

ASSESSMENT OF BEACH PLASTIC WASTE POLLUTION USING THE CLEAN COAST INDEX: EVIDENCE FROM THANH HOA PROVINCE, VIET NAM

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Received: 5 August 2026; Accepted: 25 September 2026

Abstract: Marine plastic pollution is an increasingly important environmental and socio-economic challenge for coastal provinces of Viet Nam. Thanh Hoa Province represents a typical coastal setting of the North Central Coast of Viet Nam, where diverse coastal activities, including tourism, industry, capture fisheries and aquaculture, coexist with major river systems such as the Ma, Len and Chu rivers. The presence of these river systems, together with diverse coastal activities and geomorphological settings, contributes to substantial spatial variation in beach litter accumulation. A preliminary assessment using a litter transport model identified three major areas of litter accumulation in Sam Son, Hau Loc and Nghi Son which were subsequently selected for detailed field investigation. This study assesses visible beach litter (>5 mm) across 22 transects in Sam Son, Hau Loc and Nghi Son, Thanh Hoa Province, using material classification and the Clean Coast Index (CCI). Four sampling cells per transect in each of two campaigns yield 176 cell observations ($22 \times 4 \times 2$). The national project report dates its winter field campaign to 21 October 2021–13 February 2022 and its later beach campaign to 31 March–23 July 2024; according to the authors, COVID-19 disrupted the planned sampling sequence. The source manuscript reports 15,649 debris items (0.560 items/m^2) and 235.69 kg (0.008 kg/m^2), of which plastics account for 61.97% of items and 67.51% of mass. Reported area-by-campaign plastic densities range from 0.139 to 1.390 items/m^2 . The project gives also reports an overall CCI of 11.2, with a separate CCI value of 6.9 for plastic litter across the three survey locations; this value cannot be reproduced from the published density summaries and is retained as a source-reported value pending cell-level reconciliation. Hau Loc had the highest reported area-level CCI in both survey campaigns, with values of 27.83 in Season 1 and 15.06 in Season 2. The comparison describes conditions during two seasonal windows in different years and does not isolate a causal monsoon effect.

Keywords: Beach litter, Clean Coast Index, plastic pollution, coastal monitoring, Viet Nam.

1. Introduction

Plastic debris has become a persistent component of marine litter because of its durability, low density, wide dispersal pathways and extensive use in modern production and consumption systems. Global assessments indicate that millions of tonnes of plastic waste may enter the ocean annually from land-based sources, with coastal countries in Asia contributing substantially to this pressure [1].

Plastic debris is persistent and may fragment

into smaller particles [2]. International Coastal Cleanup inventories offer a broad indication of the types of litter collected on beaches, but variable effort and volunteer methods preclude direct numerical comparison with standardized item densities [3].

In Viet Nam, national marine-plastic policies identify prevention and monitoring as priorities [4], [5]. Recent CCI-based studies on central and Southern Vietnamese beaches also demonstrate the value of standardized spatial comparisons [6], [7].

Thanh Hoa remains a useful case for area-specific field evidence, although numerical

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comparisons across studies require compatible item-size thresholds, plastic classification and surveyed-area definitions.

Thanh Hoa Province has a long coastline, developed tourism areas, river mouths, fishing communities, and coastal zones with industrial activities. The province is also characterized by several major rivers systems, including the Ma, Len, and Chu rivers, which discharge into the coastal zone, contributing to considerable diversity in beach morphology. These characteristics make the province an appropriate case for examining how beach plastic waste varies across coastal settings and monsoon seasons. This article aims to: (i) Quantify beach debris and plastic waste in selected coastal areas of Thanh Hoa; (ii) Classify dominant plastic waste categories; (iii) Assess beach cleanliness using the CCI; and (iv) Discuss implications for local monitoring and management.

The contribution of this study is empirical: it applies the established CCI of Alkalay et al. [8] to tourism, fishing/estuarine and mixed coastal-use settings in Thanh Hoa. The two campaigns provide a descriptive contrast across distinct seasonal windows; their separation in calendar years prevents attribution of observed differences solely to monsoon conditions.

