DETECTING CHANGES IN MANGROVE FORESTS FROM MULTI-TEMPORAL SENTINEL-2 DATA IN TIEN YEN DISTRICT QUANG NINH PROVINCE

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SUMMARY

Mangrove forests are intertidal wetlands and found along tropical, subtropical, and warm-temperate coastlines. They also offer valuable ecosystem services. However, mangrove forests are especially vulnerable as typhoons frequently hit during the monsoon season and under driving human pressures. The spatio-temporal change information of mangrove forest cover distribution in Tien Yen district is incomplete. Thus, this study was undertaken to detect spatial-temporal distribution of mangrove forests in Tien Yen district and then identify the drivers of mangrove cover change. Multi-temporal Sentinel-2 data were used to detect changes in the extent of coastal mangrove forests using the NDVI thresholds combined with the visual interpretation. Three land use and land covers were categorised, namely mangrove forests, non-mangrove forests, and water bodies. Mangrove forests in Tien Yen district were estimated to be 3133.8 ha in 2015 and decreased by 277.8 ha in 2020. Aquaculture, shrimp farm and agriculture expansion, and other land uses were the main drivers for mangrove deforestation during the period of 2015 - 2020. This study used the NDVI thresholds for coastal land covers (NDVI value > 0.2 for mangrove forests). The overall accuracies assessments of land covers in 2020 (reached 91.3%, Kappa coefficient of 0.83) and land covers in 2016 (assessed at 88.3%, Kappa coefficient of 0.78) have confirmed the effectiveness of using remotely sensed Sentinel-2A/B for monitoring the spatio-temporal changes of mangrove forests in Tien Yen district.

Keyword: land use and land cover, mangrove forests, NDVI, Sentinel-2, Tien Yen district.

1. INTRODUCTION

Mangrove forests are defined as assemblages of salt tolerant trees and shrubs that grow in the intertidal regions of the tropical and subtropical coastlines. They grow luxuriantly in the places where freshwater mixes with seawater and where sediment is composed of accumulated deposits of mud. Mangrove forests are one of the world's most diverse and active habitats, and they are often distributed in the close to the equator tropical and subtropical regions, where the common pierce is submerged in sea water (Thom, 1984). They are normally classified into six types on the basis of the geophysical, geomorphological and biological factors (Thom, 1984). Mangrove forests are well-known to control the shore by gathering sediments from rivers and streams, which reduce the movement of water. They also protect and shelter coastal urban areas in from the extreme weather occurrences, including hurricanes and flooding (Ewel et al., 1998). Mangrove forests are also able to filter toxins in the environment biologically, such as CO_2 emitted into the atmosphere by human activities (Jennerjahn and Ittekkot, 2002; Dittmar et al., 2006; Duke et al., 2007). One of the most diverse mangrove features is their complex root networks, which offers the ecosystem with a wide variety of ecosystems, including mollusks, and foraging crustaceans.

It is estimated that mangrove forests have covered up to 200,000 km^2 on a worldwide scale (Duke et al., 2007; Spalding et al., 2010). Since the mid-twentieth century, most of the mangrove forests have been deforested and degraded. Therefore, they have been known as among the most endangered ecosystems on the planet. Mangrove forests have been estimated with disappearing rate of 1 ÷ 2% each year around the world (Alongi, 2002; FAO, 2007), owing primarily to the growth of fisheries, agriculture, and development of residential areas (Valiela et al., 2001; Giri et al., 2008; Rahman et al., 2013), particularly those in Southeast Asia and Latin America (Keller, 2014). Furthermore, settlements within the mangrove forests will be completely incapacitated of essential food sources (Ewel et al., 1998). Thus, the protection of mangrove forests is crucial due to their great ecological and socio-economic significance.

The decline in the areas of mangrove forests can be extrapolated to the whole of Vietnam, where the areas of mangroves declined dramatically from 408,500 ha in 1943 to 290,000 ha in 1962, 252,000 in 1982, 155,290

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ha in 2000 and slightly increased to 157,500 in 2005 (FAO, 2007; McNally et al., 2011; Hai-Hoa et al., 2013; Hai-Hoa, 2014; Son et al., 2016). The loss of mangrove forests in Vietnam, mostly due to the expansion of aquaculture and the rapid growth of coastal urbanization, has had enormous environmental and socioeconomic implications. Changes in the hydrological regime, soil erosion, water contamination, and sedimentation in marine habitats are also factors to consider (FAO, 2007; McNally et al., 2011). Mangrove forests in the study area are traditional forest habitats of Vietnam's northwestern region. The mangrove system, which is diverse and rich in tree species and ecosystem values, and shelter for marine species of high economic value, has provided local people with good opportunities and stable coastal livelihoods. Recent studies have shown that there are 16 main mangrove species belonging to the real mangrove group identified, including *Kandelia obovata*, *Rhizophora stylosa*, *Bruguiera gymnorrhiza*, *Avicennia* spp., and *A. corniculatum*.

Tien Yen district has a population of 43,227 inhabitants, with over 60 businesses and households raising aquaculture, mostly shrimp, and over 20 households, each owing within 3÷ 7 ha of land. Despite the fact that this areas are being qualified as a RAMSAR site, the sea diverts it away from mangrove forests for other purposes, especially shrimp farming and aquaculture. As a result, it is important to consider the shifts in space and time within mangrove forests in the research areas for economists and ecologists and to manage natural resources in the region with useful knowledge for the conservation of the mangrove ecosystem.

Remote sensing is considered as an effective tool to detect and monitor mangrove forest changes over the time. It also has long been acknowledged as one of the most reliable methods for monitoring mangrove forests at all spatial scales. In Vietnam, remote sensing is used to monitor and assess mangrove ecosystem for sustainable mangrove management. However, most of these activities have emphasised on terrestrial forests rather coastal mangrove forests. In Quang Ninh province, changes in mangrove forests have either not been documented or are limited to monitor the success of mangrove afforestation projects. Gaps remain in the documentation of mangrove forest extent and their changes across the time in Quang Ninh province. In addition, the construction of mangrove cover map requires the high accuracy and up-to-date information, while traditional rudimentary methods are laborious and time-consuming. The outcomes of this study would enable local authorities to manage coastal mangrove forests more effectively and efficiently. Therefore, the objectives of this study were to: (1) determine the spatial extent of mangrove forests in Tien Yen district, Quang Ninh province using multi-temporal Sentinel-2A/B from 2015 to 2020; (2) estimate changes in spatio-temporal extent of mangrove forests in Tien Yen district from 2015 - 2020; (3) document the drivers responsible for the changes in the extent of mangrove forests for providing better solutions how to manage mangrove forests in a sustainable manner in Tien Yen district.

2. RESEARCH METHODOLOGY

2.1. Study site

This study selected Tien Yen district in Quang Ninh province in the Northern Vietnam to investigate the transition in the mangrove region using Sentinel-2A/B satellite imageries. The study areas span nearly 3,900 ha, with Dong Rui accounting for nearly half of the commune's natural area. The population density in the region is around 54,000 people (Hai-Hoa, 2016). With the Dan-mat shoreline, mangrove forests in Tien Yen district is being qualified as a Ramsar site. It was formed as a result of the mountainous area's erosion and tectonic phase and was then inundated by the sea. The northern bank line, from Mui Chua to the end of Hai Lang commune (bordering on National Highway 18), is nearly perpendicular to the majestic road; the west bank line, in the right North-South direction of the meridian, makes up the right angle. In addition to the mangrove biome, Dong Rui mangrove forests have been described as having notably ecosystems: namely estuarine, intertidal, lagoon, and lake ecosystems. This is also a region of high species diversity and many economically valuable species as well as biodiversity conservation principles. However, mangrove forests and their

ecosystem in general is being threatened due to both nature and human-driven forces. Many recent reports showed that mangrove deforestation and degradation have been witnessed in all of the coastal communes of Tien Yen district where mangrove forests are existing. The actions therefore should be taken to protect existing mangrove forests and mangrove afforestation should be promoted.

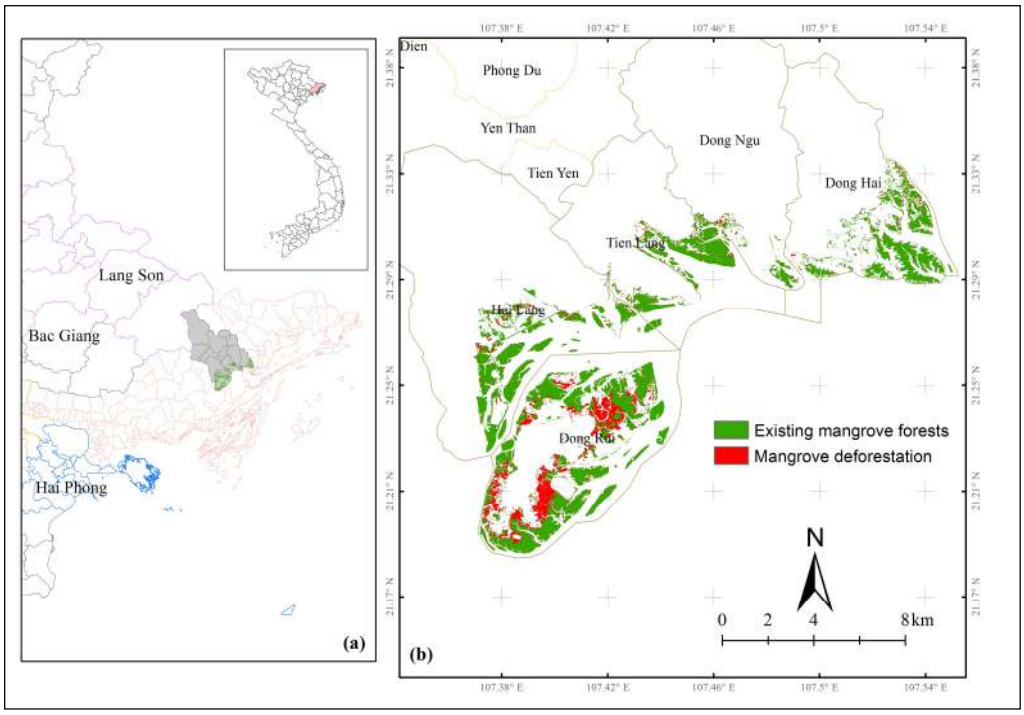

Fig. 1. Study site: (a) Geographic location of Tien Yen district in Quang Ninh province; (b) coastal communes of Tien Yen district, where mangrove forests are found in nearby shores. A recent record shows the loss of mangrove forests has been experienced (in the red color patterns).

2.2. Remote sensing data collection

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

Table 1. Remotely sensed data used for detecting changes in mangrove extent

ID	Image code	Date	Spatial resolution (m)	Note
1	L1C_T48QYJ_A000830_20150820T033001	20/08/2015	10	T48QYJ
2	S2A_20151218T033425_20151218T084033	18/12/2015	10	
3	S2A_20161202T033827_20161202T083733	02/12/2016	10	T48QYJ
4	S2A_MSIL1C_20171217T032131	17/12/2017	10	T48QYJ
5	S2B_MSIL1C_20181217T032129	17/12/2018	10	T48QYJ
6	S2A_MSIL1C_20191107T031931	07/11/2019	10	T48QYJ
7	S2A_MSIL1C_20201022T031801	22/10/2020	10	T48QYJ
8	S2B_MSIL1C_20201206T032119	06/12/2020	10	T48QYJ

Source: https://earthexplorer.usgs.gov; https://scihub.copernicus

2.3. Methods

To detect spatial-temporal changes in the extents of mangrove forests, three main steps were proceeded: (1) Data pre-processing, which included atmospheric corrections, band combination and subset of the studied areas; (2) Mangrove identification and classification with NDVI thresholds defined, accuracy assessments of mangrove mapping with the field data survey; (3) Finally, post-classification was used to examine multi-temporal shifts in Tien Yen district.

Data pre-processing: The available Sentinel-2A/B images (2015, 2016, 2017, 2018,

2019, 2020) processed at Level 1C (already an orthorectified and top-of-atmosphere reflectance), covering Tien Yen district, Quang Ninh province, were downloaded from Sentinel Scientific Data Hub as shown in Table 1. The acquired Level- 1C orthorectified, top-of-atmosphere optical Sentinel-2 images were atmospherically corrected and further processed to Level- 2A product to obtain bottom-of-atmosphere corrected reflectance image (Castillo et al., 2017) by using the Semi-Automatic Classification Plugin in QGIS Version 3.16 (Congedo, 2020). In addition, the pre-processed Sentinel-2 Level 2A were geo-referenced to UTM WGS 1984 Zone 48N projection and datum. Bands of Sentinel-2 (Bands 2 - 12) were stacked into composite bands for the visual interpretation purpose.

