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Macro- and meso- marine debris on beaches in Khanh Hoa province, Vietnam: density, composition, and pollution indicators

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ABSTRACT

Marine debris is a prevalent problem that affects oceans and coastal regions worldwide, particularly beaches. The problem of marine litter pollution is also severe on beaches in Nha Trang. In this study, marine debris with a size ≥ 5 mm was collected at seven locations along the coastline of Nha Trang during both dry and rainy seasons, accruing a total of 4436 items. During the rainy season, most beaches had more debris than that in the dry season, and marine debris density ranged between 0.009 items/m^2 to 0.418 items/m^2. Results from the beach cleanliness index (CCI) assessment showed that CCI values ranged from 0.2 to 4.4 during the dry season, with beaches classified as either very clean or clean. Meanwhile, during the rainy season, CCI values ranged from 0.36 to 8.35, resulting in beaches being categorized as very clean, clean, or average. The Plastic Abundance Index (PAI) showed that the PAI ranged from 0.004 to 0.061 during the dry season, while during the rainy season, it ranged from 0.006 to 0.118. PAI values for both seasons indicated low levels of plastic debris distribution on the beaches. However, local authorities and managers need to pay attention to potential sources of pollution, such as waste from food service activities in restaurants, ports and unsustainable waste from aquaculture activities.

Keywords: Marine debris, plastic waste, CCI, PAI.

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INTRODUCTION

Marine debris is any solid artificial material produced, processed, discarded, or abandoned in the marine and coastal environment [1], including plastic, metal, glass, processed wood, paper, rubber, and textiles. Plastic waste comprises the majority, accounting for over 80% of marine debris [2, 3]. Marine debris has been recognized as a major global environmental pollution factors that have a significant impact on marine ecosystems, wildlife, human health, the economy, society, politics, and culture [4]. Marine debris can be originated from various sources, including land-based sources (e.g., improperly disposed of waste), aquaculture and fishing activities, maritime transport, extreme weather events, and natural disasters. The size of marine debris, especially plastic waste, plays an essential role in causing negative impacts on marine organisms and is divided into four categories: microplastics (≤ 5 mm), mesoplastics (5–25 mm), macroplastics (25–1,000 mm), and mega-plastics (> 1 m) [5]. Plastic waste in the coastal environment can have negative impacts on marine ecosystems. For example, marine organisms such as fish, sea turtles, and birds can misunderstand plastic fragments for food and ingest them, leading to suffocation, digestive issues, damage, or death [6, 7]. Plastic debris, such as fishing nets and bags, can entangle marine organisms (seabirds, seals) and cause injury or asphyxiation, or drowning [8, 9]. Recent studies have shown that small-sized plastic waste can adsorb and release toxic substances, antibiotics, and microorganisms from the water environment [9a,9b]. When swallowed, these toxins harm organisms and act as intermediaries transporting pollutants and harmful invasive microorganisms widely spread in the marine environment [10, 11]. Moreover, plastic waste can also negatively impact human health, through the food chain. Sharp objects on beaches or underwater can harm beachgoers and divers.

Evaluating marine debris at beaches is essential in understanding the extent of litter accumulation on beaches and marine debris in the ocean and building a database to develop local waste reduction strategies and future initiatives to make the beaches cleaner. In this study, we investigated the distribution, density, and components of macro- and meso-sized marine debris in Nha Trang. Like many other coastal cities in Vietnam and worldwide, Nha Trang faces increasing challenges associated with marine debris due to its popularity as a tourist destination. The degree of litter pollution at beaches was revealed through indices such as the Clean Coast Index (CCI) and Plastic Abundance Index (PAI).

METHODOLOGY

Study area

Figure 1. Sampling location in this study

The research focused on studying the quality of beaches commonly used for swimming and other recreational activities. Figure 1 and Table 1 presented the specific locations of the beach samples. Area 1,

comprised of three samples, including BB1, BB2, and BB3, is located at Bai Dai, in Cam Ranh City and Cam Lam district. The length of this beach spans approximately 18 km. On the other hand, area 2 included four samples, BB4, BB5, BB6, and BB7, located on the central beach of Nha Trang City along Tran Phu Street. This beach has a length of about 10 km. Overall, we surveyed a total beach area of 43,982 m² during the study.

Table 1. Detail sampling locations in this study

Sample ID	Longitude	Latitude	Sampling area (m^2)	Note
BB1	11°59'11.7"	109°14'43.7"	3625	The starting point of Bai Dai, next to the golf course
BB2	12°01'58.8"	109°12'57.9"	2998	Mid point of Bai Dai
BB3	12°05'52.1"	109°11'40.5"	2791	The end point of Bai Dai, near Eo Gio
BB4	12°13'15.0"	109°12'16.5"	4636	Nha Trang Beach
BB5	12°15'15.3"	109°11'48.8"	2723	Nha Trang Beach
BB6	12°14'19.1"	109°11'50.8"	2462	Nha Trang Beach
BB7	12°16'29.5"	109°12'09.0"	2756	Hon Chong Beach

The sampling was conducted between December 2021 and March 2022, encompassing both the rainy and dry seasons. Unfortunately, this interval witnessed a significant decrease in tourist arrivals to Nha Trang city due to the ongoing Covid pandemic. To be specific, 2021 was a challenging year for tourism in Khanh Hoa province, including Nha Trang city, where the total number of visitors for the whole year reached 600,000, a decrease of 52% compared to 2020 and about 11.7 times lower than in 2019 [12,13]. Therefore, this period represents the time when the beaches of the city were least affected by tourism activities and services. The data obtained during this period serve as a basis for evaluating the impact of tourism and services on marine litter pollution on the city's beaches.

Sampling and analysis method

The marine debris samples on the beaches are collected according to the "European Marine Litter Surveillance Guidelines" [14] and adjusted to fit the actual research area. The sampling locations ensure the following criteria: the sampling area has a beach length greater than 100 m; the sampled beaches have slopes ranging from 8^o to 20^o [15]. The sampling sites are not affected by wave breakers or ports; the sampling sites of the research group can access the entire year-round period.

Figure 2. Sampling design: the width is measured from the low tide waterline to the concrete embankment area above the beach

Each sampling site is 100 m long along the coastline, and the width is measured from the low tide waterline to the concrete embankment area above the beach. The sampling of marine litter at Nha Trang city beaches is illustrated in Figure 2, and the area of each sampling site is presented in Table 1.

Identify the name of the debris item found in the sampling site. Unidentified items should be appropriately noted. The debris items are photographed and compared to the coding table according to OSPAR guidelines [16] and are classified as plastic, rubber, textiles, paper, processed wood, metal, glass, ceramics, and others.

Classification by size: Waste items are divided into three size ranges: Mega waste items have a considerable size of > 1 m; macro items are large waste items ranging in size from 25–1,000 mm; meso items have an average size ranging from 5–25mm.

Limits of marine debris detection

There is no upper limit on the size of all recorded waste on beaches. The lower limit is determined by the ability of the naked eye to detect, depending on the visual perception of the surveyor, the size, color, and shape of the waste (about 0.5 cm for plastic pellets). This limit may be smaller when repeated observation processes are carried out.

Characterization of plastic debris

The plastic waste samples are collected and transported to the laboratory. The plastic waste samples in the laboratory are washed with distilled water, dried, and then determined polymer properties using the Agilent Carry 630 FT-IR spectrophotometer equipped with the Agilent Polymer Handheld ATR library.

The measurement is repeated for each type of plastic waste, and the match between the actual spectrum of the sample and the comparison spectrum from the software database is 80%. Only polymers that match the comparison spectrum at >80% are accepted.

Assessment of marine debris pollution by indicators

The density of marine debris is calculated according to the following formula:

$$D = \frac{n}{w \times 1} \quad (1)$$

where: D is debris density (items/m^2); *n* is the number of debris items found in the sampling unit; *w* is the distance from the low tide edge to the concrete embankment (m); *l* is length of sampling unit (m).

The Clean Coast Index is calculated following Alkalay, 2007 [17]:

$$CCI = D \times K \quad (2)$$

where: D is marine debris density (items/m^2); *K* is a constant (*K* = 20); *CCI* is the beach clean coast index with the ratings given in Table 2.

Table 2. CCI grades and brief description of the sampling area

CCI values	0–2	2–5	5–10	10–20	> 20
Category	Very clean	Clean	Moderate	Dirty	Very dirty
Description	No debris can be seen	No debris can be seen in a large area	A few items can be detected	A lot of items with different types	Most of the beach is covered with debris

Plastic Abundance Index is calculated according to Nelson [18]:

$$PAI = \frac{\frac{n_p}{\log_{10} n}}{w \times l} \times 20 \quad (3)$$

where: n_p is the number of plastic items; *n* is the total number of debris items; *w* is the width of sampling unit (m), l is length of sampling unit (m); *PAI* can be graded into five different categories as in Table 3.

Table 3. Five categories based on PAI values

PAI	Grade	Description
0–0.1	Very low abundance	No plastics are seen
0.1–1	Low abundance	Some plastics items detected
1.1–4	Moderate abundance	Considerable number of plastics are seen
4.1–8	High abundance	A lot of plastics items found on the sampling unit
> 8	Very high abundance	Most of the debris are plastics

RESULTS AND DISCUSSION

Density and distribution

The total number of marine debris collected during the two survey periods was 4,436, of which 3,139 items were collected during the rainy season (i.e., December 2021) and 1,297 items during the dry season. The number of marine debris items per sampling unit (100m along the length of the coastline) ranged from 34 to 1,028 items. The density of marine debris on the beaches during the dry season ranged from 0.009 to 0.219 items/m^2, while during the rainy season, it ranged from 0.02 to 0.42 items/m^2. The average density was 0.112 items/m^2. The specific number and density of marine debris items per sampling unit are presented in Table 4.

The study results showed that the average density of marine debris in Area 1 was 0.0239 items/m^2, while in Area 2, it was 0.178 items/m^2. Therefore, the average density of marine debris in Area 2 was 7.4 times higher than in Area 1. This difference may be due to the difference in population density between the two sampling areas. According to the population statistics of Khanh Hoa province in 2019, the population density of Nha Trang city (Area 2) was 11,663 people/km^2, while the population density of Cam Ranh City and Cam Lam District (Area 1) was 401 people/km^2 and 199 people/km^2, respectively [19]. The average density of marine debris per sampling unit in Area 2 remained almost unchanged during both seasons. However, the average density of marine debris during the rainy season was 2.4 times higher than during the dry season, proving that waste inputs from the mainland influence the density of marine debris on beaches in this area through two large rivers (e.g., Cai river and Be river).

Furthermore, the results showed that the density of marine debris in Khanh Hoa province was low compared to other beaches worldwide. Specifically, the density of marine debris on the beaches of Thanh Hoa province was 0.28 to 1.4 items/m^2 [20], 3.4 items/m^2 in Japan [21], 1.8 items/m^2 in Chile [22], 1.9 items/m^2 in the Balearic Islands, 0.28 items/m^2 in Italy, 0.24 items/m^2 in Greece, and 0.22 items/m^2 in Albania [23]. It should be noted that the density of marine debris in Khanh Hoa could be higher due to the timing of the samples coinciding with the outbreak of Covid-19, resulting in a lack of tourists and low density. In contrast, in Thanh Hoa, the sampling occurred during the tourist season when there were many tourists, leading to more debris.

Table 4. Density of marine debris on the beaches of Nha Trang city

Samples	Rain season (Dec 2021)		Dry season (Mar 2022)	
	Items (*n*)	Density (items/m^2)	Items (*n*)	Density (items/m^2)
BB1	65	0.018	34	0.009
BB2	97	0.032	72	0.024
BB3	112	0.040	54	0.019
BB4	587	0.127	110	0.024
BB5	615	0.226	281	0.103
BB6	1028	0.418	539	0.219
BB7	635	0.230	207	0.075

Types of marine debris

The marine debris collected in the studied area consists of four types including plastic, paper, rubber, and metal. The result of marine debris composition is presented in Figure 3.

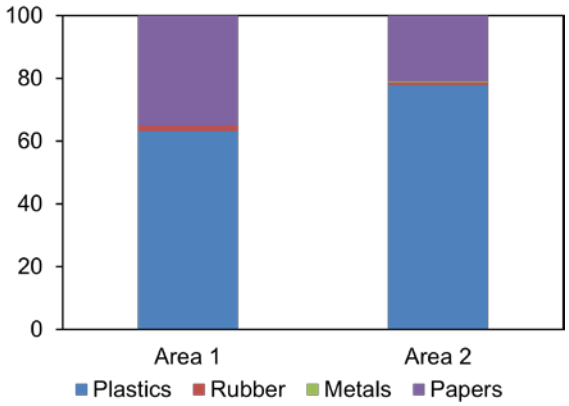

Figure 3. Marine debris composition in the studied area

Plastic is a predominant material found in marine debris, accounting for 79% of the total marine debris, followed by paper which accounts for 20% (mainly cigarette filters), while rubber and metal account for a small amount of approximately 1%. Plastic debris represents the major component is found in many locations worldwide. Specifically, plastic debris accounts for 88.14–98.46% [24] in beaches located in Turkey, 65.08% of beaches situated in Southern India [25], and 90% of the total marine debris of beaches located in the western Mediterranean Sea [26]. The main types of marine debris are plastic and paper. A small portion consists of metals. In Area 1, there is no presence of metal waste. In essence, metal waste is less likely to drift to the shore due to its high density. Lighter waste tends to accumulate along the coastlines.

Size of marine debris

The marine debris collected in the study area consists of two size categories: macro (25–1,000 mm) and meso (5–25 mm). The size range with the largest proportion of marine debris is macro, accounting for 71% of the total. This category includes cigarette filters, tiny plastic fragments, small plastic bags, water bottles, detergent containers, plastic cups and single-use paper products, food packaging boxes, and some other items. Meso-sized debris accounts for 29% of the total debris items, with foam fragments being the predominant component. In both areas, most marine debris falls within the size range of 25–1,000 mm. Marine debris larger than 1 m is typically relatively scarce. Debris with smaller sizes (< 25 mm) also has a relatively low proportion (Figure 4).

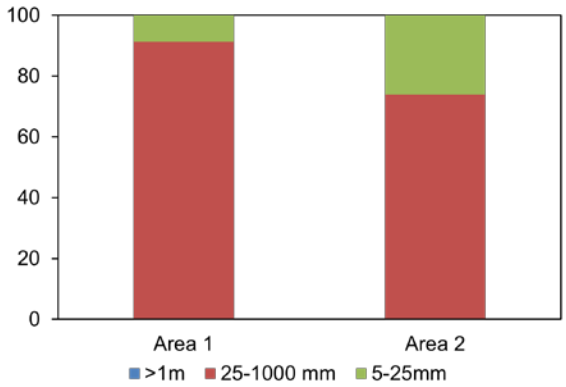

Figure 4. Size composition of marine debris at the studied area

Characterization of plastic debris

To elucidate the origin of plastic waste on beaches, plastic waste collected from beaches was cleaned, stored, and transported to a laboratory for polymer characterization. The results revealed that plastic waste present in the studied beach areas consisted of the following polymers: polystyrene (PS), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyethylene terephthalate (PET), and a few other polymers. Among them, PS was the most predominant polymer, accounting for 47% of the total plastic waste, followed by LDPE, HDPE, and PP, accounting for 25%, 15%, and 12% of the total plastic waste, respectively. PET and some other plastics accounted for a small proportion of approximately 2% of the total plastic waste (Figure 5).

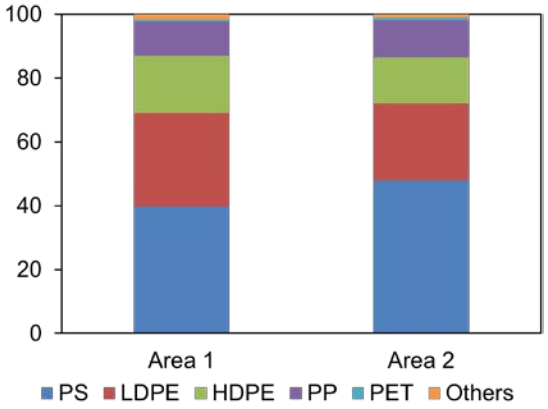

Figure 5. Chemical composition of plastic debris in the studied area

Based on the field survey conducted by the research team, fragments of expanded polystyrene (EPS) were found on beaches sourced from aquaculture, fishing, and seafood trade activities in coastal estuaries. For instance, residents used EPS fragments as buoyancy aids for their shrimp farming activities in the estuarine area, waste disposal from the port where vessels are anchored, and bustling seafood trade activities (Figure 6). Based on the above reality, there should be a mechanism to assess the density of waste, plastic waste, and microplastics in the aquaculture water and port area.

Using foam as a floating material for raising clams in the Be river estuary

Debris at Hon Ro port

Figure 6. Sources of marine debris from aquaculture and fishing activities in Nha Trang

Marine debris pollution evaluation

The pollution indices are calculated and presented in Figure 7. The CCI values indicate that most beaches serving recreational activities and tourism are clean throughout rainy and dry seasons. Only BB6 beach in Nha Trang City during the rainy season has a CCI value of 8.35, indicating moderate pollution. The remaining areas within Nha Trang city are nearing the warning level, approaching the average pollution threshold. As a result, the local government to enforce stringent waste management measures during tourist activities to prevent further decline in beach cleanliness. Besides, BB6, the most polluted area, is only moderately polluted. The remaining beaches are lower than the moderate level and cannot reach the warning level - the alert level.

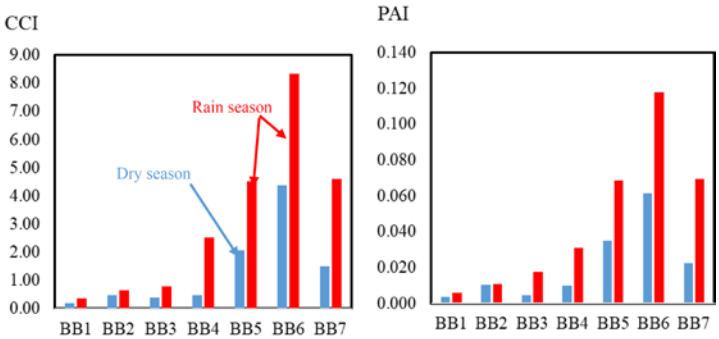

Figure 7. The CCI and PAI values to evaluate the marine debris pollution

The PAI values range from 0.004 to 0.118, with most beaches rated as very low in plastic debris density (Figure 7). However, the average PAI during the dry season is 0.021, and during the rainy season is 0.046. The PAI in the rainy season is 2.2 times higher than in the dry season, indicating that plastic waste, due to its durable and lightweight properties, is carried from inland areas to the sea via rivers and deposited on beaches by waves, winds and tides.

CONCLUSION

In this study, a comprehensive investigation has been done to assess the extent of marine debris pollution at beaches in Khanh Hoa province. This province is well-known for its pristine beaches and is a popular destination for many international tourists. The study provides information about the quantity, density, and evaluation of marine debris pollution levels at these beaches. It has been observed that plastic waste, particularly PS plastic originating from aquaculture, fishing, and seafood purchasing activities, is the primary component of marine debris in this area. During the rainy season, most beaches experienced a higher number of debris compared to the dry season, with marine debris density ranging between 0.009 and 0.418 items/m^2; it is worth noting that in Khanh Hoa, the density of marine debris is relatively low due to the timing of the samples coinciding with the outbreak of Covid-19, resulting in a lack of tourists. The CCI values show that most beaches catering to recreational activities and tourism maintain high cleanliness during the rainy and dry seasons. It is imperative to take measures to limit the utilization of PS materials as floating devices, food containers, and cooler boxes to mitigate the impact of this problem. These materials are easily degraded by various factors such as temperature, light, and impact, and are difficult to retrieve and recycle.

Paper waste accounts for approximately 20% of the marine debris found at these beaches, with cigarette filters being the main contributor. Therefore, local authorities must implement stricter management measures regarding cigarette butts and ensure proper disposal to combat the increasingly harmful environmental pollution situation. By taking appropriate actions, we can work towards preserving the natural beauty of these beaches, ensuring a sustainable environment for both the locals and visitors alike.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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