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ESTABLISHING A PLASTIC WASTE MAP USING REMOTE SENSING DATA IN THE COASTAL AREA OF THANH HOA PROVINCE (VIETNAM)

Plastic pollution, particularly in oceans, is a growing environmental threat. Monitoring this pollution is challenging due to the shortage of data and tools. Remote sensing offers a promising solution by using various types of satellite and aerial images to detect and track plastic waste movement.

Purpose. The study aims to establish a plastic waste map using remote sensing technology, focusing on the case study of the coastal area of Thanh Hoa province, Vietnam.

Methodology. The study involves several steps, including the collection of plastic waste data (samples in the case study and indices from remote sensing images) as well as topographic and base map collection, statistics of plastic samples, grid design, calculation, interpolation, accuracy assessment, and mapping. Field surveys involved taking pictures of plastic debris along designated routes and a grid system was used to classify and calculate waste samples. Satellite images, especially Sentinel-2 MSI optical satellite imagery, are utilized to identify water areas of high plastic concentration.

Findings. A map of plastic wastes in coastal areas of Thanh Hoa was created, with indices like NDWI (Normalized Difference Water Index) and FDI (Floating Debris Index) helping identify potential plastic waste signals. The resulting map reveals high concentrations of plastic waste in sea areas near the major river mouths of the Ma River basin and tourist areas, which aligns with areas of high human activity.

Originality. This is the first study of plastic waste in the coastal area using remote sensing data in Thanh Hoa province, Vietnam.

Practical value. This study can contribute to the effective management of marine plastic waste in Thanh Hoa while opening up opportunities for applying the method to create marine plastic waste maps throughout Vietnam and foster long-term monitoring and management.

Keywords: *plastic waste, remote sensing, coastal area, Thanh Hoa, Vietnam*

Introduction. Plastic pollution, particularly in oceans, is rapidly becoming a major environmental threat. Plastic wastes do not break down easily, persisting for years and harming ecosystems [1]. According to the United Nations Environment Programme [2], the world uses a staggering 5 trillion plastic bags annually, with at least 8 million tons ending up in our oceans – equivalent to a truckload of plastic being dumped into the sea every minute. In Vietnam, plastic waste accounts for approximately 8–12 % of the total solid waste generated daily, causing severe environmental pollution to land, water, and air, posing a national challenge [2]. Human economic and domestic activities are the main causes of plastic waste pollution in coastal and ocean areas, seriously affecting marine ecological environments and tourism. The amount of plastic waste has multiplied exponentially over the past 70 years, from 1.7 million tons in 1950 to 322 million tons in 2015.

To monitor the status of plastic waste pollution, regular monitoring is essential to detect and forecast areas at risk of plastic waste pollution. However, one of the current challenges facing the investigation, surveying, and monitoring of plastic waste pollution at sea is the lack of scientific infrastructure, technology, data, and information regarding the current situation. Additionally, there is a shortage of regular and effective monitoring tools for assessing the status of plastic waste pollution in marine environments [3]. Therefore, controlling, monitoring, and supervising plastic waste pollution at sea is a pressing global issue, especially in the Asian region, including Vietnam. Currently, there are still no effective tools to address this issue due to the vast scope of monitoring, making traditional monitoring methods difficult to implement regularly.

Remote sensing technology utilizes various types of images captured from space, offering large coverage areas and increasingly high repetition rates. It provides information collected through multiple spectral channels [4]. Remote sensing can be an effective tool to support and overcome some limitations of direct monitoring activities at sea. Therefore, combining different types of remote sensing data with direct investigation and survey data at sea is a very feasible and highly effective approach to monitoring plastic waste pollution at sea. This approach allows monitoring the dispersion of plastic waste into the sea from various sources, such as from land through river systems, coastal socio-economic activities, activities at sea, and the movement of waste from the ocean and adjacent sea areas into the East Sea of Vietnam.

Studies worldwide assessing plastic waste pollution at sea focus on two main issues: firstly, detecting and classifying plastic waste at sea; and secondly, predicting areas at risk of plastic waste pollution based on analyzing relationships with hydrological and marine characteristics. To detect and classify plastic waste, the majority of studies utilize satellite data. Topouzelis and colleagues [5] indicate that Sentinel-2 MSI images, with shortwave infrared channels at a central wavelength of 1,610 nm, can be used to detect marine plastic debris and are suitable for monitoring pollution in coastal areas. Sentinel-2 satellite images are provided completely free of charge with an update cycle of 5 days, making them a suitable data source for studies on plastic waste in estuarine and coastal areas. Murphy, et al. [6] studied hyperspectral imagery in detecting plastic waste debris at sea. Based on the analysis of spectral reflectance characteristics of plastic waste and seawater, Murphy identified suitable spectral bands for detecting plastic waste at sea. Thereby, they constructed a model for identifying and classifying plastic waste debris. Overall, compared to Sentinel-2 MSI images, hyperspectral imagery has lower spatial and temporal resolutions. However, due to its large number of spectral channels and narrow bandwidths, hyperspectral remote sensing has great potential in detecting, classifying, and monitoring plastic waste pollution.

Determining plastic waste presence in estuarine and coastal areas is often more feasible than in the open ocean due to reduced impact from ocean waves. Moy, et al. [7] employed aerial imagery to classify and map marine debris along the coastlines of the Hawaiian Islands. The ultra-high resolution of aerial imagery enabled the detection of plastic waste pieces as small as 0.05 m². In another study, Martin, et al. [8] assessed the potential of combining images captured from unmanned aerial vehicles (UAVs) with machine learning methods to detect and establish marine debris maps. The results demonstrated that using UAV imagery allowed for the detection and monitoring of marine debris 39 times faster than traditional survey methods.

Narangerel, et al. [9] utilized Sentinel-1A and Cosmo-Skymed radar images to investigate the detection of plastic pollution at sea in specific areas of the North Pacific and North Atlantic Oceans. Additionally, the authors collected and analyzed other marine physical data such as sea surface temperature, wind, chlorophyll, and characteristics of ocean surface waves. The analysis of radar images revealed that surface wind speed, along with the Langmuir circulation mechanism, are key meteorological factors influencing the distinct appearance of biological traces resulting from plastic waste, compared to the surrounding water surface. The initial results indicated that radar image data enabled the detection of plastic pollution in open sea areas, suggesting the potential applicability of this method to other regions. Thus, it highlights the potential and effectiveness of remote sensing technology in detecting and monitoring plastic waste pollution. Furthermore, based on the early detection results of plastic waste at sea using remote sensing data, models simulating the accumulation and movement of plastic waste have been developed, facilitating the prediction of areas at high risk of plastic waste pollution.

In Vietnam, the Institute of Strategy, Policy for Natural Resources and Environment conducted a study on the theoretical basis and international experience in controlling ocean plastic waste [10]. This study provided an overview of plastic waste at sea, clarifying the theoretical basis of marine plastic waste and elucidating the sources and underlying causes of plastic waste generation, as well as the current situation of marine plastic waste and its impacts on economic, social, and environmental sectors. The study employed the DPSIR framework (Drivers – Pressures – State – Impacts – Responses) to analyze international experiences in controlling marine plastic waste. It focused on understanding the international legal framework for managing marine plastic waste, proposing appropriate solutions, and conducting a preliminary assessment of the current situation of plastic waste control.

Another study by Do, et al. presents a method for identifying plastic debris using a Deep Convolutional Neural Network (DCNN), trained with labeled spatial data. The DCNN was trained and evaluated using 95 images captured by a Phantom 4 Pro UAV equipped with a CMOS camera, flying over the coastal area of Hoi An in Quang Nam province. The findings demonstrate that the network is capable of accurately detecting plastic waste, achieving precision and cross-validation scores of 0.87 and 0.83, respectively [11].

A study by Le conducted field surveys at 38 locations, including 14 coastal sites at 8 locations and 24 riverside sites at 10 locations, spanning various provinces and cities across Vietnam [12]. These locations included Lào Cai and Hai Phong in the North; Thua Thien-Hue, Da Nang, Quang Nam, and Khanh Hoa in the Central region; and Soc Trang, Ho Chi Minh City, Can Tho, and Kien Giang (Phu Quoc Island) in the South. The study utilized UAV drones and net trawling for surveys. The research revealed that riverbank pollution averaged 22.5 pieces per unit at the surveyed locations, with plastic waste accounting for 79.7 % by number and 57.2 % by weight. Single-use plastics constituted 72 % of the total plastic waste. Coastal pollution, on the other hand, saw plastic waste accounting for 95.4 % of the total solid waste, with an average of 81 pieces per meter of coastline.

Le, et al. [13] conducted research on the identification and classification of plastic mesh in Vietnam's coastal regions using high spatial resolution optical images from Sentinel-2 MSI. Spectral indices such as NDVI and NDWI were employed to enhance classification accuracy, and high-resolution satellite images from Google were utilized to assess the accuracy of plastic mesh classification.