2. Materials and methods

2.1. Study area and survey design

The study was conducted along 22 survey transects, including 7 in Sam Son (SS-01-

SS-07), 7 in Hau Loc (HL-01-HL-07), and 8 in Nghi Son (NS-01-NS-08) (Figures 1-3 and Table 1). The transects were selected to represent the main shoreline morphologies in the study area. Each 100 m transect contained four randomly selected sampling cells. Across two survey campaigns, this resulted in 176 sampling-cell observations ($22 \times 4 \times 2$), with repeated sampling of the same cell treated as separate observations. The first campaign was conducted from 21 October 2021 to 13 February 2022, and the second from 31 March to 23 July 2024 [9]. COVID-19-related restrictions interrupted the planned survey schedule. Therefore, although the two campaigns represent different seasonal periods, season and survey year are confounded, preventing their effects from being fully separated.

The project report records GPS positions and stable transect IDs for repeated work [9]. It describes four cells per transect and gives example cell areas of 29.8-46.5 m² in Tables 5.7-5.9, while its Sam Son design text specifies 60-100 m². For reproducibility, each density must use the area actually surveyed for the corresponding sampling unit. The complete set of 176 measured areas, recent cleaning logs and observer-calibration records was not included in the supplied report; hence these aspects cannot yet be independently verified. Figure 4 outlines the analytical sequence.



Figure 1. Survey transects in Hau Loc. [Source: Authors' field-survey mapping; compare the national project report [9]]



Figure 2. Survey transects in Sam Son. Source: Authors' field-survey mapping; compare the national project report [9]]



Figure 3. Survey transects in Nghi Son. [Source: Authors' field-survey mapping; compare the national project report [9]]

Table 1. Survey design and analytical scope

Component	Specification
Study province	Thanh Hoa Province, North Central Coast of Viet Nam
Surveyed coastal areas	Sam Son, Hau Loc and Nghi Son
Number of transects	22 transects
Seasonal campaigns	Two campaign windows: 21 Oct 2021-13 Feb 2022 and beach survey 31 Mar-23 Jul 2024 [3]; see §2.1 on label reconciliation
Minimum item size	Visible debris larger than 5 mm
Main indicators	Item count, weight, density, material composition and CCI

Source: Authors' synthesis from field survey design

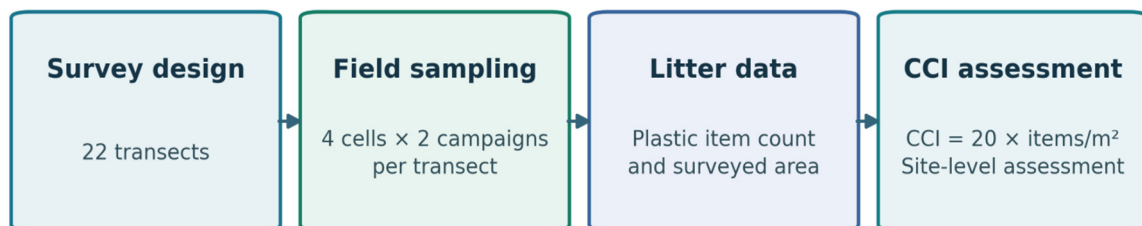


Figure 4. Analytical framework for assessing beach plastic waste in Thanh Hoa. [Source: Authors' synthesis based on field survey design]

2.2. Waste classification and CCI calculation

Item-size and material-classification terminology follows GESAMP guidance for marine plastic litter [10]; NOAA provides the operational basis for repeated shoreline-debris monitoring [11]. The present study considers visible items >5 mm. The project report lists bags, ropes, food packaging, disposable products, hard plastics, foam, woven sacks, rainwear and fishing gear [9]. Expanded polystyrene (EPS) is a polymer, but the report's example tables label foam separately from plastic; whether EPS was

included in the plastic numerator used for the reported CCI must be checked against the field coding sheet.

Plastic-item density is calculated for each specified cell or transect from its plastic count and measured area; an aggregate index requires the corresponding summed plastic counts and sampled areas. Category definitions must be held constant across the two campaigns.

The Clean Coast Index, originally proposed by Alkalay et al., was used to assess beach cleanliness based on the density of plastic items [8]. The indicator was calculated as follows:

$$CCI_i = 20 \times \left(\frac{P_i}{A_i} \right)$$

Where P_i is the number of plastic items and A_i is the measured sampling area (m²) for unit i

[8]. The pooled CCI, if calculated, is $20 \times \left(\frac{\sum P_i}{\sum A_i} \right)$;

it need not equal the arithmetic mean of site or transect CCI values.

The resulting CCI values were classified into five levels: very clean, clean, moderate, dirty and extremely dirty (Table 2).

GESAMP [10] and NOAA [11] guidance inform material classification and repeated shoreline monitoring, whereas CCI [8] translates plastic-item density into a five-class index. Table 3 summarizes the complementary functions of these established methods.

Table 2. CCI classification used for beach cleanliness assessment [8]

CCI value	Class	Interpretation
$0 \leq CCI \leq 2$	Very clean	No visible litter
$2 < CCI \leq 5$	Clean	No litter over a large area
$5 < CCI \leq 10$	Moderate	A few pieces of litter detected
$10 < CCI \leq 20$	Dirty	A substantial amount of debris present
$CCI > 20$	Extremely dirty	Most of the beach area is visibly affected

Table 3. Rationale for combining international guidance and CCI in the study

Methodological element	Role in this study	Main advantage
GESAMP plastic-litter guidance	Defines material categories and supports harmonized monitoring	Improves comparability with international practice
NOAA shoreline protocol	Guides repeated shoreline transect surveys and item counting	Practical for field teams and community-based monitoring
Clean Coast Index	Transforms plastic-item density into beach cleanliness classes	Simple indicator for communication and local management
Seasonal comparison	Describes two surveys in distinct seasonal windows and years	Supports descriptive comparison; does not identify a monsoon effect

Source: Authors' synthesis from GESAMP [10], NOAA [11] and CCI methodology [8]

2.3. Data processing

The study used 5-m sampling cells as the unit for recording litter presence and 100-m transects as the spatial monitoring units. Across 22 transects and two survey campaigns, four sampling cells were randomly selected per transect, resulting in 176 sampled cells in total. The "occurrence probability" was defined as the frequency of occurrence of each plastic litter category across the sampled cells, calculated as: $100 \times (\text{number of cells containing at least one item in the category})/176$. This indicator reflects the spatial prevalence of a litter category rather than its percentage contribution to the total number of items. The reported litter totals

and densities by area were retained from Table 4. Because detailed cell-level data were unavailable, uncertainty estimates and statistical tests of dispersion were not performed.

The published report and manuscript differ in their campaign and overall totals; this discrepancy is treated as a data-reconciliation requirement. GPS identifiers and photographic cross-checks are described in project documentation [9], but observer agreement, EPS allocation and site-specific cleaning histories are not established by the supplied materials.

The analysis also distinguishes between abundance-based and weight-based interpretations. Abundance is more sensitive to

small disposable items such as caps, wrappers, straws and plastic bags; weight is more sensitive to bulky items such as fishing gear, containers and hard plastic fragments. For beach management,

both metrics are needed: abundance reflects exposure, aesthetics and fragmentation risk, whereas weight reflects collection workload and transportation demand.

Table 4. Original manuscript’s debris counts and reported plastic-item densities by area and campaign (numerical entries retained pending reconciliation with the field database)

Area	Items: SW monsoon	Items: NE monsoon	Plastic density SW/NE (items/m²)
Sam Son	676	594	0.202 / 0.139
Hau Loc	1,522	1,427	1.390 / 0.750
Nghi Son	3,466	2,012	0.471 / 0.202

Source: Initial manuscript; compare the national project report [9]. The displayed density and item-count columns refer to different quantities and are not independently recalculated here

3. Results and discussion

3.1. Overall quantity and material composition

The source manuscript reports 15,649 visible debris items (>5 mm), 235.69 kg, an item density of 0.560 items/m² and mass density of 0.008 kg/m², matching figures stated in the national project report [9]. These figures are retained as reported, rather than treated as an independently reconciled aggregate. Specifically, the report also lists 5,664 plastic items in Season 1 and 4,033 plastic items in Season 2 (9,697 in total). Plastic waste accounted for the largest share, representing 61.97% of the total number of items (corresponding to a mean density of 0.35 items/m²) and 67.51% of the total mass

(corresponding to a mean mass density of 0.01 kg/m²) (Figure 5). These proportions indicate that plastic waste was a major component of beach litter in the Thanh Hoa coastal zone and was dominant relative to other litter categories, including textiles, wood, glass, and metals.

The dominance of plastic by both item count and weight is important for management. Item abundance indicates the level of visual pollution and the likelihood of fragmentation into smaller particles, while weight is more relevant for estimating removal effort, transportation needs and operational costs. The combined use of both indicators therefore provides a more balanced basis for local planning than either indicator alone.

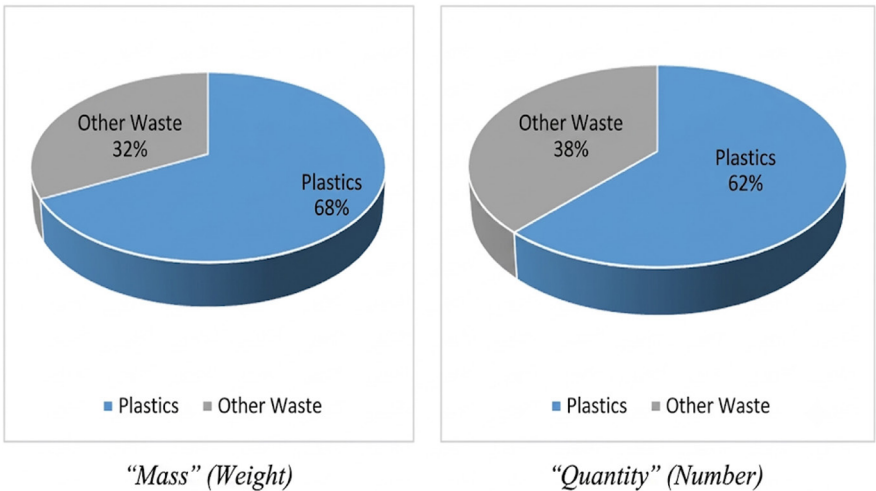


Figure 5. Proportion of beach litter by item count and mass (percentages rounded). [Source: Authors’ compilation of the retained manuscript data; see Table 4 and the national project report [9]]

3.2. Seasonal and spatial variation

As retained, Table 4 reports 1,187 and 840 debris items at Sam Son, 1,810 and 1,901 at Hau Loc, and 6,487 and 3,424 at Nghi Son in its two campaign columns (Figure 6). These six counts total 15,649. The published report does not allow the manuscript's Southwest/Northeast column labels to be matched unambiguously to its dated winter 2021-2022 and spring-summer 2024 campaigns. We therefore treat these numbers as source-reported descriptive summaries rather than proof of an isolated monsoon effect. The percentages implied by each pair of counts are descriptive and depend on comparable sampling effort.

The originally reported plastic densities are retained in Table 4: Sam Son 0.202/0.139, Hau Loc 1.390/0.750, and Nghi Son 0.471/0.202 items/m² across the two reported columns. Applying the published CCI multiplier of 20 yields, respectively, 4.04/2.78, 27.80/15.00 and 9.42/4.04 (Figure 6).

At the transect level, 45.5% of the surveyed transects in Season 1 had CCI values >10, corresponding to the “dirty” to “extremely dirty” categories. Among these, 18.2% had CCI >20 and were classified as “extremely dirty.” The CCI >20 transects included HL-03, HL-06 and HL-07 in Hau Loc and NS-07 in Nghi Son. In Season 2, the proportion of transects with CCI >10 decreased to 31.8%, while the proportion with CCI >20 decreased to 9.1%, corresponding to HL-03 and HL-07, both in Hau Loc. The proportion of clean transects increased from approximately 18% to 32%, while the proportion of extremely dirty transects decreased from 18.2% to 9.1%. These descriptive differences indicate a change in beach plastic-litter accumulation between the two survey periods; however, given the temporal separation of the campaigns and the COVID-19-related interruption, they should not be interpreted as definitive evidence of a causal monsoon effect. Figure 7 presents the reported transect-level CCI values for both campaigns.

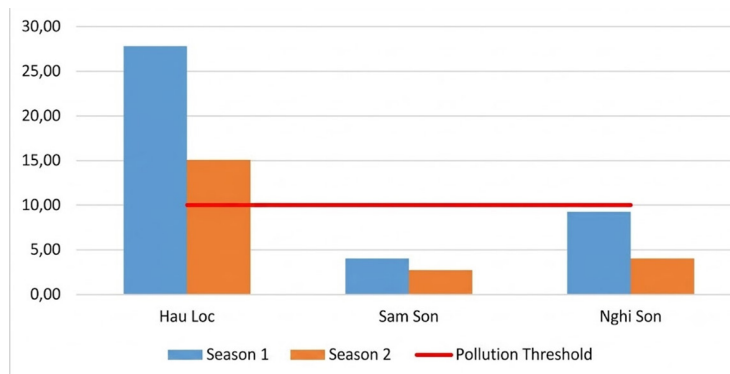


Figure 6. CCI by study region and reported survey campaign. [Source: Authors' calculation from the plastic-item densities retained in Table 4 using $CCI = 20 \times \text{items/m}^2$; compare [8]]

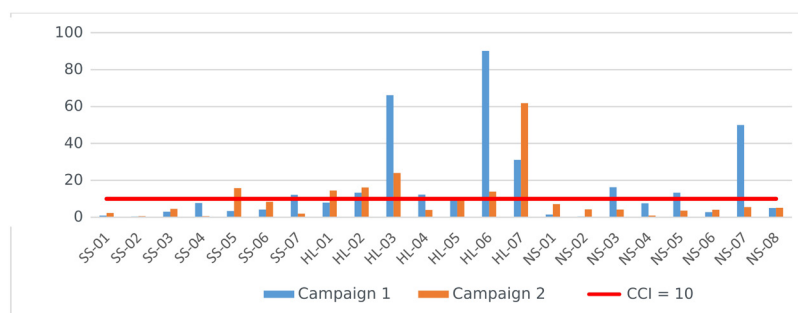


Figure 7. Seasonal CCI values. [Source: Initial manuscript; compare the national project report [3]. The displayed density and item-count columns refer to different quantities and are not independently recalculated]

In addition, tourism activities, riverine waste inputs, fishing activities, and beach-cleaning practices may also contribute to the observed differences (Figure 9 illustrates beach litter and cleaning activities; the photographic dates and precise sites are not documented in the supplied records).

3.3. Dominant plastic waste categories

Across the 176 reported cell observations,

food containers occurred in 25.00%, bags/films/gloves in 24.43%, toys/hard-plastic fragments in 23.86%, and cutlery/straws in 22.16% (Figure 8; Table 5). These percentages describe occurrence across cells, not the fraction of all litter items attributable to a product category. Figure 8 includes further groups beyond the four highest ranked categories listed in Table 5.

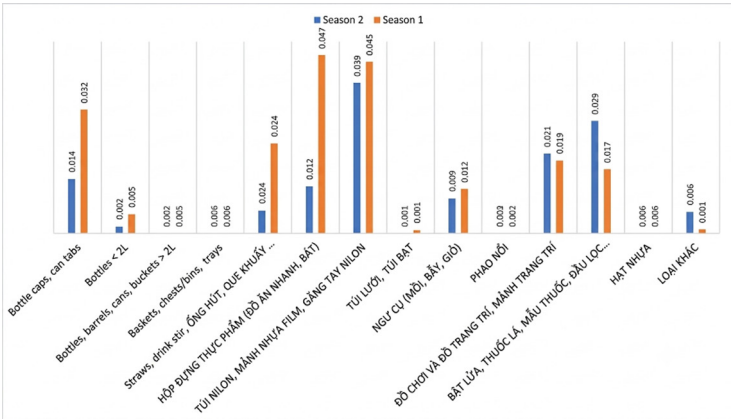


Figure 8. Frequency of occurrence of plastic litter categories across 176 cell observations. [Source: Authors’ field-survey summary; category frequencies are calculated as cells with a category divided by 176. Authors’ reported field-survey data]

Table 5. Four highest-ranked plastic categories by frequency of occurrence across 176 cell observations (Figure 8 shows additional categories)

Rank	Plastic waste category	Occurrence (%)
1	Food containers, cups and lunch boxes	25.00
2	Plastic bags, film fragments and gloves	24.43
3	Toys, decorations and hard plastic fragments	23.86
4	Knives, forks, spoons, straws and stirrers	22.16

Source: Authors’ calculation from field survey data

3.4. CCI results and management interpretation

The project report also reports an overall CCI of 11.2, with a separate CCI value of 6.9 for plastic litter across the three survey locations. The six site-by-campaign density values in Table 4 imply CCI values from 2.78 to 27.83. These estimates have different aggregation levels and must not be silently substituted for one another. The report identifies 4/22 transects (18.2%) as extremely dirty in its first classification and 2/22 (9.1%) in the second; a complete five-

class distribution and the pooled CCI await verification from each transect’s plastic count and surveyed area.

For management, the most consistent site-level result is the high reported CCI for Hau Loc relative to Sam Son and Nghi Son. Its interpretation should be combined with item composition, site use and records of cleaning. Fixed transects and comparable survey effort are essential to determine whether conditions change between monitoring periods.



Figure 9. Field photographs of plastic waste and cleaning activities; survey dates, exact locations and image scale should be confirmed from the original photo log. [Source: Authors' field survey photographs]

3.5. