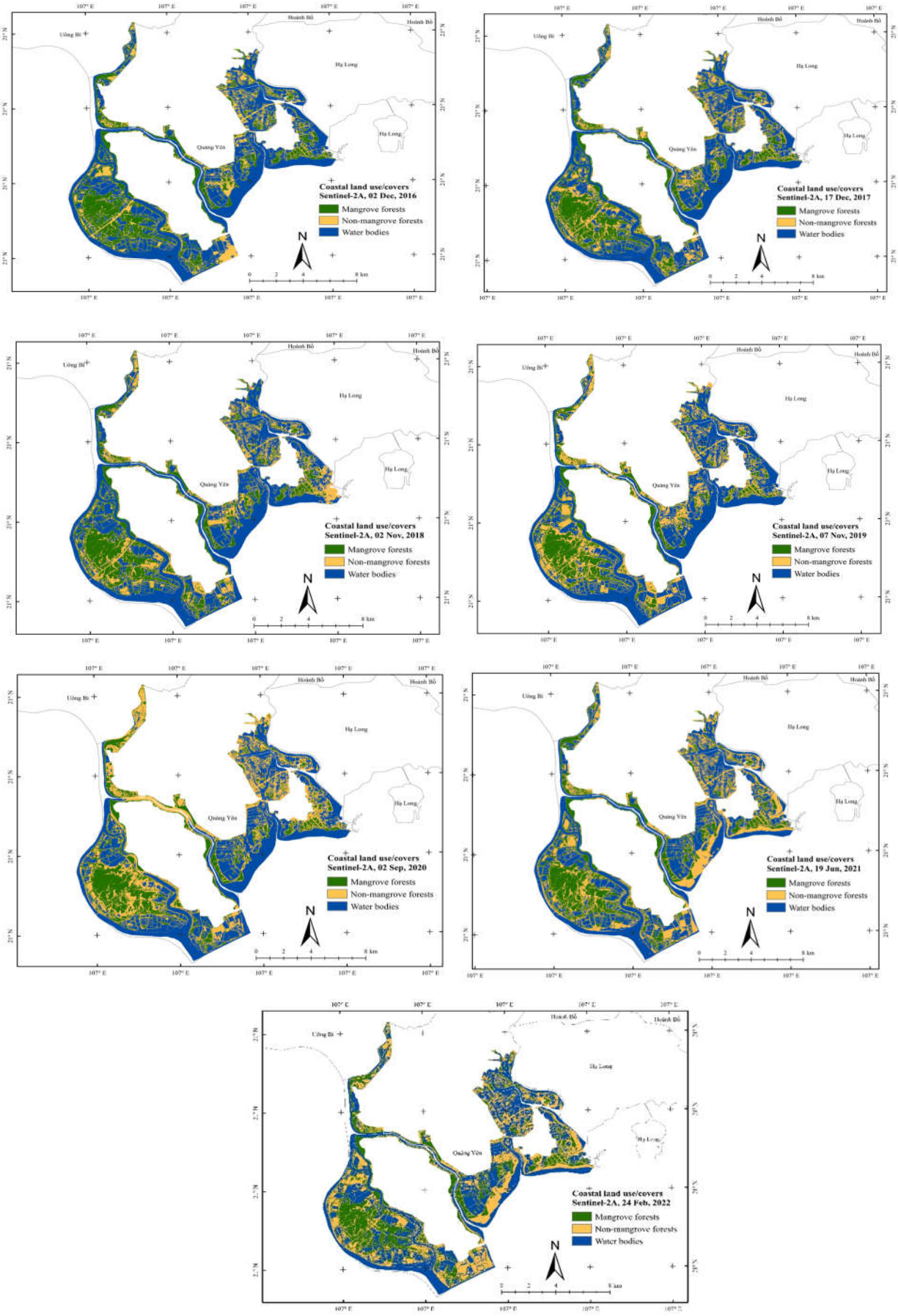

Fig. 2. Land covers and mangrove cover along the coast of Quang Yen from 2016 to 2022

3.2. Dynamics of mangrove cover and drivers of changes

Changes in coastal land covers/mangrove cover during 2016-2022:

Multi-temporal changes in coastal land covers in Quang Yen town, Quang Ninh province are presented in Table 4 and illustrated in Fig. 3. From 2016 to 2022, the overall extent of mangrove forests decreased by 343.7 ha (equivalent to 57.3 ha, 1.7% of mangrove forests lost each year; 11.1% of mangrove forest areas lost during the period of 2016–2022). In the same period, the extent of non-mangrove forests was sharply increased 1,709.6 ha from 2,765.1 ha in 2016 to 4,474.7 ha in 2022, while the area covered by water decreased by 1,365.9 ha (equivalent to 19.6%).