Despite the significance of plastic waste in Vietnam, there has been limited research on marine plastic waste, its hotspots, and its impacts. Data on types and quantities of marine debris, especially plastic waste in severely affected coastal areas, remain lacking. In response, the authors conducted a pioneering study on creating a plastic waste map using remote sensing technology, particularly focusing on the coastal area of Thanh Hoa, Vietnam.

Study area. Thanh Hoa is a large province in North Central Vietnam (Fig. 1), covering a vast area of 11,129.48 km². It shares borders with three provinces to the North: Son La, Hoa Binh, and Ninh Binh; to the South, it borders Nghe An; to the East, it faces the East Sea with a coastline stretching 102 km; and to the West, it borders the Hua Phan province of the Lao People's Democratic Republic. With a coastline shaped like a long arc spanning 102 km, this area holds significant potential for tourism and port development. The coastline, relatively flat overall, is intersected by seven estuaries, all highly sensitive natural areas with high biological productivity. Additionally, Thanh Hoa boasts a large ecological area with diverse ecosystems, making its geographical location favorable for the economic, cultural, and social development of the province. The terrain of Thanh Hoa is quite complex, gradually decreasing from west to east. It encompasses mountainous regions, midlands, plains, and coastal areas. The coastal area alone spans approximately 17,000–18,000 km², which is 1.6 times the size of the mainland.

Thanh Hoa province has long been a renowned destination in the domestic tourism industry. However, in recent years, residents in coastal communes of Thanh Hoa province have been confronted with beaches marred by plastic waste, posing significant risks of disease transmission. The amount of plastic waste has surged in tandem with the province's economic, manufacturing, and tourism activities.

Methodology and data. The process of establishing a marine plastic waste map is shown in Fig. 2.

Firstly, the process involves collecting map data sources, including topographic maps of the areas to be established, seabed sediment maps of the Thanh Hoa coastal area, and updated data that comply with current state regulations on geographic databases. The base map is constructed with administrative, transportation, hydrological, and socio-economic cultural objects within the established area according to prede-

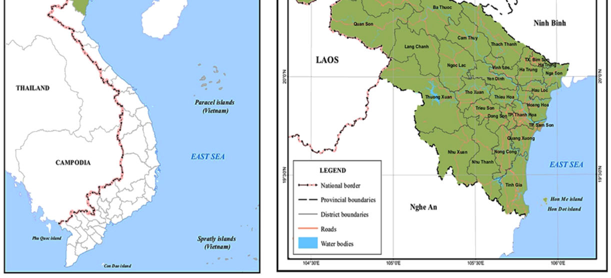


Fig. 1. Study area

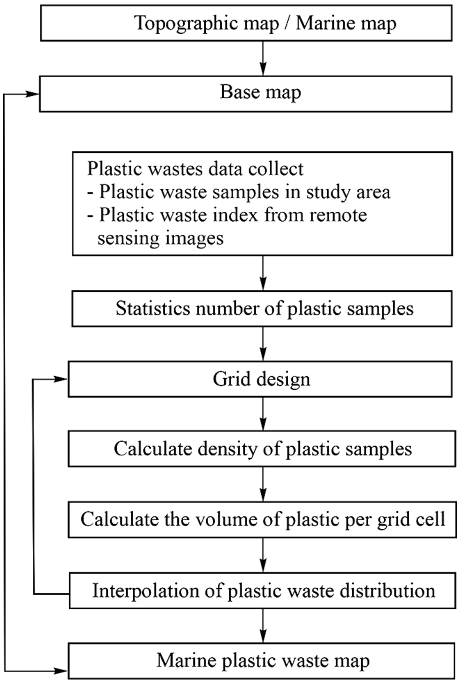


Fig. 2. Process of establishing a marine plastic waste map

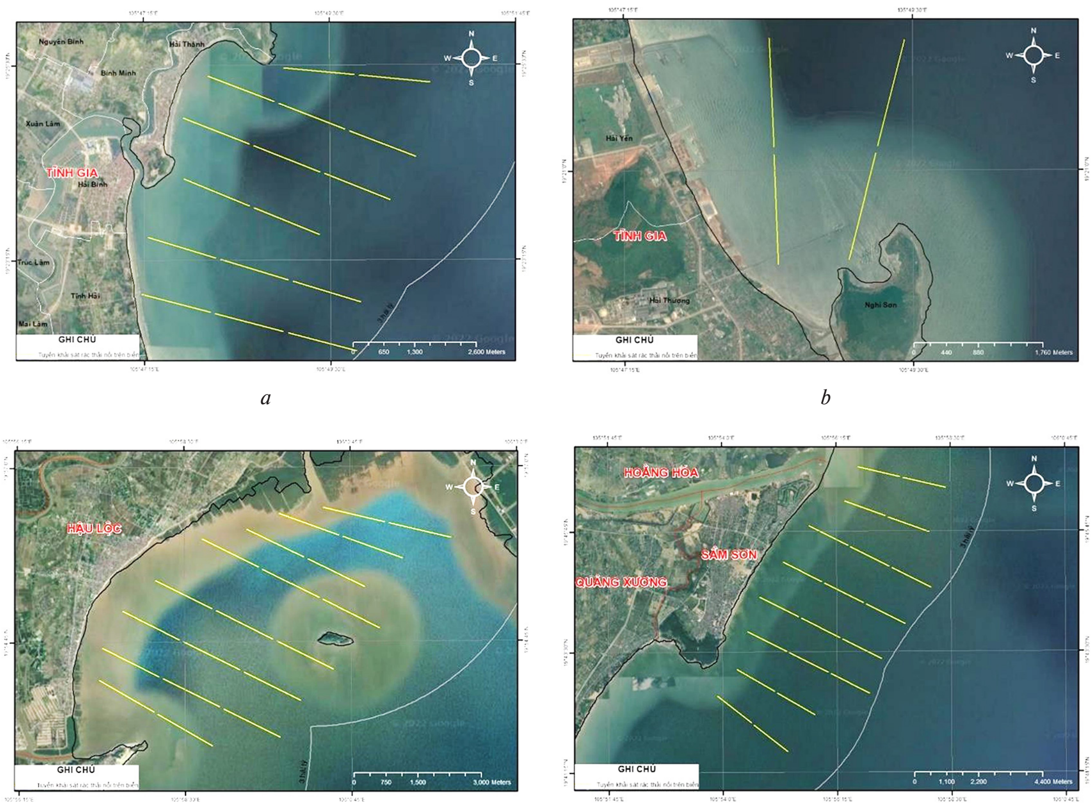
termined scales. The mathematical basis of the current plastic waste map is determined based on collected topographic maps. We utilize the Projection System and the VN2000 National Coordinate System with parameters including: UTM projection grid and Ellipsoid WGS84. The Projection Zone is 6°, with a scale distortion adjustment factor of $k_0 = 0.9996$, a meridian longitude of 105°00'0, and an elevation at Hon Dau. The scale of the established map is 1:300,000.

The collection of plastic waste data includes data from sampling plastic debris in the sea and plastic debris indices from satellite images. Field survey data on the sea are conducted along designated routes (yellow, dashed line) at four research locations (Fig. 3). The method for investigating and surveying plastic waste at sea involves using a digital camera attached to the bow of the boat or a pole on the boat, which automatically takes pictures every 4 seconds. Subsequently, the amount of waste in the surveyed area is quantified from the image data, and estimates are made regarding the size, type, and weight of the plastic. Statistical calculations are then employed to determine the density of waste across the entire area. Additionally, a grid system is utilized to collect plastic waste on the sea surface and in floating near-surface layers, which are then analyzed and classified to determine the type, volume, and weight of each type of plastic waste.

Extracting information on plastic waste at sea from satellite imagery includes:

1. Calculating the NDVI vegetation index.
2. Calculating the NDMI (Normalized Difference Moisture Index) humidity index.
3. Calculating the NDWI water difference index [14, 15].
4. Calculating the MNDWI (Modified Normalized Difference Water Index).
5. Normalized Difference Bare Index (NDBI); Floating Debris Index (FDI).

Then, the plastic sample is statistically analyzed from the collected data, and a detailed table of volumes, quantities, and types of plastic waste is compiled; designing a grid to evaluate plastic samples on software to fit the conditions and satellite imagery used; calculating the number of plastic samples in each grid cell. In the interpolation step of plastic waste distribution using software, if the interpolation results do not adequately reflect the nature of the data, the grid design is refined to obtain the most accurate interpolation results, depending on the input data and image processing quality. Once the interpolation re-



a *b* *c* *d*

Fig. 3. Map of survey routes (yellow, dashed line) for floating trash at sea in Thanh Hoa province: a, b – Tinh Gia district; c – Hau Loc district; d – Sam Son city

sults meet the requirements, they are displayed as a base map using ArcGIS software. Finally, the map is edited and finalized.

The design of the survey grid for investigating floating and seabed plastic waste must ensure that areas with high risks of occurrence and accumulation of plastic waste, as well as various forms of marine resource exploitation, are allocated multiple survey stations. It should ensure that survey locations represent coastal areas, including near river mouths, industrial zones, economic zones, tourist areas, aquaculture zones, residential areas, coastal urban areas, marine conservation areas, coastal waste collection areas, and other relevant areas according to the characteristics of the survey area. Therefore, surveys are conducted at several locations: in Nghi Son commune (including Hai Binh, Hai Thanh, and Tinh Hai wards – Nghi Son town), Nghi Son Bay, Hau Loc district, and Sam Son city.

Due to the high cost of commercially available optical satellite images with high spatial resolution, especially for large marine and ocean areas, the requirement for a large number of images makes the use of commercial optical satellite images impractical. Considering the vast expanse of the sea and the long coastline of Vietnam, the option of using freely available optical satellite images is entirely appropriate.

The Sentinel-2 Multispectral Instrument (MSI) optical satellite imagery can effectively be utilized for investigating and monitoring plastic pollution at sea. With two Sentinel-2A and Sentinel-2B satellites operating in tandem, the temporal resolution is improved to 5 days. Moreover, the channels in the visible and near-infrared spectral bands of Sentinel-2 MSI imagery have high spatial resolution (10m for visible and near-infrared bands, 20 m for shortwave infrared bands). Therefore, using Sentinel-2 MSI imagery for studying marine plastic pollution is a completely suitable approach, ensuring cost-effectiveness compared to other data types. The MSI sensor on the Sentinel-2 satellite also includes 13 channels, including those characteristic of plastic waste reflection such as NIR, SWIR1, and channels for vegetation indices, and water indices calculation. This study utilizes Sentinel-2 MSI optical satellite imagery to facilitate the investigation and monitoring of plastic pollution at sea. With its highest spatial resolution of up to 10 meters, equivalent to approximately 100 square meters per image pixel, Sentinel-2 MSI imagery can detect and classify floating debris at sea. Many recent studies worldwide, such as those by [16–18], have also used Sentinel-2 MSI imagery for the detection, identification, and classification of plastic waste at sea, achieving high-accuracy results.

Results and discussion. The calculation of the Normalized Difference Water Index (NDWI) was performed using Sentinel-2 imagery. This index is utilized to differentiate areas with water from those without water. In Fig. 4, the NDWI values indicate that dark areas represent regions without water, while areas with water are depicted by lighter regions with positive NDWI values.

Fig. 5 illustrates the results of the Floating Debris Index (FDI) calculation from remote sensing imagery. These results reveal signs of plastic waste in the sea and along the coast of the Thanh Hoa region. However, to accurately identify and display plastic waste signals, a thresholding step is required.

After thresholding to extract information about plastic waste signals at sea, the results are output as a point cloud (Fig. 6) for further processing. However, since this is an index, it does not yet provide plastic waste quantities in conventional units such as mass per unit area (e.g., g/km²). To determine the mass of the plastic waste, the data from plastic waste surveys are combined with statistical information on the number of plastic waste samples per unit area (g/km²) in the study area, thereby creating a detailed map. The point cloud extracted after processing the image data is shown in Fig. 7. Finally, the map depicting plastic waste in the coastal area of Thanh Hoa is established (Fig. 8).

In terms of map accuracy, national measurement points play a crucial role in establishing the map of marine plastic waste at various scales. These points, which include state coordinates and elevation points from level 3 and above, are directly transferred from topographic or cadastral maps or digital orthophotos of the same scale. Geographical background elements maintain their original positions as on the topographic or cadastral maps used as the base. Thematic content elements, whose positions can be accurately determined, are allowed to be represented on the map within an error margin equal to or greater than twice the error margin for representing content elements on the topographic or cadastral maps used as the base.

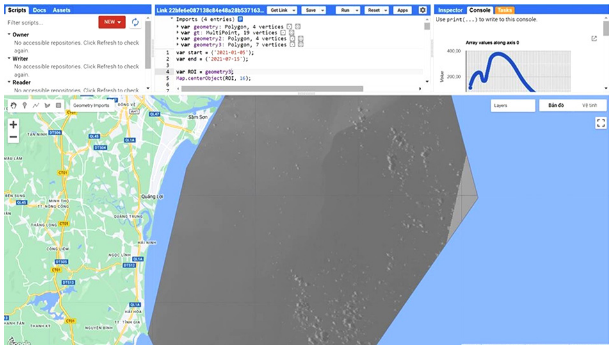


Fig. 4. NDWI map in the research area

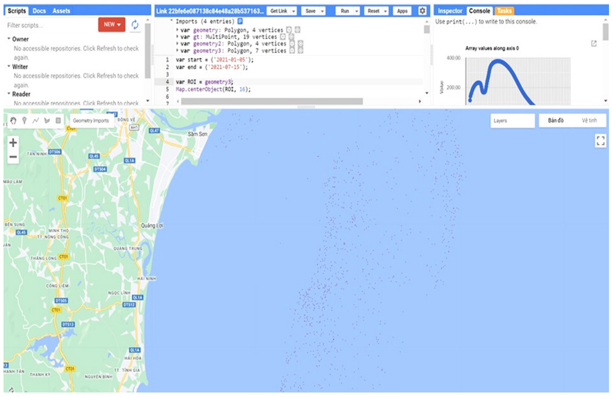


Fig. 5. FDI map

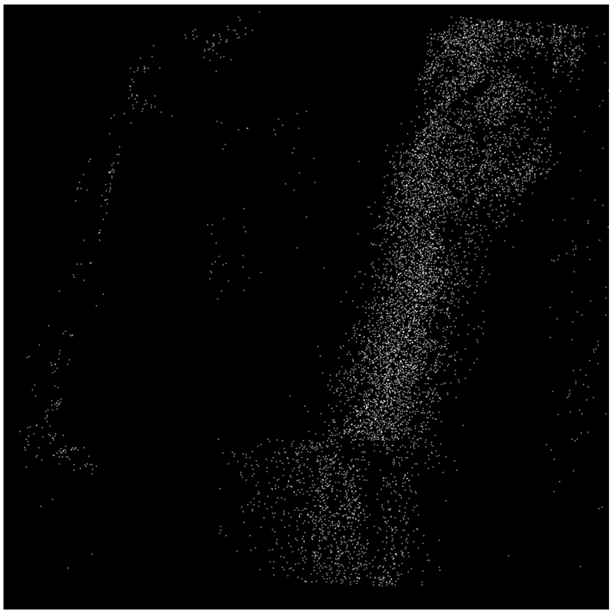


Fig. 6. Signs of plastic waste on satellite images processed across the entire research area

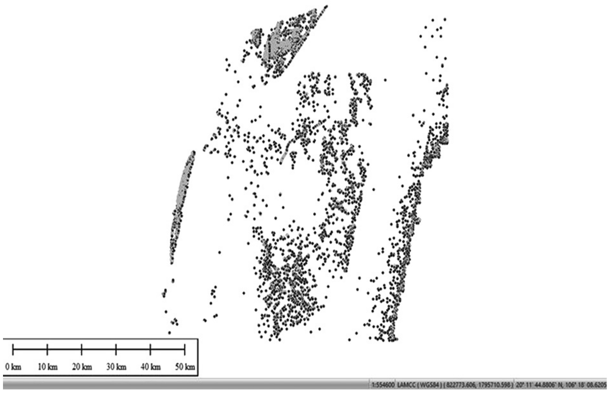


Fig. 7. Point cloud result after processing satellite images

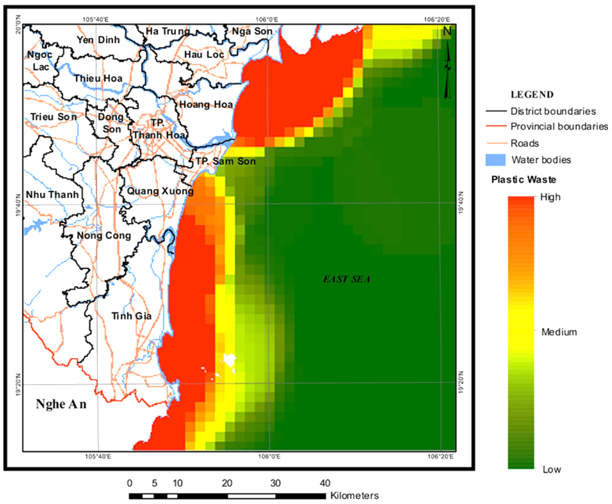


Fig. 8. Map of plastic waste in the coastal area of Thanh Hoa province

The map indicates dense concentrations of plastic waste in the districts of Hoang Hoa, Hau Loc, and Nga Son, particularly near the major river mouths of the Ma River basin, including the Hoi and Sung river mouths. These areas are significant due to their proximity to major outlets of the Ma River and their involvement in aquaculture, seafood harvesting, trading, and transshipment activities, all of which are significant sources of plastic waste. Moderate to high concentrations of plastic waste are also observed in regions within districts such as Tinh Gia. This is attributed partly to plastic waste generated from the Yen River, a tributary of the Ma River, and the accumulation of plastic waste driven by coastal currents and winds. River mouths such as the Day River, Ma River, and Hoang River exhibit high waste densities, particularly at the Day River mouth, indicating significant plastic waste input from residential and domestic sources via these river mouths. Sam Son beach shows a high density of plastic waste compared to adjacent areas, consistent with its status as a tourist destination generating substantial plastic waste. Offshore, the density of plastic waste gradually decreases.

Thanh Hoa province comprises five districts and one coastal city. Among them, Hoang Hoa district, Tinh Gia district, and Sam Son city are actively developing the marine tourism industry, making coastal environmental protection a top priority for local authorities, functional departments, and residents. Conversely, Nga Son district, Hau Loc district, and Quang Xuong district are home to many fishermen who depend on marine fishing, aquaculture in coastal areas, and fishery logistics services. In these regions, the six coastal communes of Hau Loc district are particularly affected by environmental pollution.

Walking along nearly 4 kilometers of the coastal dike road from Hai Loc to Minh Loc, Ngu Loc, Hung Loc, and Da Loc in Hau Loc district, one encounters a significant amount of solid waste, including plastic bags, plastic bottles, and packaging, piled up on the seawall. In densely populated areas such as Diem Pho market in Minh Loc commune and the border area between Minh Loc and Ngu Loc, various types of waste are heaped into large piles. The seawater in this area has turned black and emits an unpleasant odor. As the tide rises and falls, the waste is washed out to sea and then brought back to shore by the waves, forming odorous piles that significantly impact residents' health.

For decades, residents living around Diem Pho market have endured severe environmental pollution due to tons of waste being dumped daily by locals onto the coastal area, just a few hundred meters from residential areas. The persistent waste accumulation is attributed to the unique bowl-shaped coastline of Ngu Loc, located between two river mouths, which brings in a large amount of waste with each tidal cycle. Additionally, some residents lack awareness and irresponsibly dispose of waste into the environment. The coastal pollution in Ngu Loc commune will worsen if authorities and relevant agencies do not implement effective solutions to manage the accumulating waste.

When selecting optical remote sensing images for studying plastic pollution, the following points are crucial:

1. *Spectral bands*. The input images must include a sufficient number of spectral bands, especially near-infrared (NIR) and shortwave infrared (SWIR1) bands, which exhibit high spectral reflectance for plastic waste, distinguishing it from the surrounding sea area. Additionally, the input images should have other bands useful for calculating vegetation indices and water indices to enhance the detection and classification of marine plastic waste.

2. *Spatial resolution*. The spatial resolution of the remote sensing images used for investigating and monitoring plastic pollution must be high enough to identify plastic waste at sea. Since floating objects in the sea are not very large, remote sensing images with low spatial resolution would make it challenging to detect and classify plastic waste.

3. *Temporal resolution*. The optical sensor's temporal resolution must be short to collect sufficiently dense data for investigating, detecting, and monitoring plastic waste. Satellite images with a temporal resolution of 16 days, such as Landsat, or 26 days, like SPOT, are difficult to use effectively for monitoring plastic waste, especially in areas with complex weather conditions that are not suitable for optical imaging, such as coastal regions.

From this study, several solutions are proposed as follows. To monitor marine plastic waste, it is necessary to first develop an automated monitoring system using space technology such as remote sensing and GIS-based on big data analysis and artificial intelligence to identify the sources of marine plastic waste. It is necessary to improve the marine environmental monitoring network, including monitoring marine plastic waste, to track trends and developments of plastic waste in marine and coastal areas. Additionally, it is important to build a database on the quantity (the number and volume) and composition of plastic waste present in the sea, the amount and composition of plastic waste entering the sea annually, and the quantity of marine plastic waste collected and treated.

Based on this, scientific and effective management measures should be established to reduce plastic waste at the source. Additionally, regular monitoring will help identify areas at high risk of marine plastic pollution so that appropriate collection and treatment measures can be taken to minimize environmental pollution caused by plastic waste. Improve legal policies and organizational structures for controlling marine environmental pollution; promote the application of economic tools in managing marine plastic waste; enhance research and development of science and technology to serve the effective management and control of marine plastic waste; strengthen international cooperation in managing and controlling marine plastic waste, and promote education and awareness about marine plastic waste. Most plastic waste consists largely of single-use and low-value products.

It is proposed that Vietnam's Ministry of Natural Resources and Environment develop technical guidelines, and a policy development roadmap, and implement these policies at both national and local levels to address low-value and single-use plastic waste. There is a need to evaluate policy tools to address plastic waste issues, including bans, taxes and fees, design requirements, extended producer responsibility programs, and standards for alternative products to plastics. In the fishing and aquaculture sectors, plastic fishing gear is the most common type of waste in coastal areas. Developing communication strategies and raising community awareness about the most common types of plastic waste in the environment is essential.

Efforts should be made to educate the public and young people about reducing, reusing, and limiting plastic waste to decrease the demand for low-utility plastics, support more cost-effective waste management infrastructure systems, and reduce littering in rivers and seas. A communication and awareness-raising strategy should be developed alongside policy analysis and roadmap implementation.

Conclusion. In conclusion, the results of our study demonstrate that quantifying the amount of plastic waste distributed in the sea using data extracted from remote sensing and field surveys shows the feasibility of this solution in creating distribution maps of plastic waste in offshore, hard-to-reach areas. The two important data sources used were field survey and plastic sample collection data, along with information extracted from remote sensing, which were analyzed, synthesized, and identified to serve the construction of specialized marine plastic waste distribution maps. Specialized software and supplementary tools were used to analyze, evaluate, and calculate data collected from multiple sources with diverse and complex information, contributing to the development of a coastal plastic waste database, maps, and geographic information systems. These tools provided accurate and objective results that aligned with the research objectives.

The creation of the current distribution map of marine plastic waste in the Thanh Hóa area also opens up the possibility of applying this method to create plastic waste distribution maps for the entire marine region of Vietnam. This would aid in investigating plastic waste, evaluating its impact on the marine environment over long periods, and supporting management units in timely addressing and handling environmental and ecological issues, as well as marine biological resources, across the entire marine region of Vietnam.

Future research will focus on designing and constructing a classification table for the distribution of plastic waste in the sea and continuing in-depth studies to refine the processes, criteria, techniques, and guidelines necessary for creating zonal plastic waste maps that meet practical application requirements. Currently, human resources in this field are not yet proficient, and there are few leading experts. Therefore, it is essential to train human resources to develop more leading experts in applying science and technology for monitoring and evaluating marine plastic waste in Vietnam. Further research is needed on methods for detecting and assessing coastal plastic waste using various remote sensing sources with diverse cycles and data to achieve the most accurate and objective results possible.

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Створення карти пластикових відходів з використанням даних дистанційного зондування у прибережній зоні провінції Тхань Хоа (В'єтнам)

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Забруднення пластиком, особливо в океанах, стає все більшою екологічною загрозою. Моніторинг цього забруднення є складним через брак даних та інструментів. Дистанційне зондування пропонує багатообіцяюче рішення завдяки використанню різних типів супутникових і аерофотознімків для виявлення й відстеження переміщення пластикових відходів.

Мета. Створення карти пластикових відходів за допомогою технології дистанційного зондування, аналізуючи приклад прибережної зони провінції Тхань Хоа, В'єтнам.

Методика. Дослідження включає в себе кілька етапів, серед яких збір даних про пластикові відходи (зразки практичного дослідження та індекси із зображень дистанційного зондування), збір топографічних і схематичних карт, статистика зразків пластику, проєктування сітки, обчислення, інтерполяція, оцінка похибки й картографування. Польові дослідження включали фотографування продуктів пластикового забруднення вздовж визначених маршрутів, а систему сіток була використана для класифікації й розрахунку зразків відходів. Супутникові зображення, особливо оптичні супутникові зображення Sentinel-2 MSI, використовуються для визначення акваторій з високою концентрацією пластику.

Результати. Була створена карта пластикових відходів у прибережних зонах Тхань Хоа з такими індексами, як NDWI (індекс нормалізованої різниці води) і FDI (індекс плаваючого сміття), що допомагають визначити потенційні сигнали щодо пластикових відходів. Отримана карта показує високу концентрацію пластикових відходів у морських зонах поблизу головних гирл річок басейну річки Ма та туристичних районів, що збігаються з районами активної людської діяльності.

Наукова новизна. Це перше дослідження пластикових відходів у прибережній зоні з використанням даних дистанційного зондування у провінції Тхань Хоа, В'єтнам.

Практична значимість. Це дослідження може сприяти ефективній організації роботи з морськими пластиковими відходами у Тхань Хоа, одночасно відкриваючи можливості для застосування методу для створення морських карт відходів по всьому В'єтнаму та сприяння довгостроковому моніторингу та управлінню.

Ключові слова: *пластикові відходи, дистанційне зондування, прибережна зона, Тхань Хоа, В'єтнам*

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