Mangrove extraction: This study primarily used the Normalized Difference Vegetation Index (NDVI) in conjunction with the visual representation approach to classify mangrove forests, non-mangrove forests, and water bodies. The study specified the NDVI threshold value for each land use and cover (mangrove forests, non-mangrove forests, and water bodies), which were then used to create thematic maps of land use/cover. The NDVI was calculated as the following formula (Saleh, 2007; Ramdani et al., 2018):

$$NDVI = (Band_{NIR} - Band_{RED}) / (Band_{NIR} + Band_{RED})$$

Where: $Band_{NIR}$ stands for Near infrared (Band 8 in Sentinel-2), and $Band_{RED}$ is Red band (Band 4 in Sentinel-2). The wavelength of the Near infrared band ranges from 0.7 to 1.0 μm, while the wavelength of the Red band ranges from 0.4 to 0.7μm. NDVI is used to classify areas with vegetative layers (mangrove forests) and non-vegetation (non-mangrove forests) since it allows for a precise depiction. The chlorophyll in the leaves absorbs visible light (0.4 - 0.7μm) and reflects lattice light (0.7 - 1.0 μm) in the near infrared spectrum (Green et al., 1998). NDVI is commonly used to study vegetation, such as calculating crop yields, cultivability, and field conversion. NDVI is also related to parameters, such as topsoil layer, plant photosynthesis, water, and biomass computation (Fenshoult et al., 2009). The determined NDVI values, which range from -1.0 ÷ 1.0, demonstrate a simple distribution of vegetation cover in the sample area (Wang and Tenhunen, 2004; Fensholt et al., 2009). It also reflects various plant classes by using the values of each plant type. They are usually divided into levels: from a negative value to 0 is water; value less than 0.1 usually represents soil, rock, and sand or snow; from approximately 0.2 to 0.5 it is scrub, grass, or dry field; from 0.6 to 0.9 or close to 1.0 are trees and plants (Singh, 1989; Tucker et al., 2005). Therefore, NDVI has been considered as a useful tool and selected to determine the presence of mangrove forests in the study.

Visual Interpretation: This study also used the visual interpretation approach to separate mangrove areas from other land uses from remote sensing imageries (Hai-Hoa et al., 2020a; 2020b).

Accuracy assessments: The accuracy assessment is an important process for evaluating the result of post-classification as the user of land cover outputs should know how accurate the results are. To evaluate the accuracies of Sentinel-2A/B images classified and assess the accuracies of NDVI among selected years, randomly selected sampling points were used to quantitatively assess the coastal land cover classification accuracy. Total sampling points used for the classification accuracy estimation were 300 GPS points, 200 points for mangrove forests, 50 non-mangrove forests, and 50 points for water class in 2020, while 2016 Sentinel-2A was assessed by using points generated from Google Earth data. The overall classification accuracy, producer's accuracy and Kappa statistics, were then estimated for quantitative classification performance analysis (Foody, 2013). To use the data correctly, we considered the minimum level of the overall interpretation accuracy in

coastal and use and land cover map would be at least 85.0% as suggested by previous studies of Foody (2002; 2003).

3. RESULT AND DISCUSSION

3.1. Multi-temporal coastal land use and land cover in Tien Yen district

Accuracy assessments of coastal land cover classification:

This study used the NDVI thresholds defined by Hai-Hoa et al. (2020b) with adaption to classify coastal land cover with thresholds for mangrove forests (NDVI > 0.2), for non-mangrove forests (NDVI > 0 and NDVI <= 0.2), and for water bodies (NDVI <= 0.0). The classification accuracy was evaluated by the confusion matrix. The classified images showed an overall accuracy of 91.3% in 2020 and 88.3%, with Kappa coefficients of 0.83 and 0.78, respectively (Table 2 and 3). User's and producer's accuracies of individual classes for 2020 and 2016 of coastal land covers are presented in Table 2 and 3, and indicate that all classes have user's and producer's accuracies higher than 80.0%, with exception of non-mangrove forests in producer's accuracy assessments. The classification accuracy of the results was assessed based on the field survey results in 2020. It was also shown that the ground reference data used in this study was prepared from existing LUC maps and the high-resolution Google Earth imagery in 2016, while other years (2017, 2018, and 2019) were unable to conduct accuracy assessments due to the unavailable reference data. The accuracies assessments achieved confirmed the effectiveness of using remotely sensed Sentinel-2A/B for monitoring the spatio-temporal changes of mangrove forests in Tien Yen district (Thomlinson et al., 1999; Foody, 2002; 2003).

Table 2. Accuracy assessments of coastal land covers in 2020

Sentinel classified	GPS				
	Man	**Non-man**	**Waters**	**Total**	**User's Accuracy (%)**
Man	183	14	3	200	91.5
Non-man	5	44	1	50	88.0
Waters	0	3	47	50	94.0
Total	188	61	51	**300**	
Producer's Accuracy (%)	97.3	72.1	92.2		
Overall accuracy (%): 91.3; Kappa coefficient is 0.83; Sentinel-2A 22/10/2020					

Man: Mangrove forests; Non-man; Non-mangrove forests (rice paddy field/agriculture, residential areas/built-up areas, muddy flats); Waters (Shrimp ponds, rivers, open sea water).

Table 3. Accuracy assessments of coastal land covers in 2016

Sentinel classified	GPS				
	Man	**Non-man**	**Waters**	**Total**	User's Accuracy (%)
Man	175	20	5	200	87.5
Non-man	5	42	3	50	84.0
Waters	0	2	48	50	96.0
Total	188	61	51	**300**	
Producer's Accuracy (%)	97.2	65.6	85.7		
Overall accuracy (%): 88.3; Kappa coefficient is 0.78; Sentinel-2A 02/12/2016					

Man: Mangrove forests; Non-man; Non-mangrove forests (rice paddy field/agriculture, residential areas/built-up areas, muddy flats); Waters (Shrimp ponds, rivers, open sea water).

Coastal land use and land cover mapping:

As thresholds adapted from Hai-Hoa et al. (2020b) for classifying mangrove forests, non-mangrove forests, and water bodies. The thematic maps of coastal land use and land covers have been constructed as indicated in Fig. 2.

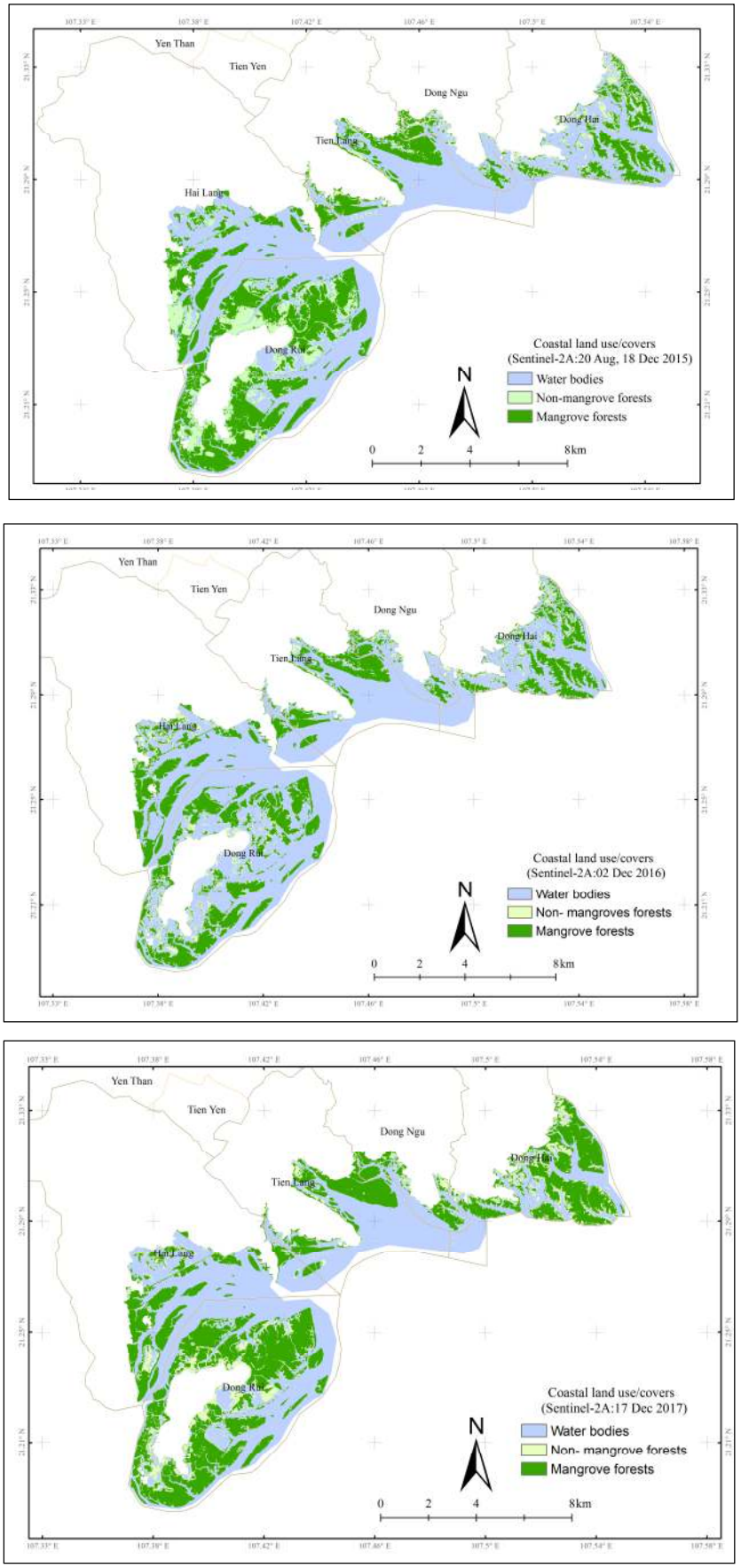

Fig. 2. Land use and land covers in coastal communes of Tien Yen district, Quang Ninh province obtained Sentinel-2A/B 2015- 2020

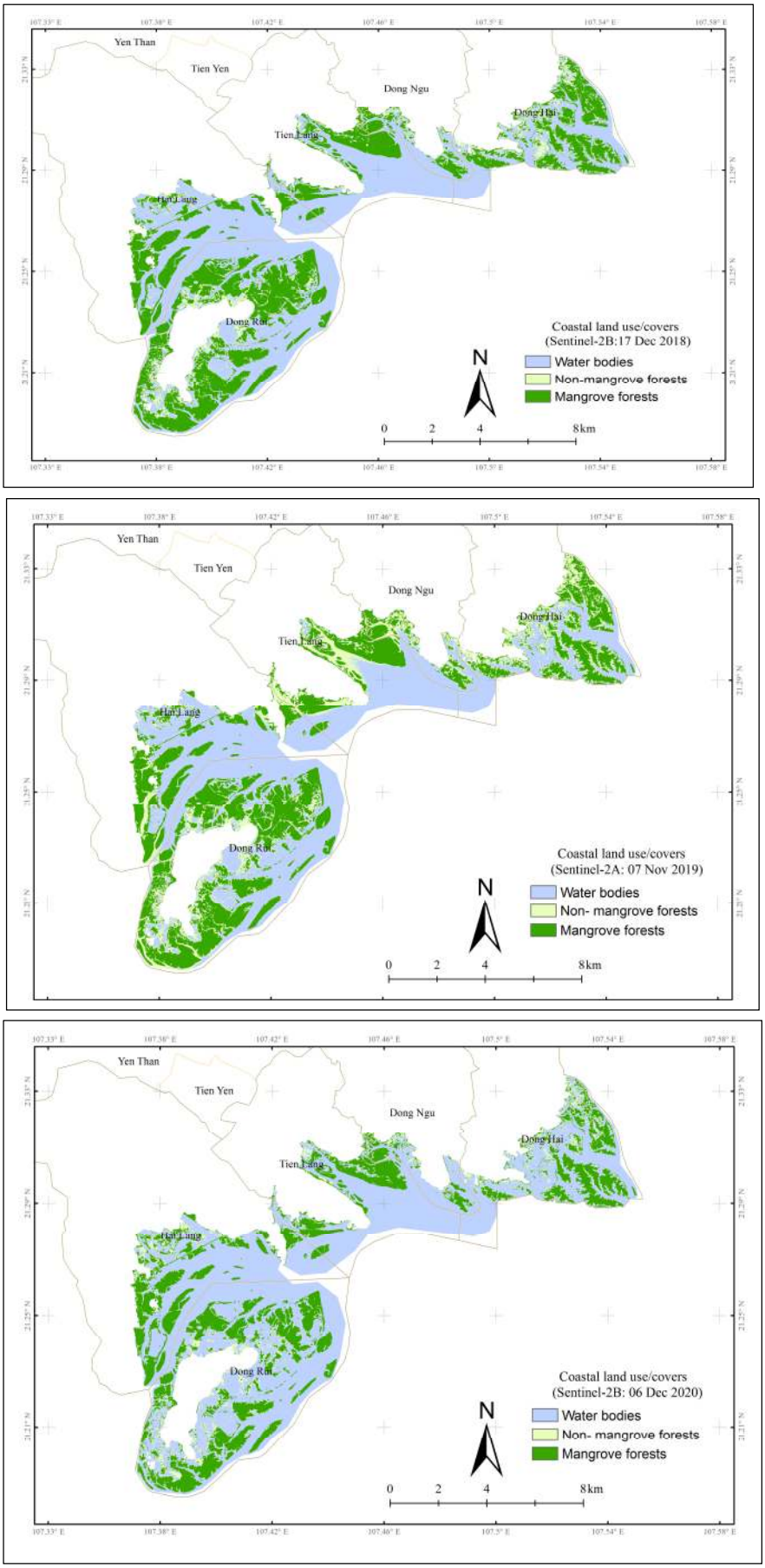

Fig. 2 (conts). Land use and land covers in coastal communes of Tien Yen district, Quang Ninh province obtained Sentinel-2A/B 2015 - 2020

As indicated in Fig. 2, mangrove forests spatially distribute across all of five coastal communes of Tien Yen district. However, large areas mangrove forests are found in Dong Rui commune, followed by Hai Lang and Tien Lang communes. The areas of mangrove forests have been spatially and temporally changed across five coastal communes.

3.2. Land use and land cover from 2016 to 2020 in Tien Yen district

Coastal land use/cover changes during 2016- 2020 in Tien Yen district:

Multiple-temporal changes in coastal land use/covers in Tien Yen district, Quang Ninh province are presented in Table 4 and illustrated in Fig. 3. From 2015 to 2020, the overall extent of mangrove forests decreased by 277.8 ha (equivalent to 55.6 ha, 1.8% of mangrove forests lost each year; 8.7% of mangrove forest areas lost during the period of 2015 - 2020). Over the same period, the extent of non-mangrove forests decreased by 532.6 ha in Tien Yen district, while the extent of water cover increased by 810.4 ha.

In December 2020, the extent of non-mangrove forests, including rice paddy field/agriculture, residential areas/built-up areas, and intertidal muddy flats were estimated at 881.5 ha from Sentinel-2B. These intertidal areas in Tien Yen district offer potential targets for future mangrove restoration projects. The areas of water cover fluctuated during differently studied years, but generally increased from 5361.8 ha in 2015 to 6172.2 ha in 2020. In particular, the areas of water covers decreased continuously from 2017 to 2018 compared to 2015, but exceptional in 2016 and 2020 in Tien Yen district.

Table 4. Estimated areas of coastal land use/covers (ha, %) in Tien Yen district for different years: 2016, 2017, 2018, 2019, and 2020

Years	2015	2016	2017	2018	2019	2020
Mangrove forests	3133.8	3210.8	3943.8	3700.9	3525.2	2856.0
Non-mangrove forests	1414.1	988.9	999.6	968.4	1736.4	881.5
Water bodies	5361.8	5710.1	4966.4	5240.5	4647.2	6172.2
Change in water bodies (+, -) compared to 2015		348.3	-395.4	-121.3	-714.6	+810.4
Total	**9909.8**	**9909.8**	**9909.8**	**9909.8**	**9909.8**	**9909.8**

Non-mangrove forests: Rice paddy field/agriculture, residential areas/built-up areas, muddy flats; Waters; Shrimp ponds, rivers, open sea water.

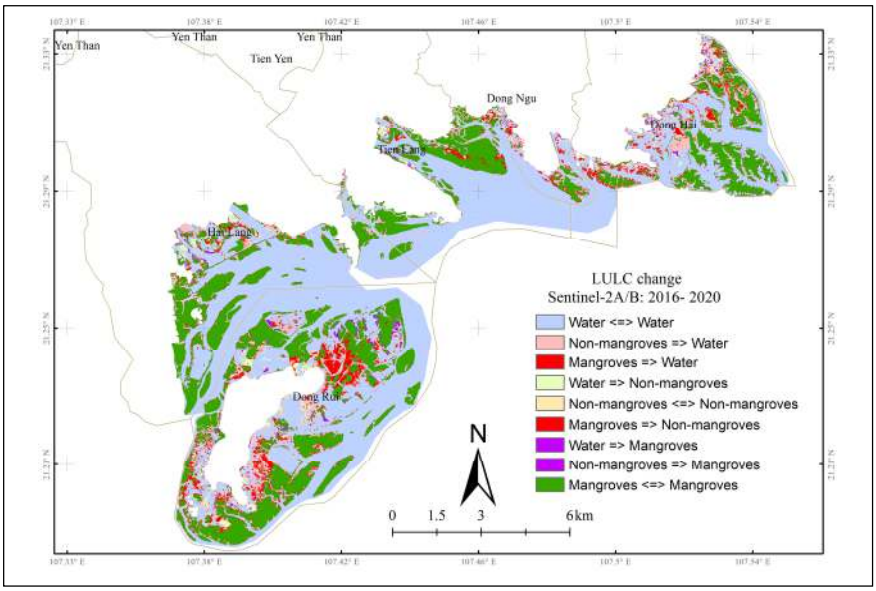

Fig. 3. Changes in land use and land cover in coastal communes of Tien Yen district, Quang Ninh province during the period of 2015 - 2020

As can be seen in Fig. 3, it is evident that some areas have been experienced with the stability of mangrove forests, and non-mangrove forests, while non-mangrove forests

and water bodies (intertidal areas) were witnessed with the replacement of newly planted mangrove forests. Mangrove forests were also cleared to other land use purposes, such as shrimp farm expansion, agriculture expansion, and newly created built-up areas. In addition, Dong Rui, Hai Lang, Dong Ngu and Dong Hai communes have been witnessed with mangrove deforestation, while mangrove afforestation has been recorded mainly in Dong Rui commune.

Changes in mangrove forests in Tien Yen district from 2016 - 2020:

The extent of mangrove forests and changes differed between coastal communes within Tien Yen district (Table 5, Fig. 4). Mangrove forests were evident in Dong Rui, Hai Lang, Tien Lang, Dong Ngu and Dong Hai communes in 2015. The period of 2015 - 2020 witnessed the fluctuations in mangrove extent in Tien Yen district. By 2020, the extent of mangrove forests (2856.8 ha) decreased by 227.8 ha compared to 2015 (3133.8 ha). Significantly, mangrove cover sharply increased by 810.0 ha in 2017 and 567.1 ha in 2018 in comparison with 2015. In particular, Dong Rui, Dong Ngu and Dong Hai communes experienced with large changes in mangrove cover, resulting in an overall increase of mangrove forest extent in 2017 and 2018. In contrast, Hai Lang and Tien Lang communes were observed with almost constant extent of mangrove forests from 2015 to 2020.

Table 5. The estimated extent of mangrove forests (ha) in coastal communes of Tien Yen district for years: 2016, 2017, 2018, 2019, and 2020

Communes	2015	2016	2017	2018	2019	2020
Dong Rui	1597.5	1405.3	1812.4	1727.7	1660.9	1194.3
Hai Lang	509.5	651.2	632.4	644.3	635.0	618.6
Tien Lang	399.4	410.6	454.0	433.4	436.8	385.3
Dong Ngu	117.3	143.4	864.3	159.9	154.2	114.6
Dong Hai	510.2	599.8	180.8	735.7	639.2	543.2
Total	**3133.8**	**3210.8**	**3943.8**	**3700.9**	**3526.1**	**2856.0**
Change (-: Decrease -; +: Increase)		+77.0	+810.0	+567.1	+392.3	- 227.8

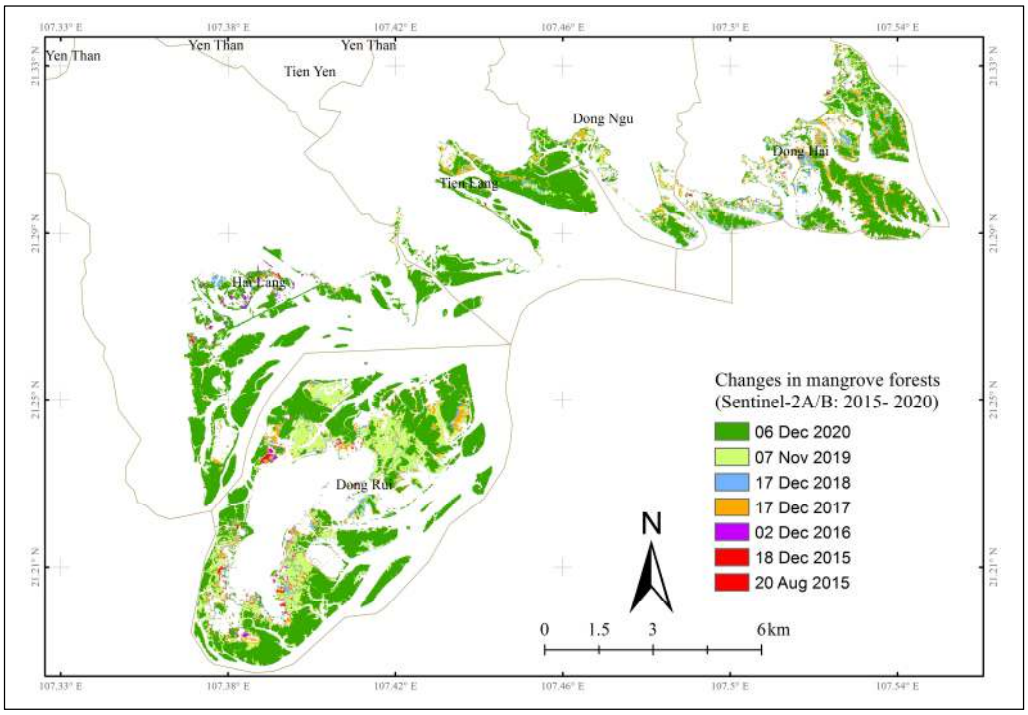

Fig. 4. Changes in mangrove forests in coastal communes of Tien Yen district, Quang Ninh province in selected years (2015, 2016, 2017, 2018, 2019, 2020)

As can be seen there is a spatio-temporal change in mangrove forests from 2015 to 2020. The change has experienced across all of five coastal communes of Tien Yen district. In

particular, Dong Rui commune has been witnessed with a large change in the extent of mangrove forests from 2015 to 2020, followed by Dong Hai and Dong Ngu communes. The main drivers of change in mangrove forests were aquaculture expansion, other land use, and afforestation projects (Hai-Hoa, 2014; Hai-Hoa et al., 2015; Hai-Hoa, 2016). Other land use was also a key drivers of mangrove deforestation in Tien Yen district. The study has found that the expansion of rice production was responsible for driving mangrove deforestation in coastal communes of Tien Yen district. However, recent afforestation projects have significantly contributed to increase the extent of mangrove forests during the studied periods. The Sentinel-2A/B data revealed young mangrove forests, mangrove planted in recent years were able to be included in the 2019 and 2020 mangrove forest maps (Fig. 4). Therefore, it assumes that the satellite imagery (Sentinel-2A/B) are able to identify whether afforestation projects have been implemented successfully or not in Tien Yen district.

3.3. Drivers of changes in mangrove forests in Tien Yen district

The drivers of changes in mangrove forests over the period of 2015 - 2020 were in the order of aquaculture, shrimp farm expansion > other land uses > natural factors > afforestation.

Table 6. Estimated changes in land use/cover (ha) in different periods in Tien Yen district

Years	2015-2017	2017-2018	2018-2019	2019-2020	2015-2020
Mangrove forests	+810.0	-242.9	-175.7	-669.2	-277.8
Non-mangrove forests	-414.5	-31.2	768.0	-854.9	-532.6
Waters	-395.4	274.1	-593.3	1525.0	810.4

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

As shown in Table 6, we can see the changes in land use/covers in Tien Yen district. Overall, the extent of mangrove forests decreased by 277.8 over the period of 2015 - 2020. Similarly, the non-mangrove forests, including rice paddy field/agriculture, residential areas/built-up areas, muddy flats, have been recorded with a reduction of 532.6 ha, while water bodies, such as shrimp farms, ponds, rivers, open seawater, have been increased by 810.4 ha. Key periods of changes in land use/covers are summarized as below:

Period of 2015 - 2017: In this period, the areas increased by 810.0 ha as evidenced by international participation in mangrove afforestation project. By NGOs and Vietnamese government programs, with the project KVT (Netherlands), ACTMANG (Japan), Vietnam Academy of Forestry Science, Department of Environment (Ministry of Natural Resources and Environment), mangroves aims to increased resistance to good construction. This is a project signed with the comfort of every household involved in planting and protecting mangroves (Hai-Hoa, 2016).

Period of 2017 - 2018: In this period as the areas of mangrove forests decreased by 242.9 ha due to indiscriminate logging and deforestation, the exploitation of aquatic resources under the forest canopy was not controlled, leading to mangroves and mangroves being degraded. degradation, seriously affecting the ecological environment, production and the lives of local people. Non-mangrove forests were also converted to other purposes, while other areas of water cover increased by 274.1 ha.

Period 2018 - 2019: In this period, the areas of mangrove forests continued to decrease by 175.7 ha, mainly because people after being allocated forests only cared about economic benefits. Therefore, local people have cleared the areas of mangrove forests to fill the lagoon, exploited mangrove trees for firewood, cut bark to dye fishing nets, and raise seafood.

Period 2019 - 2020: During this period, the areas of mangrove forests and non-mangrove forests continued to decrease significantly by 669.2 ha and 854.9 ha, respectively. Apart from the same drivers of mangrove deforestation and non-mangrove forest conversion to other purposes in the period of 2019 - 2020, unmanaged and untreated solid wastes and domestic water discharged directly into the nearby sea water, thus affecting the ecological environment and biodiversity, including mangrove ecosystem. Marine and mangrove ecosystems have seriously affected by the pollution. Along with that, there are no mechanisms and policies to encourage people to participate in the protection and development of mangroves.

4. CONCLUSION

Remote sensing technology is an effective tool to detect and monitor mangrove change over time. Three land use and land covers were classified using Sentinel-2A/B from 2015 - 2020, namely mangrove forests, non-mangrove forests, and water bodies. This study used the NDVI thresholds for coastal land covers (NDVI value > 0.2 for mangrove forests). The overall accuracies assessments of land covers in 2020 (assessed at 91.3% of accuracy, Kappa coefficient of 0.83) and land covers in 2016 (88.3% of accuracy, Kappa coefficient of 0.78) have confirmed the effectiveness of using Sentinel-2 data for monitoring the spatio-temporal changes of mangrove forests in Tien Yen district.

The areas of coastal mangrove forests in Tien Yen district, Quang Ninh province in 2015 were 3133.8 ha and non-mangrove forests are 1414.1 ha, while the areas of mangrove forests and non-mangrove forests in 2020 were estimated at 2856.0 ha and 881.5 ha, respectively. Overall, mangrove forests in Tien Yen district decreased by 277.8 ha in 2020 compared to 2015 and main drivers for mangrove deforestation during the period of 2015 - 2020 were aquaculture development, shrimp farm and agriculture expansion, and other land use conversions recorded.

Acknowledgments

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.08-2017.05. The authors also would like to thank Commune People's Committee and local people in Dong Rui, Hai Lang, Tien Lang, Do Ngu, Dong Hai, and Dong Ngu communes of Tien Yen district, Quang Ninh province for supporting us when collecting data.

REFERENCES

1. Alongi, D.M., (2002) Present State and Future of the World's Mangrove Forests. *Environmental Conservation*. 29:331-349. http://dx.doi.org/10.1017/S0376892902000231.

2. Castillo, J. A.A., Apan, A.A., Maraseni, T. N., Salmo, S.G. (2017) Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using Sentinel imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*. 134:70-85. https://doi.org/10.1016/j.isprsjprs.2017.10.016.

3. Congedo, L. (2020) Semi-Automatic Classification Plugin documentation. Release 6.4.0.2. 243p.

4. Dittmar, T., Hertkorn, N., Kattner, G.R., Lara, J., (2006) Mangroves, amajor source of dissolved organic carbon to the oceans, GlobalBiogeochem. Cycles, 20, GB1012, doi:10.1029/2005GB002570.

5. Duke, N.C., Meynecke, J-O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K.C., Field, C.D., Koedam, N., Lee, S.Y., Marchandm C., Nordhaus, I., Dahdouh-Guebas, F. (2007) A world without mangroves? *Science*. 317:41–42.

6. Ewel, K., Twilley, R., Ong, J.I.N. (1998) Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters*. 7:83–94.

7. FAO (2007) Mangroves of Asia 1980–2005 (country reports). Food and Agriculture Organisation (FAO), Rome.

8. Fensholt, R., Rasmussen, K., Nielsen, T.T., Mbow, C. (2009) Evaluation of earth observation based long term vegetation trends – inter-comparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOT VGT data. *Remote Sens Environ*.113:1886–1898.

9. Foody, G.M. (2002) Status of land cover classification accuracy assessment. *Remote Sensing of Environment*. 80:185–201.

10. Foody, G.M. (2009) Classification accuracy comparison: hypothesis tests and the use of confidence intervals in evaluations of difference, equivalence and non-inferiority. *Remote Sensing of Environment*. 113:1658–1663.

11. Foody, G.M. (2013) Ground reference data error and the mis-estimation of the area of land cover change as a function of its abundance. *Remote Sensing Letters*. 4:783-792.

12. Giri, C., Zhu, Z., Tieszen, L.L., Singh, A., Gillette, S., Kelmelis, J.A. (2008) Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. *Journal of Biogeography*. 35:519– 528.

13. Green, E.P., Clark, C.D., Mumby, P. J., Edwards, A.J., Ellis, A.C. (1998) Remote sensing techniques for mangrove mapping. *International Journal of Remote Sensing*. 19(5):935-956. doi: https://doi.org/10.1080/014311698215801.

14. Hai-Hoa, N., McAlpine, C., Pullar, D., Duke, N.C., Johansen, K (2013) The relationship of spatial – temporal changes in fringe mangrove extent and adjacent land - use: case study of Kien Giang coast, Vietnam. *Ocean & Coastal Management*. 76:12-22.

15. Hai- Hoa, N., McAlpine, C., Pullar, D., Leisz, S.T., Galina, G. (2015) Drivers of coastal shoreline change: Case study of the Hon Dat coast, Kien Giang, Vietnam. *Environmental Management Journal*, 55:1092-1108.

16. Hai- Hoa, N (2014) The relation of coastal mangrove changes and adjacent land-use: A review in Southeast Asia and Kien Giang, Vietnam. *Ocean and Coastal Management*. 90:1- 10.

17. Hai-Hoa, N. (2016) Application of multi-temporal Landsat remote sensing and GIS to assess changes in coastal mangrove areas in Tien Yen district, Quang Ninh province in the period 1994- 2015. *Journal of Forestry Science and Technology. 4208-4217.*

18. Hai-Hoa, N., Nghia, N.H., Hien, N.T.T., An, L.T., Lan, T.T., Linh, D., Simone, B., Michael, F. (2020a) Classification Methods for Mapping Mangrove Extents and Drivers of Change in Thanh Hoa Province, Vietnam during 2005-2018. *Forest and Society*. 4:225.

19. Hai-Hoa, N., Lan, T.T.N., An, L.T., Nghia, N.H., Linh, D.V.K., Thu, N.H.T., Bohm, S., Premnath, C.F.S (2020b) Monitoring changes in coastal mangrove extents using multi-temporal satellite data in selected communes, Hai Phong city, Vietnam. *Forest and Society*. 4 256–720.

20. Jennerjahn, T.C., Ittekkot, V. (2002) Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *The Science of Nature - Naturwissenschaften*. 89:23-30.

21. Keller, E,A,m (2014). Environmental science: earth as a living planet 9E WileyPlus Lms student package. John Wiley & Sons, Incorporated.

22. McNally. R., McEwin, A., Holland, T. (2011) The potential for mangrove carbon projects in Vietnam. Netherlands Development Organization (SNV). The Hague.

23. Ramdani, F., Rahman, S., Giri, C. (2018) Principal polar spectral indices for mapping mangroves forest in South East Asia: study case Indonesia. *International Journal of Digital Earth*. 12:1103-1117.doi: https://doi.org/10.1080/17538947.2018.1454516.

24. Saleh, M. (2007) Mangrove vegetation on Abu Minqar Island of the Red Sea. *International Journal of Remote Sensing*. 28(23):5191-5194. doi:https://doi.org/10.1016/j.jaridenv.2006.05.016.

25. Singh, A. (1989) Review article digital change detection techniques using remotely-sensed data. International *Journal of Remote Sensing*. 10(6):989-1003. https://doi.org/10.1080/01431168908903939.

26. Son, N.T., Thanh, B.X. Da, C.T (2016) Monitoring Mangrove Forest Changes from Multi-temporal Landsat Data in Can Gio Biosphere Reserve, Vietnam. *Wetlands*. 36:565–576. https://doi.org/10.1007/s13157-016-0767-2.

27. Spalding, M., Kainuma, M., Collins, L., (2010). World atlas of mangroves. Earthscan.

28. Thom, B.G. (1984) Coastal landforms and geomorphic processes. In S.C. Snedaker and J.G. Snedaker (eds.). The Mangrove Ecosystems: Research Methods. Monograph on Oceanographic Methodology 8. UNSECO, Paris.

29. Tucker, C.J., Pinzon, J.E., Brown, M.E., Slayback, D., Pak, E.W., Mahoney, R., Vermote, E., El Saleous, N. (2005) An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT vegetation NDVI data. *International Journal of Remote Sensing*.

30. Valiela, I., Bowen, J.L., York, J.K. (2001) Mangrove forests: one of the World's threatened major tropical environments. *Bioscience.* 51:807–815.

31. Wang, Q., Tenhunen, J.D. (2004) Vegetation mapping with multi-temporal NDVI in North Eastern China Transect (NECT). *International Journal of Applied Earth Observation and Geoinformation*. 6(1):17–31. doi: 10.1016/j.jag.2004.07.002.

PHÁT HIỆN THAY ĐỔI RỪNG NGẬP MẶN BẰNG DỮ LIỆU ẢNH ĐA THỜI GIAN SENTINEL-2 TẠI HUYỆN TIÊN YÊN, TỈNH QUẢNG NINH

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TÓM TẮT

Rừng ngập mặn là loài thực vật phát triển ở vùng nước triều ven biển, phân bố ở các khu vực ven biển nhiệt đới, cận nhiệt đới và ôn đới. Rừng ngập mặn có giá trị cung cấp các dịch vụ hệ sinh thái cao. Tuy nhiên, hiện nay hệ sinh thái rừng ngập mặn đang bị tổn thương do tác động của thiên tai và áp lực từ phía con người. Tiên Yên là một huyện ven biển thuộc tỉnh Quảng Ninh. Hiện nay, dữ liệu về phân bố và biến động diện tích rừng ngập mặn theo thời gian và không gian còn nhiều hạn chế, các số liệu định lượng còn ít và tản mạn. Nghiên cứu được thực hiện nhằm lượng hoá và cập nhật dữ liệu về phân bố rừng ngập mặn theo không gian và thời gian, xác định các nguyên nhân chính dẫn đến mất rừng và suy thoái rừng trong giai đoạn 2015 - 2020. Dữ liệu ảnh đa thời gian Sentinel-2 được sử dụng để phát hiện thay đổi về diện tích rừng ngập mặn thông qua ngưỡng chỉ số NDVI kết hợp với phương pháp giải đoán ảnh bằng mắt. Kết quả nghiên cứu đã phân loại thảm phủ thành ba đối tượng khác nhau, bao gồm rừng ngập mặn (mangrove forests), đối tượng không là rừng ngập mặn (non-mangrove forests: đất trống, đất nông nghiệp, đất thổ cư, đất vùng triều…) và đối tượng là nước (water bodies). Rừng ngập mặn ở huyện Tiên Yên được ước tính là 3133,8 ha vào năm 2015 và đã giảm đi 277,8 ha vào năm 2020. Hoạt động nuôi trồng thủy sản, mở rộng trang trại đầm nuôi tôm và phát triển nông nghiệp, và việc thay đổi mục đích sử dụng đất khác là nguyên nhân chính dẫn đến rừng ngập mặn bị mất và suy thoái trong giai đoạn 2015 - 2020. Nghiên cứu đã sử dụng ngưỡng chỉ số NDVI để phân loại các lớp phủ ven biển (giá trị chỉ số NDVI > 0,2 đối với rừng ngập mặn). Đánh giá độ chính xác tổng thể về phân loại thảm phủ ven biển năm 2020 đạt 91,3% với hệ số Kappa 0,83, và năm 2016 đạt độ chính xác 88,3% với hệ số Kappa 0,7 đã khẳng định hiệu quả của việc sử dụng tư liệu ảnh viễn thám Sentinel-2A/B để đánh giá và giám sát sự thay đổi của rừng ngập mặn theo không gian và thời gian tại huyện Tiên Yên.

Từ khóa: ảnh viễn thám Sentinel-2, chỉ số NDVI, huyện Tiên Yên, lớp phủ và sử dụng đất, rừng ngập mặn.

Received : 21/5/2021
Revised : 25/6/2021
Accepted : 02/7/2021