Table 4. Extent of coastal land covers, mangrove cover along the coast of Quang Yen in selected years (ha)

Years	2016	2017	2018	2019	2020	2021	2022
Mangrove forests	3,109.1	3,113.2	3,020.5	2,529.2	2,813.9	2,910.5	2,765.4
Non-mangrove forests	2,765.1	3,171.6	3,210.3	3,689.3	4,132.6	4,111.4	4,474.7
Water bodies	6,964.2	6,553.6	6,607.6	6,619.9	5,891.9	5,816.5	5,598.3
Total	**12,838.4**	**12,838.4**	**12,838.4**	**12,838.4**	**12,838.4**	**12,838.4**	**12,838.4**

Non-mangrove forests include Rice paddy field/agriculture, residential areas/built-up areas, muddy flats; Water bodies refer to areas covered by water, including shrimp ponds, rivers, and open sea water.

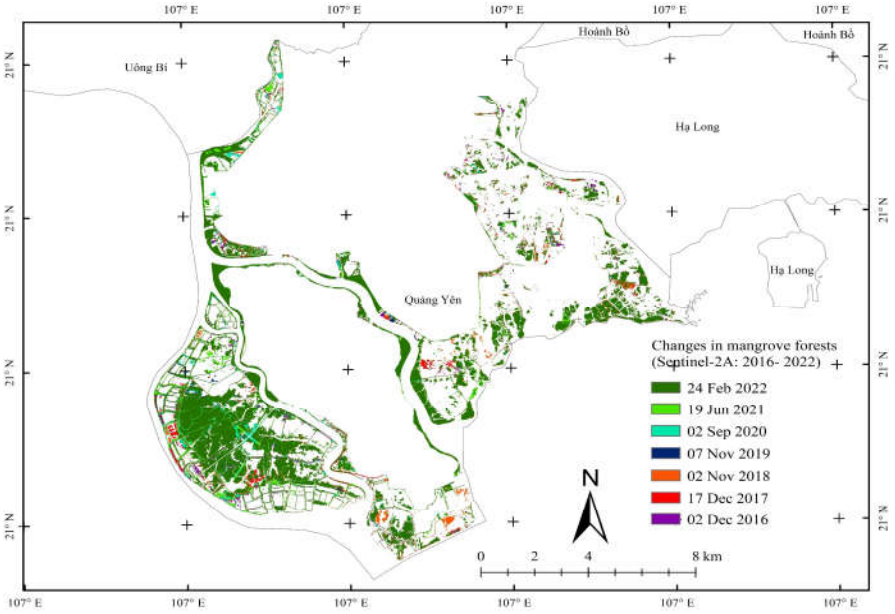

Fig. 3. Changes in land covers, mangrove cover along the coast of Quang Yen during 2016-2022

As indicated in Table 4 and Fig. 3, there was 3,109.1 ha of mangrove forests estimated in 2016 for the whole coast of Quang Yen, Quang Ninh province, it slightly increased to 3113.2 ha in 2017 and then decreased to 3020.5 ha in 2018. Remarkably, the total extent of mangrove forests dramatically increased to 2529.2 ha in 2019, it kept sharply increasing to 2813.9 ha in 2020 and to 2910.5 ha in 2021. However, the extent of mangrove forests gradually dropped to 2765.4 ha in 2022 (Table 4 and Fig. 3).

Drivers of changes in mangrove forests in Quang Yen town

As can be seen from Table 4, there is a spatial-temporal change in mangrove forests from 2016 to 2022. The change has been observed across all coastal communes of Quang Yen. In this study, the main drivers of changes in mangrove forests included aquaculture expansion, conversion of mangrove forests into other land uses, and afforestation projects.

The expansion of aquaculture has been known as one of the biggest drivers of mangrove deforestation, in particular, the expansion of coastal aquaculture and shrimp farm development (Seto and Fragkias, 2007).

Our study found that aquaculture expansion in general is a dominant contributor to mangrove deforestation in Quang Yen town, then followed by socio-economic development as newly-constructed expressway from Hanoi to Hai Phong, then from Ha Long to Van Don and Mong Cai over the period of 2016–2022. However, by examining specific segments along the coast of Quang yen town, the dominant drivers of mangrove deforestation might be slightly different and due to other factors (Table 4 and Table 5). In particular, the loss of mangrove forests was strongly associated with the expansion of aquaculture and urbanization and socio-economic development during the period of 2018–2019 as a newly-constructed expressway from Ha Long to Van Don and Mong Cai. Our findings in relation to drivers of mangrove forest changes are similar to previous studies of Hai-Hoa et al., (2019); Hai-Hoa et al., (2022a, 2022b). Mangrove conversion to other land-uses has been found in many coastal mangrove provinces in Vietnam (Hai-Hoa et al., 2013; Huong et al., 2021). Through our field investigation, we found that the mangrove conversion into other land uses, including rice production, and coastal urbanization is another main contributors to the loss of mangrove forests.

Table 5. Estimated changes in land covers in different periods in Quang Yen (ha)

Years	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022	2016-2022
Mangrove forests	+4.1	-92.7	-491.2	+284.7	+96.6	-145.1	-343.7
Non-mangrove forests	+406.5	+38.7	+478.9	+443.3	-21.2	+363.3	+1,709.6
Water bodies	-410.6	+54.0	+12.3	-727.9	-75.5	-218.2	-1,365.9

Change: (+) refers to the loss; and (-) refers the gain

Conversely, mangrove forests along the coast of Quang Yen were notably witnessed an increase of their extent from the period of 2019–2021 (Table 5). According to Hai-Hoa et al., (2022a, 2022b); Que (2012); Thuy (2019), both international and national mangrove afforestation programs, including PAM Program, RED-Cross and Japan International Cooperation Agency (JICA) programs, have significantly contributed to increase the extent of mangrove forests in Quang Ninh province in general, Quang Yen in particular over the last decades. As a result, the extent of mangrove forests in some periods of 2019–2020 and 2020–2021 was recorded with an increase of 284.68 ha and 96.61 ha, respectively (Table 5). During the period of 2016-2017, mangrove forests were also witnessed with a slight increase of 4.09 ha. Therefore, it can be concluded that the international mangrove afforestation programs (NGOs) have been significantly contributed to mangrove afforestation and restoration over the last decades not only in Quang Yen, but also in other coastal regions in Vietnam.

4. CONCLUSION

Remote sensing technology offers an effective tool to monitor and detect changes in coastal land covers and mangrove cover over time. This study used the Sentinel-2A derived CMRI thresholds (10m×10m) for coastal land covers (threshold of CMRI> 0.47 for mangrove forests, –0.25 <CMRI ≤0.47 for non-mangrove forests, and CMRI ≤-0.25 for water bodies). The CMRI index is suitable for mangrove cover mapping along the coast of Quang Yen town with overall accuracy over 93.0% and Kappa coefficient greater than 0.89 for whole selected years, from 2016 to 2022. Overall, the extent of coastal mangrove forests along the coast of Quang Yen town, Quang Ninh province decreased by 343.71 ha in 2022 compared to 2016. The main drivers for mangrove deforestation during the period of 2016–2022 were aquaculture expansion, socio-economic development, other land use conversions, and mangrove afforestation programs. The study highly suggests that Sentinel-2A derived CMRI can be used to monitor changes in mangrove forests along the coast of Quang Yen town and

to expand in other similar coastal regions of Quang Ninh Province.

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SỬ DỤNG CHỈ SỐ CMRI TỪ ẢNH SENTINEL-2A ĐA THỜI GIAN (2016-2022) XÂY DỰNG BẢN ĐỒ RỪNG NGẬP MẶN KHU VỰC QUẢNG YÊN, TỈNH QUẢNG NINH

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TÓM TẮT

Rừng ngập mặn phân bố ở vùng triều và dọc các đường bờ biển nhiệt đới, cận nhiệt đới và ôn đới ấm. Chúng có chức năng quan trọng trong việc ngăn chặn xói mòn bờ biển, giảm thiểu tác động của sóng và bảo vệ môi trường sống ven biển. Tuy nhiên, rừng ngập mặn dễ bị tổn thương do tác động của những cơn bão và chịu sức ép từ con người. Nghiên cứu đã xây dựng bản đồ phân bố rừng ngập mặn từ năm 2016 đến năm 2022 bằng cách sử dụng dữ liệu ảnh viễn thám Sentinel-2A. Dữ liệu được sử dụng để phát hiện biến động diện tích rừng ngập mặn bằng việc kết hợp phương pháp giải đoán ảnh bằng mắt với sử dụng các ngưỡng chỉ số CMRI (giá trị CMRI> 0,47 đối với rừng ngập mặn, -0,25 <CMRI ≤0,47 cho đối tượng không ngập mặn và CMRI ≤- 0,25 cho đối tượng che phủ bởi nước). Kết quả đánh giá độ chính xác tổng thể cho từng đối tượng lớp phủ từ năm 2016 đến năm 2022 cho thấy độ chính xác trên 94,0% với hệ số Kappa lớn hơn 0,89. Kết quả này đã xác nhận sử dụng ảnh Sentinel-2A đảm bảo độ tin cậy để lập bản đồ biến động lớp phủ và rừng ngập mặn vùng ven biển thị xã Quảng Yên. Nghiên cứu cũng cho thấy diện tích rừng ngập mặn thị xã Quảng Yên giảm 343,7 ha vào năm 2022 (2.765,4 ha) so với năm 2016 (3.109,1 ha). Nuôi trồng thủy sản, phát triển trang trại nuôi tôm, mở rộng diện tích đất nông nghiệp, chuyển đổi đất rừng ngập mặn sang các mục đích sử dụng khác là những nguyên nhân chính dẫn diện tích rừng ngập mặn suy giảm giai đoạn 2016-2022. Nghiên cứu đề xuất nên sử dụng dữ liệu viễn thám Sentinel-2A để theo dõi và giám sát biến động diện tích rừng ngập mặn tại Quảng Yên và mở rộng sang các khu vực ven biển khác thuộc tỉnh Quảng Ninh, hướng tới đề xuất các giải pháp quản lý rừng ngập mặn bền vững.

Từ khóa: Chỉ số thực vật, CMRI, Quảng Yên, rừng ngập mặn, Sentinel-2A.

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