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A METHOD FOR DETECTING PLASTIC WASTE FLOATING USING SENTINEL 2 HIGH SPATIAL RESOLUTION IMAGE: A CASE STUDY IN THE COASTAL AREA OF VIETNAM

ABSTRACT

Ocean plastic waste pollution is now becoming a serious environmental problem, especially for a country with a long coastline and wide sea like Vietnam. The remote sensing method is considered suitable and effective in early detection and classification of ocean plastic waste due to the difference in spectral reflectance of plastic waste compared to the surrounding sea. This paper presents the results of identification and classification of plastic mesh in coastal areas of Vietnam by using Sentinel 2 MSI high spatial resolution optical images. First, water was extracted from Sentinel 2 image by thresholding method on a near-infrared band. Then, the plastic mesh was identified and classified based on Float Debris Index (FDI) index using Otsu thresholding algorithm. In the study, spectral indices such as NDVI, NDWI were also used to improve the accuracy in classifying plastic mesh. In the study, Google high spatial resolution satellite images were also used to evaluate the accuracy of plastic mesh classification. The obtained results show that, in 02 test areas, the proposed method allows detecting plastic mesh with an accuracy of over 90 %. The results obtained in the study can be used to provide input information for models of forecasting and assessing the impact of ocean plastic waste pollution on coastal environments.

KEYWORDS: ocean plastic waste pollution, remote sensing, Sentinel 2 image, FDI index, Vietnam

INTRODUCTION

Plastic products are very convenient to use, so the production of plastic products is continuously increasing all over the world. The increase in production, trade and use of plastic products leads to an increase in plastic waste. With 112 estuaries, 80 % of Vietnam's marine waste comes from activities on land [*Chu* et al., 2020]. According to the United Nations Environment Program, each year Vietnam discharges into the ocean 0.28 to 0.73 million tons of plastic waste (accounting for 6 % of the world), ranking fourth in the world [*Hahladakis*, 2020]. Plastic waste pollution is becoming a global environmental problem, causing extremely serious impacts on marine species as well as the marine ecological environment [*Abalansa* et al., 2020; *Smith, Brisman*, 2021].

Previously, the studies for monitoring ocean plastic waste pollution were mainly based on the results of investigation and field exploration. However, due to the large area and complicated weather conditions, the use of traditional monitoring methods in detecting and monitoring plastic waste pollution faces many difficulties. These limitations can be overcome when using remote sensing data, especially remote sensing images with high spatial resolution. Recently, a number of studies have used remote sensing data for early detection and classification of floating plastic waste in the sea [*Conchubhair* et al., 2019; *Sakti* et al, 2021].

Plastic objects at sea have spectral reflectance characteristics that are different from the surrounding water on optical satellite images [*Murphy, Dufaur*, 2018]. Plastic waste can be most clearly distinguished from the surrounding sea in the near-infrared (NIR) and short-

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wave infrared (SWIR) bands, in which is particularly sensitive to the wavelength range around 1215 nm and 1732 nm [*Biermann* et al., 2020; *Ciappa*, 2021]. Themistocleous et al. (2020) analyzed the spectral reflectance characteristics of plastic waste on Sentinel 2 satellite images, in which the plastic fragments have a much higher reflectivity than the surrounding seawater, especially from the red to NIR wavelength [*Themistocleous* et al., 2020].

Kikaki et al. (2020) used multiple remote sensing data sources, including 400 Planet high spatial resolution optical satellite images (spatial resolution from 3 to 5 m), 340 Sentinel 2 images (spatial resolution up to 10 m), 125 Landsat 8 images (30 m spatial resolution) and in situ data to create a plastic pollution map in the Caribbean and Motagua estuary (Honduras) [*Kikaki* et al., 2020]. In addition, the studies [*Moy* et al., 2018; *Martin* et al., 2018; *Vicente* et al., 2019; *Topouzelis* et al., 2019] also used optical remote sensing data in monitoring ocean plastic waste pollution. The results obtained in these studies show that remote sensing data is an effective tool to monitor the origin and spread of plastic waste in marine ecosystems, thereby supporting marine management strategies at different scales.

Research by Topouzelis shows that the short-wave infrared band of Sentinel 2 MSI imagery with the central waveband 1610 nm can be used in marine plastic debris detection and suitable for monitoring pollution in coastal areas [*Topouzelis* et al., 2019]. Because the Sentinel 2 satellite data (including 02 satellites: Sentinel 2A and Sentinel 2B) is provided free with temporal resolution of 5 days, this is an appropriate data source in the study of plastic pollution in estuary and coastal areas.

Since the difference in spectral reflectance values between floating plastic waste and seawater is not large, it is very difficult to detect and classify marine plastic waste from optical satellite image bands. To overcome this limitation, Biermann et al. (2020) proposed a Floating Debris Index (FDI) using red (band 4), NIR (band 8), Red Edge 2 (band 6) and SWIR1 (band 11) of Sentinel2 imagery. To improve the accuracy in classifying ocean plastic waste, the authors used a combination of FDI and NDVI, NDWI indices to eliminate the effects of seawater and plants on plastic waste [*Biermann* et al, 2020]. Ciappa (2021) also uses Sentinel 2 data to detect plastic waste in Hawaii and Caribbean seas. The obtained results show that the NDVI index and the near-infrared band (band 8) of Sentinel 2 images allow detecting and classifying plastic waste at sea with high accuracy [*Ciappa*, 2021].

Recently, several studies have also used active remote sensing data (SAR and LIDAR images) [*Behrenfeld* et al., 2013; *Arii* et al., 2014; *Narangerel* et al., 2018] or a combination of optical remote sensing data, SAR data and images taken from unmanned aerial vehicles (UAVs) to improve accuracy in detecting and classifying ocean plastic waste [*Garaba* et al., 2021; *Romero* et al., 2021]. The results obtained from these studies show that satellite remote sensing data is suitable for early detection of plastic fragments in the sea, while UAVs data is suitable for studying plastic waste pollution in coastal areas.

This study presents the results of classification of marine plastic debris from Sentinel 2 high spatial resolution satellite images. The Float Debris Index (FDI) is used in combination with Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) to identify and classify plastic fragments. Two test areas were selected in the coastal region of Da Nang and Hoi An (Central Vietnam). All Sentinel 2 data products are provided free of charge to all data users with a short temporal resolution, the results obtained in the study can provide timely input for the models of ocean plastic pollution monitoring.

The study areas

The selected study areas are the coastal waters of Da Nang (Da Nang city, test area 1) and Hoi An (Quang Nam province, test area 2), Central region of Vietnam (Figure 1). The coastal areas of Da Nang and Quang Nam provinces have a large population, rapid urbanization, various types of industrial activities and busy sea traffic. These activities lead to negative impacts on the environment, including an increase in the amount of plastic waste dumped into the sea every year. In addition, aquaculture and maritime tourism activities in coastal areas also release a large amount of plastic waste into the marine environment. This is one of the areas in Vietnam most affected by ocean plastic pollution.

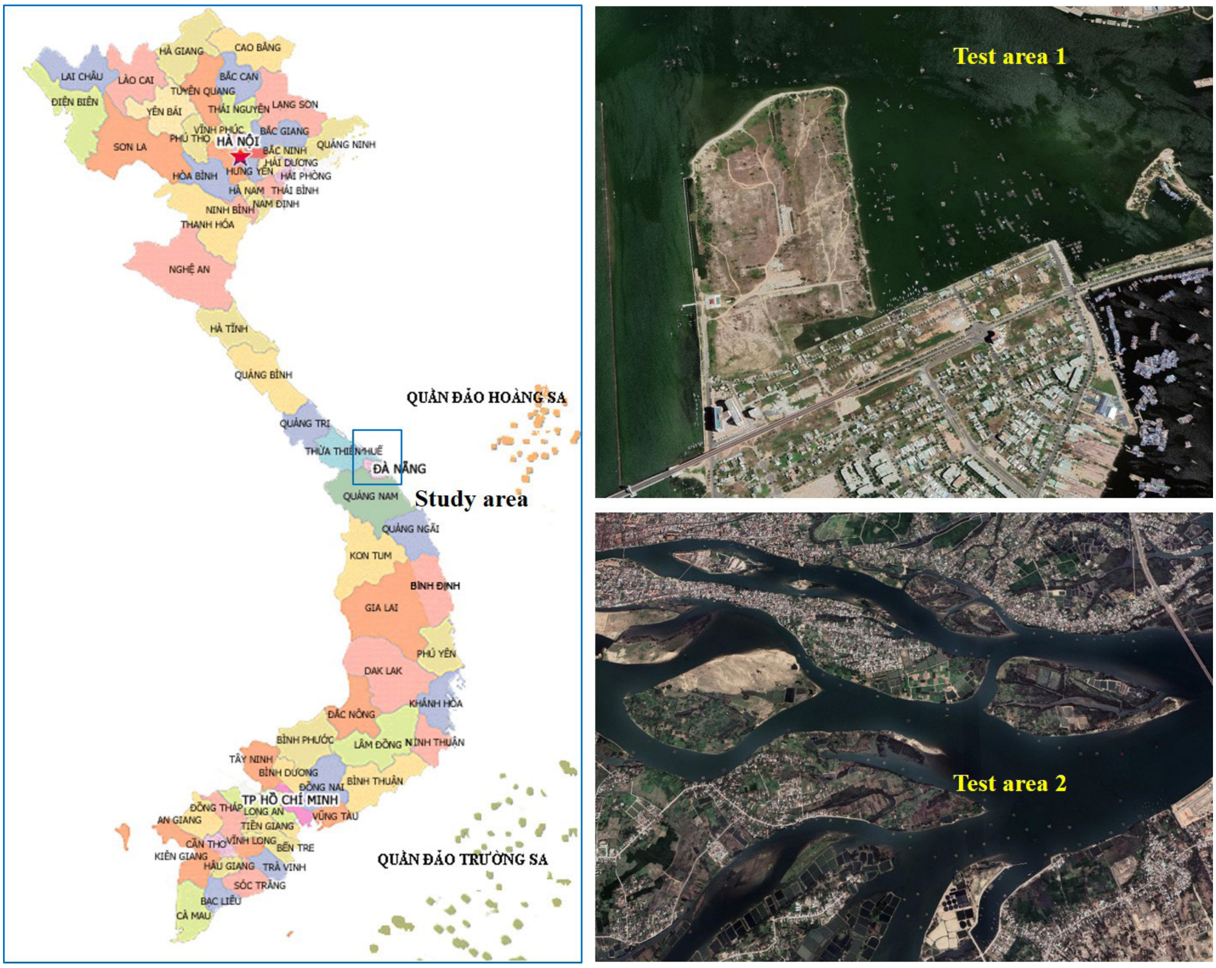

Fig. 1. The study area

MATERIAL AND METHODOLOGY

Remote sensing data

In this study, Sentinel 2A multispectral image with L2A level product acquired in July 11, 2020 (Figure 2) was used to detect the plastic waste on the sea surface. The Level-2A product provides Bottom Of Atmosphere (BOA) reflectance images derived from the associated Level-1C products[1]. Each Level-2A product is composed of 100×100 km^2 tiles in cartographic geometry (UTM/WGS84 projection). The Sentinel 2A image after collection is geometrically corrected to the VN-2000 coordinate system.

The Sentinel 2 mission consists of two satellites (Sentinel 2A and Sentinel 2B), acquires optical imagery at high spatial resolution (10 m to 60 m) to support land cover and environmental monitoring. Together they cover all Earth's land surfaces, large islands, and inland and coastal waters every five days. After the launch of the second twin satellite (Sentinel 2B), the Sentinel 2 temporal resolution improved from 10 to 5 days [*Phiri* et al., 2020]. The Sentinel 2 MultiSpectral Instrument (MSI) acquires 13 spectral bands ranging from Visible and Near-Infrared (VNIR) to Shortwave Infrared (SWIR) wavelengths along a 290 km orbital swath [*Kikaki* et al., 2020] – Table 1.

[1] Web resource: https://sentinels.copernicus.eu/

Fig. 2. Sentinel 2A image, acquired in July 11, 2020

Table 1. Characteristic of Sentinel 2 satellite imagery

Sentinel - 2 Bands	Central wavelength (μm)	Resolution (m)
Band 1 – Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation Red Edge	0.705	20
Band 6 – Vegetation Red Edge	0.740	20
Band 7 – Vegetation Red Edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation Red Edge	0.865	20
Band 9 – Water vapour	0.945	60
Band 10 – SWIR-Cirrus	1.375	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

Figures 3 and 4 show the Sentinel 2A images taken on June 11, 2020 of test area 1 (coastal area of Da Nang city) and test area 2 (coastal area of Hoi An city, Quang Nam province). The bright blue objects on the sea surface are plastic fishing nets and aquaculture rafts in the study area. In this paper, an algorithm is developed based on FDI index to detect and classify plastic fishing nets.

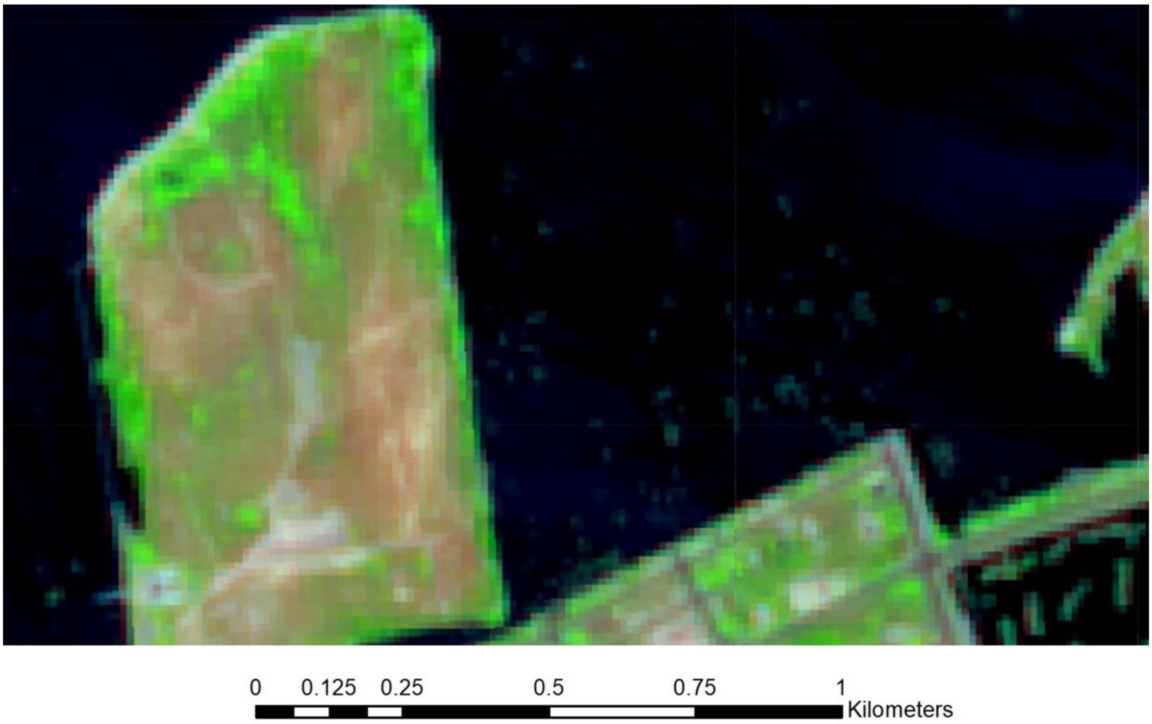

Fig. 3. Sentinel 2A image acquired June 11, 2020, coastal area of Da Nang city

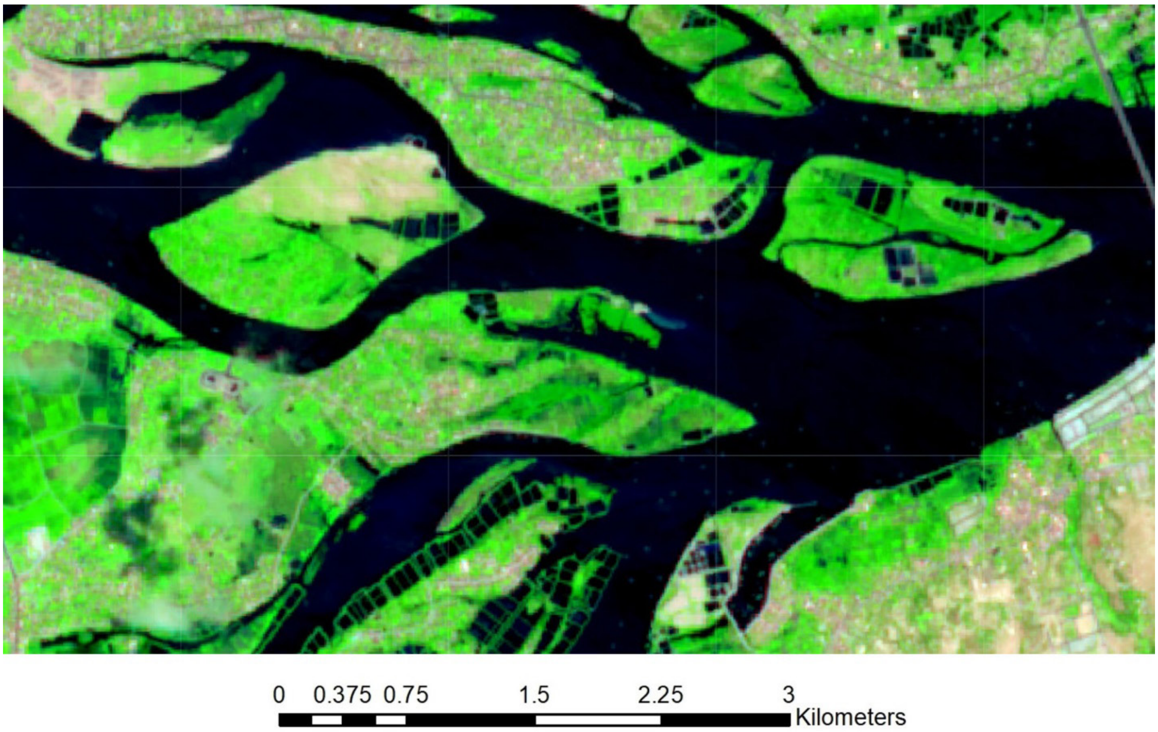

Fig. 4. Sentinel 2A image acquired June 11, 2020, coastal area of Hoi An city

Methodology

Image processing started with radiometric and geometric correction. Then, four bands of Sentinel 2 image, including RED (band 4), RE2 (band 6), NIR (band 8) and SWIR1 (band 11) are used to calculate the FDI index according to the following formulas (1 – 2):

$$FDI = Band_{NIR} - Band_{temp} \tag{1}$$

$$Band_{temp} = Band_{RE2} + (Band_{SWIR1} - Band_{RE2}) \times \frac{(\lambda_{NIR} - \lambda_{RED})}{(\lambda_{SWIR1} - \lambda_{RED})} \times 10 \quad (2)$$

Besides using the FDI index, the study used the Normalized Difference Vegetation Index – NDVI [*Rouse* et al., 1974] and the Normalized Difference Water Index – NDWI [*McFeeters*, 1996] to reduce noise in process of plastic waste detection and classification from Sentinel 2 data. These indices are determined according to the following formulas (3 –4):

$$NDVI = \frac{Band_{NIR} - Band_{RED}}{Band_{NIR} + Band_{RED}} \quad (3)$$

$$NDWI = \frac{Band_{GREEN} - Band_{NIR}}{Band_{GREEN} + Band_{NIR}} \quad (4)$$

Where: $Band_{GREEN}$, $Band_{RED}$ and $Band_{NIR}$ are reflectance values of green, red, near infrared (NIR) bands of Sentinel 2 multispectral image.

To improve the accuracy in detecting and classifying plastic waste at sea from Sentinel 2 remote sensing images, in the study, water body was extracted from the near-infrared band (band 8). The NIR band is a suitable choice for creating image thresholds for water classification because water has high absorption in the NIR range. Meanwhile, the soil and the vegetation cover have a high reflectivity in the NIR band. Thus, water body is represented by dark pixels in the NIR band, while soil and vegetation cover are represented by light colored pixels. The FDI index image and water body classification results are merged to extract the sea water area, thereby helping to improve the efficiency when detecting plastic waste at sea.

In the next step, the Otsu thresholding algorithm is used to classify floating waste in the sea. It is the most referenced thresholding methods, as it directly operates on the gray level histogram. Finally, the classification result of floating plastic waste is combined with the NDVI, NDWI index to eliminate the effects of seawater and plants on plastic waste. Flowchart for the methodology used in this study to classify plastic waste based on Sentinel 2 data is shown in Figure 5.

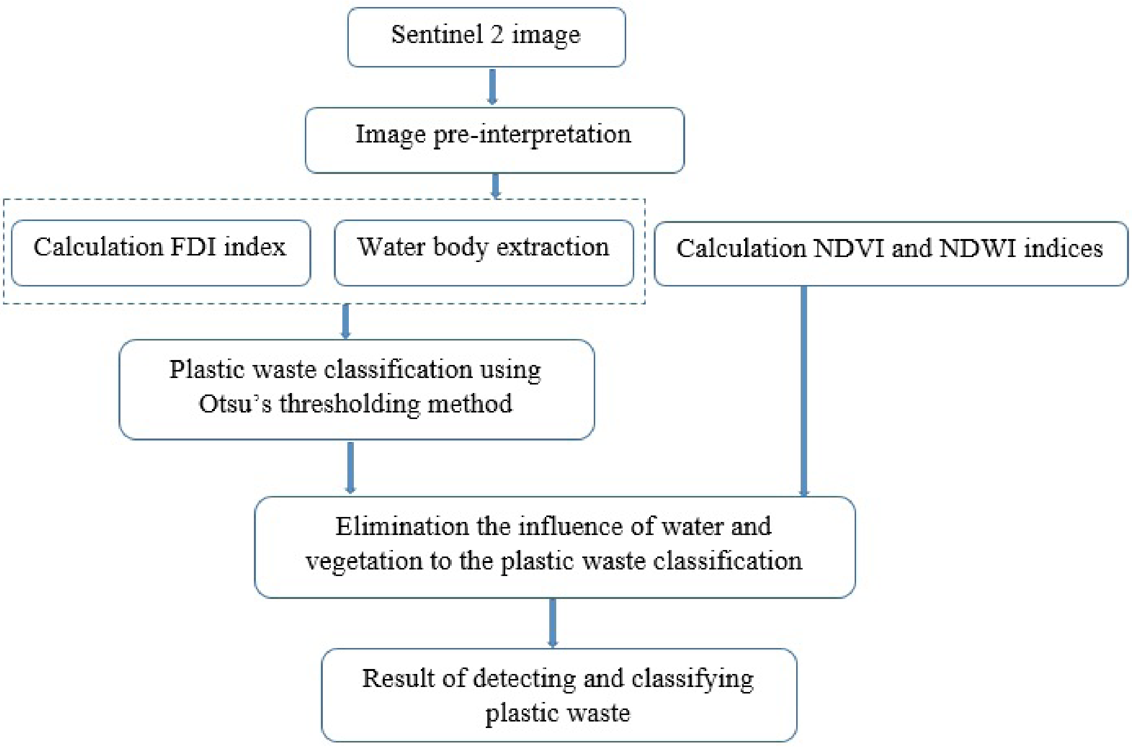

Fig. 5. Flowchart of the methodology for plastic waste classification based on Sentinel 2 imagery data

RESULTS AND DISCUSSION

Test area 1:

The selected research area is Da Nang coastal area. Sentinel 2A image acquired on June 19, 2020, after collection and preprocessing is used to calculate the FDI index according to formulas (1) and (2).

The FDI index image, calculated from Sentinel 2A data for the test area 1 is shown in Figure 6. On the FDI index image, vegetation cover is represented by bright white pixels, plastic fishing nets are represented by gray pixels, while bare land, built-up land and seawater represented by dark colored pixels.

Using the Otsu thresholding method, the plastic fishing nets were classified from the FDI index image. The result of classifying plastic fishing nets by thresholding method is presented in Figure 7, where plastic fishing nets are shown in red color.

To improve the accuracy of detecting and classifying plastic fishing nets, the NDVI index (according to formula 3) and the NDWI index (according to formula 4) were also used in the study. The NDVI and NDWI indices calculated from Sentinel 2A image dated June 11, 2020, in test area 1 are presented in Figures 8 and 9. Analysis of the obtained results shows that the plastic fishing nets have an NDWI index value greater than 0.3 and an NDVI index value between 0 – 0.3. These threshold values were used to remove the effects of water and vegetation when classifying plastic fishing nets from the FDI index.

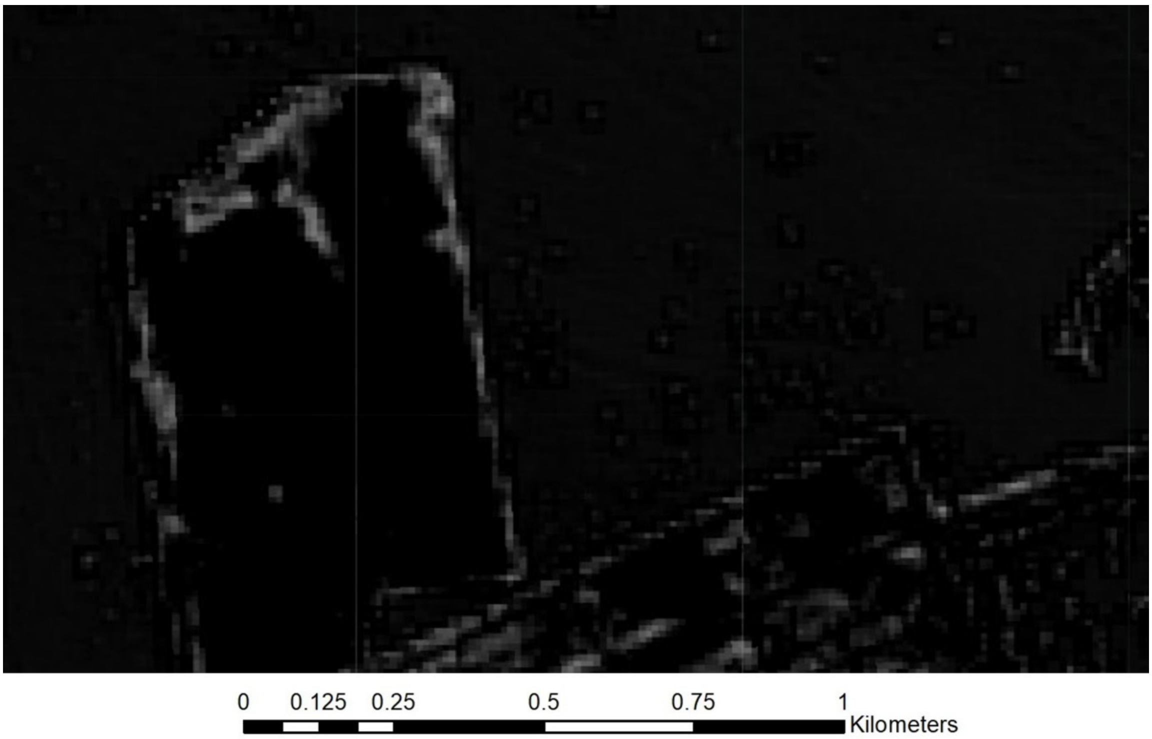

Fig. 6. FDI index in the test area 1, calculated from Sentinel 2A image, 11/6/2020

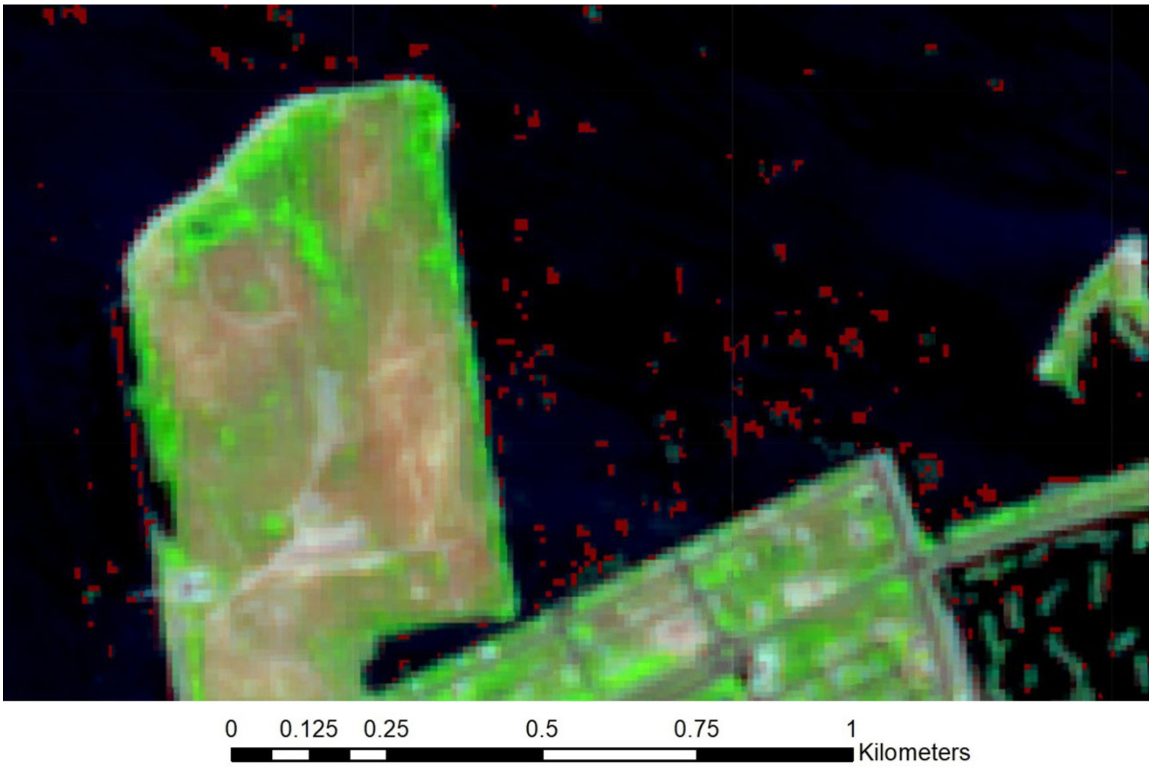

Fig. 7. Results of detection and classification of plastic fishing nets in test area 1

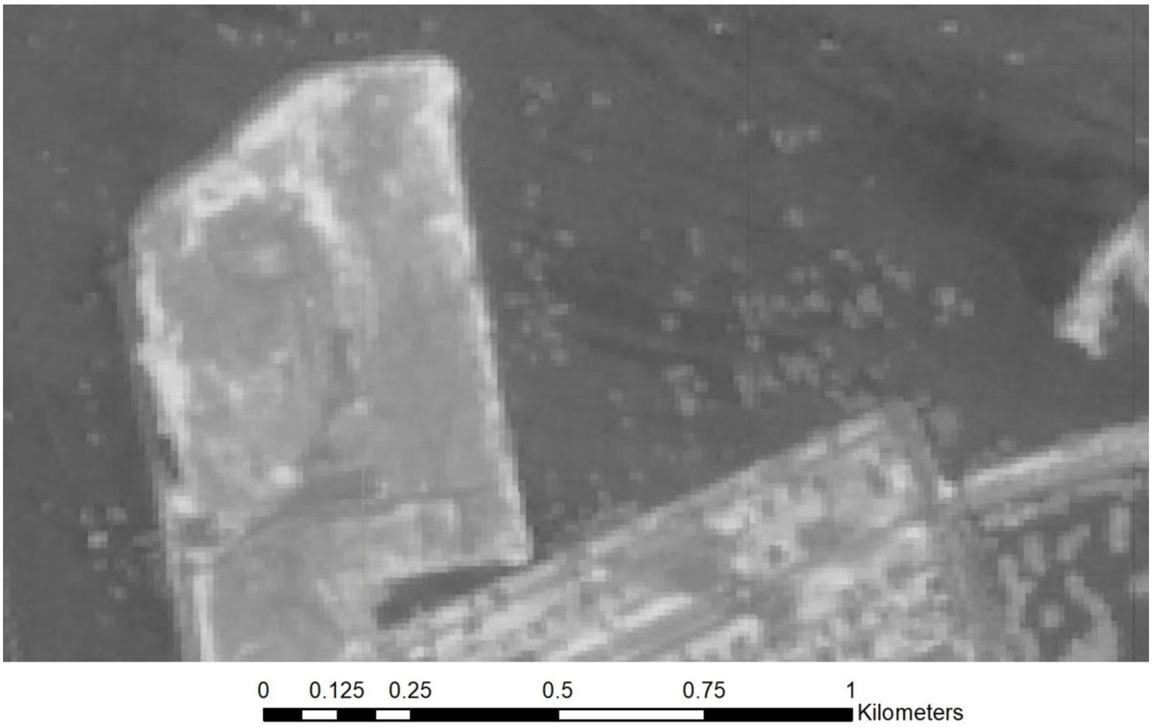

Fig. 8. NDVI index in the test area 1, calculated from Sentinel 2A image, June 11, 2020

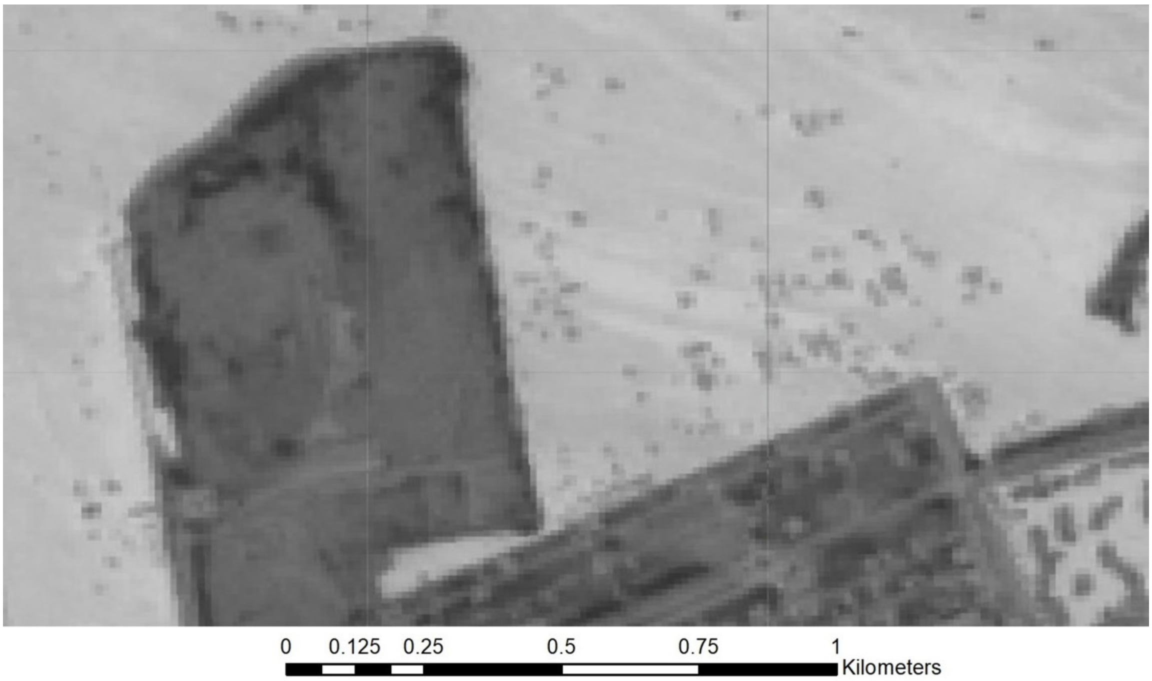

Fig. 9. NDWI index in the test area 1, calculated from Sentinel 2A image, June 11, 2020

To evaluate the accuracy of the classification results, in this study, high spatial resolution remote sensing images from Google were used. 50 locations of plastic fishing nets in the Da Nang coastal area were determined from high spatial resolution Google images, then compared with classification results from Sentinel 2A satellite images. The obtained results showed that 42 plastic fishing net positions were classified correctly, reaching 84 %. Although the ships and boats have similar colors and are distributed near the plastic fishing nets, the classification results from Sentinel 2A images still separate these objects.

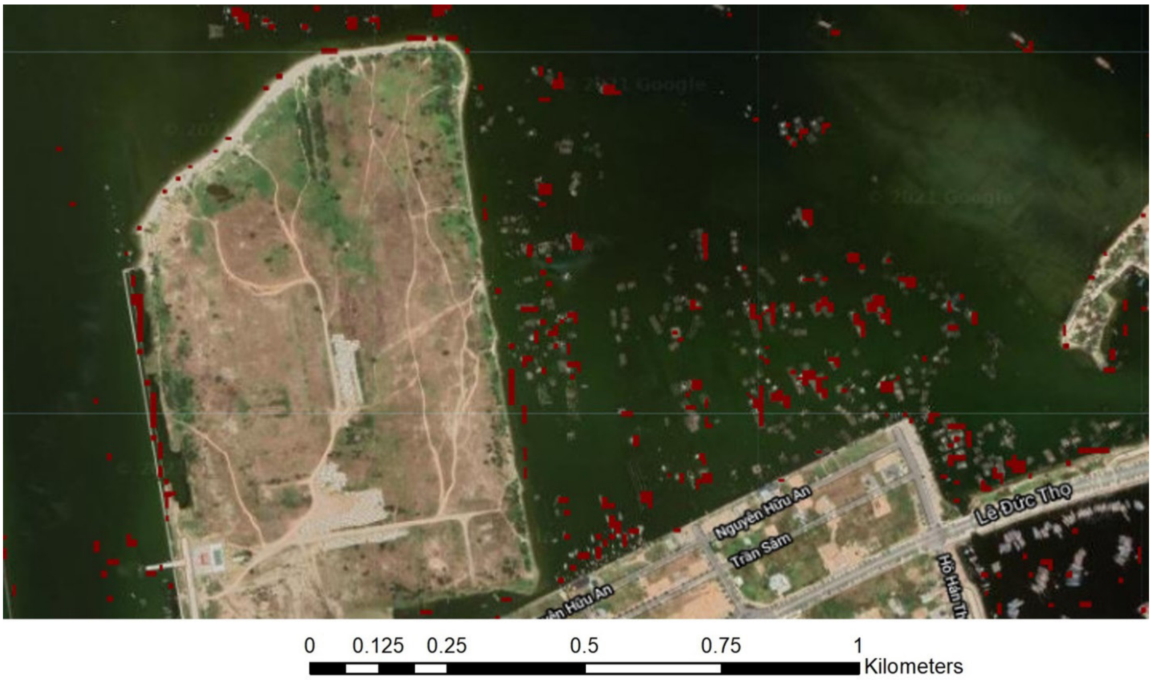

Fig. 10. Comparison of classification results of plastic fishing nets in test area 1 and high-resolution satellite images of Google Earth

Test area 2:

The experimental area 2 is the area of Thu Bon River mouth, Quang Nam province. This is an area with bustling waterway traffic, a large population density around. This leads to a rapid increase in the amount of plastic waste dumped into the sea from the Thu Bon estuary in recent years.

The FDI index, calculated from Sentinel 2A image acquired June 11, 2020, for the test area 2 is shown in Figure 11. Like study area 1, NDVI and NDWI indices are used to reduce the influence of vegetation and water on the classification results of plastic fishing nets. These indices, which calculated from Sentinel 2A image are presented in the Figure 12 and Figure 13.

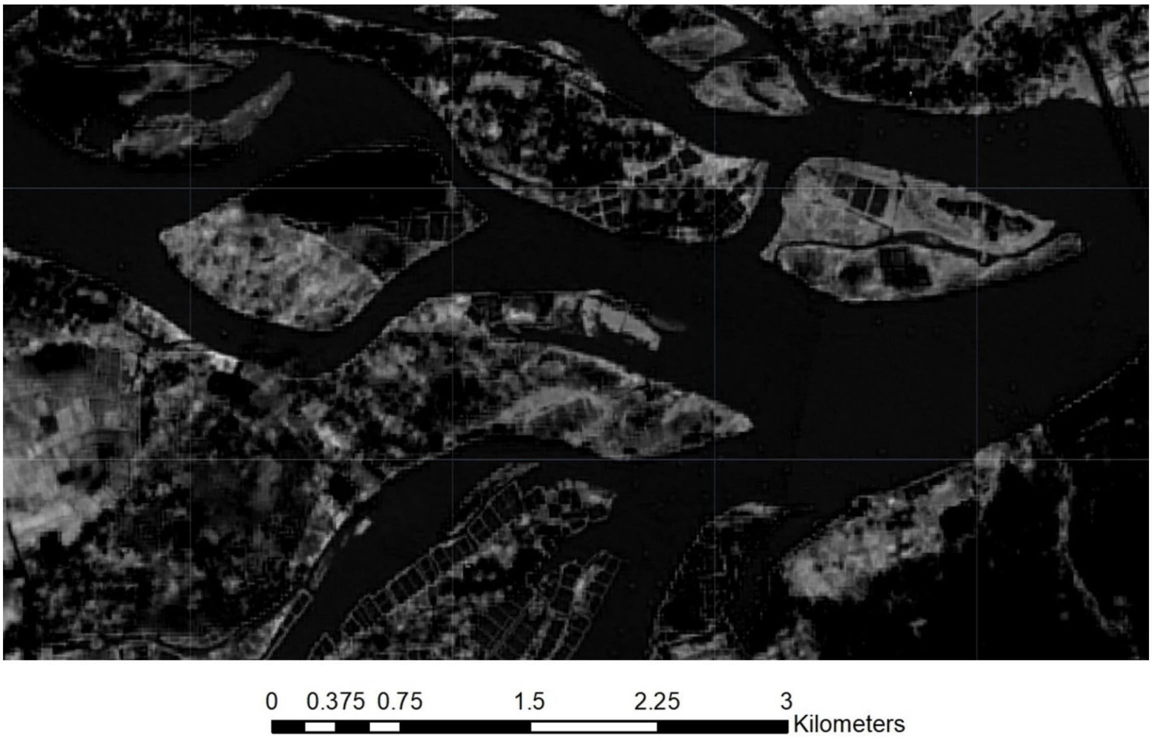

Fig. 11. FDI index in the test area 2, calculated from Sentinel 2A image, June 11, 2020

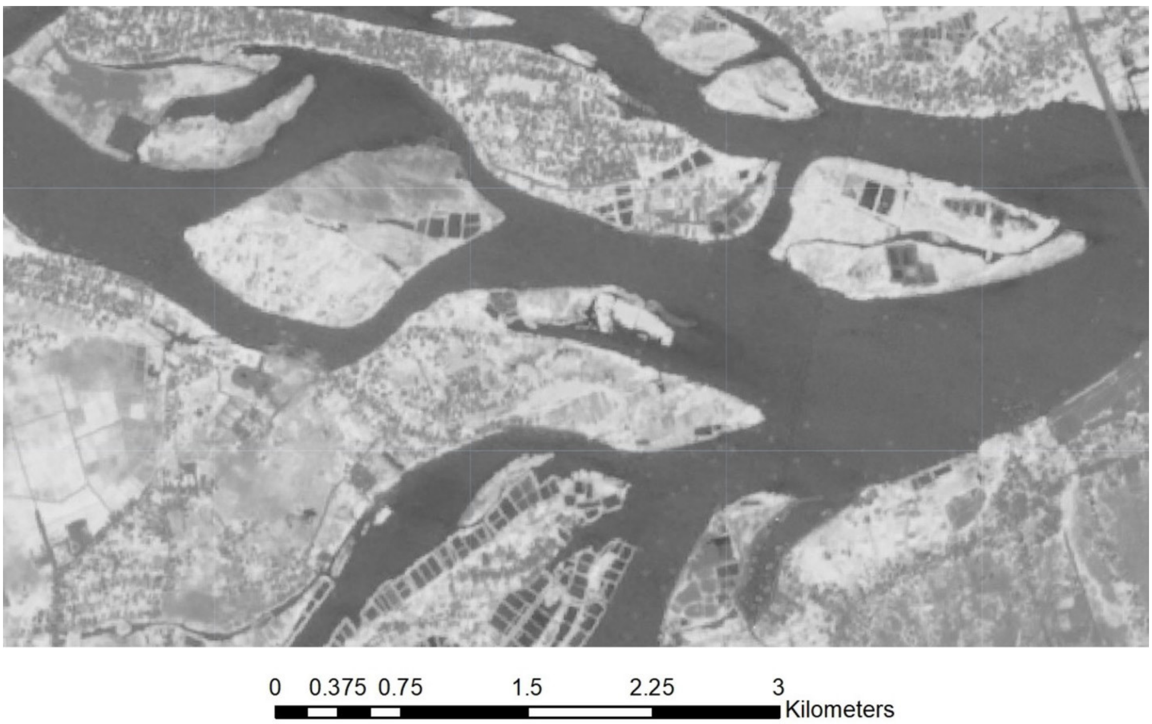

Fig. 12. NDVI index in the test area 2, calculated from Sentinel 2A image, June 11, 2020

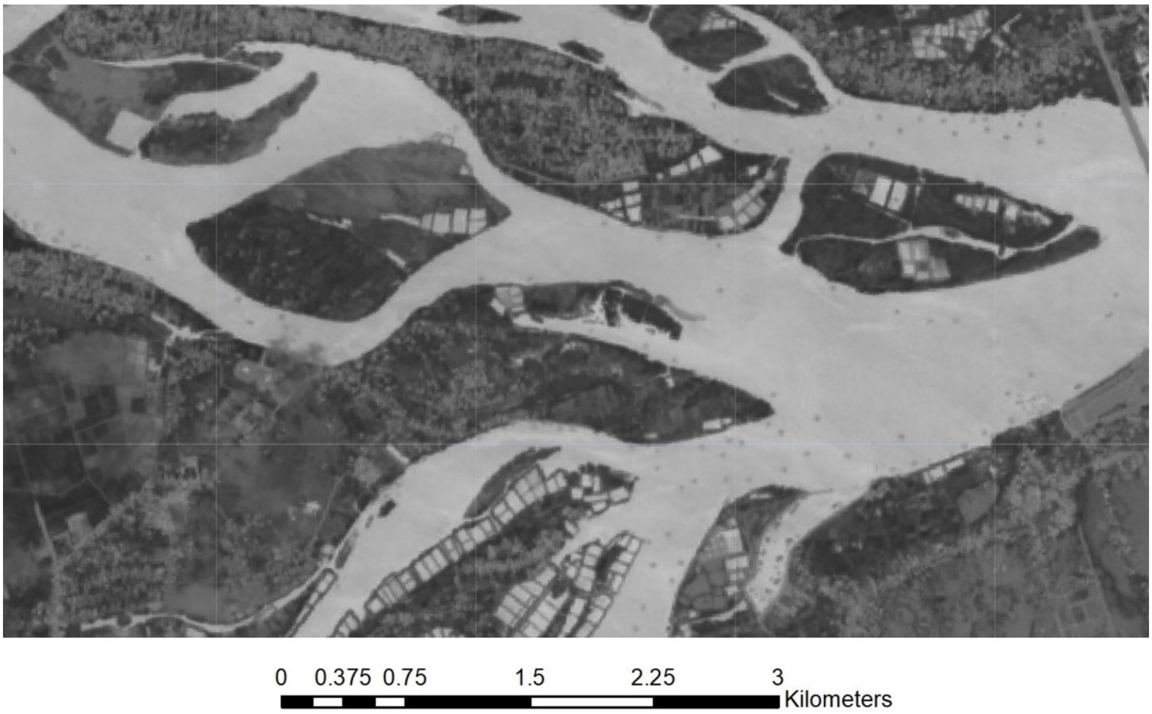

Fig. 13. NDWI index in the test area 1, calculated from Sentinel 2A image, June 11, 2020

Plastic fishing nets were classified from the FDI index image by Otsu thresholding method, then NDVI and NDWI indexes were used to reduce the influence of water and vegetation on the classification results. The classification result of plastic fishing nets in test area 2 is presented in Figure 14 (red color).

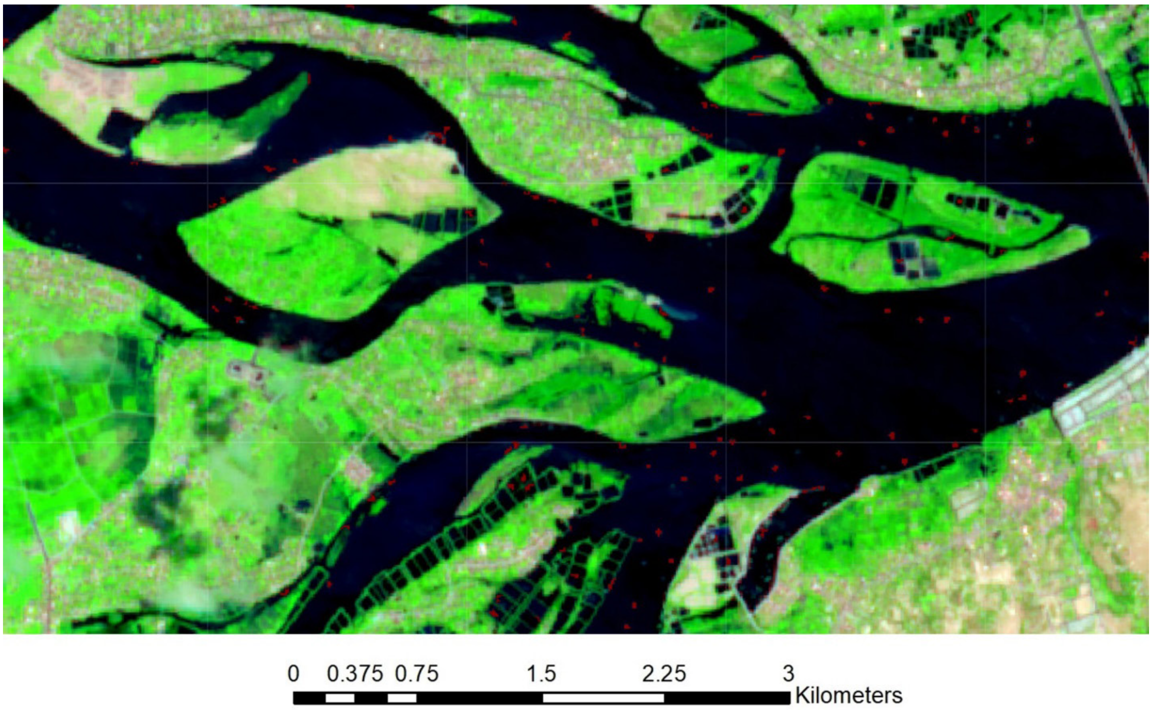

Fig. 14. Results of detection and classification of plastic fishing nets in test area 2

Like experimental area 1, in experimental area 2 at Thu Bon estuary (Quang Nam province) also uses Google high spatial resolution images to compare with the results of plastic fishing net classification, which uses 43 sample points. The obtained results showed that

38 positions of plastic fishing nets were properly classified, so the classification accuracy of plastic fishing nets from Sentinel 2A satellite images reaches 90 % (Figure 15).

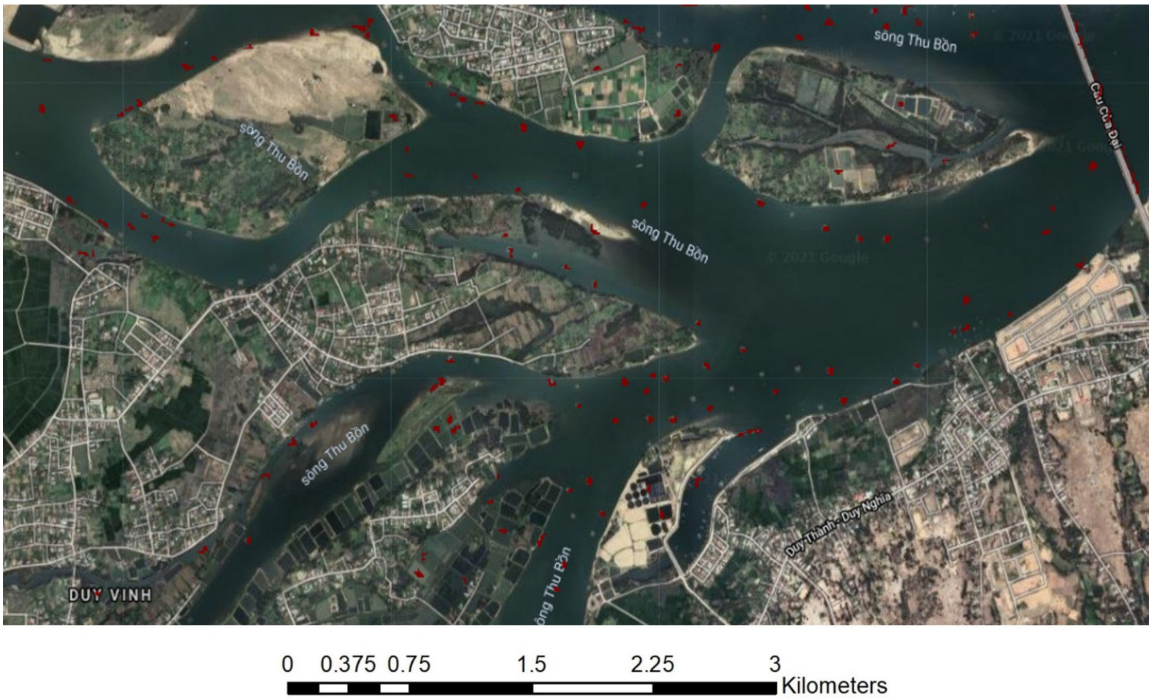

Fig. 15. Comparison of classification results of plastic fishing nets in test area 2 and high-resolution satellite images of Google Earth

CONCLUSION

In this study, Sentinel 2A high spatial resolution satellite image taken on June 11, 2020 in the central coastal area of Vietnam is used to classify plastic fishing nets. First, the Float Debris Index (FDI) is used to classify plastic fishing nets based on the Otsu thresholding method. Then, vegetation index (NDVI) and water index (NDWI) were used to improve the accuracy of plastic fishing net classification results, where plastic fishing nets have NDVI value greater than 0.3 and NDVI value is between 0 and 0.3. The results obtained in 2 test areas (Da Nang coastal area and Thu Bon estuary area, Quang Nam province) show that the accuracy when classifying plastic fishing nets from Sentinel 2A satellite images are all reached over 80 %. The results obtained in the study can be effectively used to quickly detect floating plastic waste in the sea, providing timely information for managers in responding to ocean plastic waste pollution.

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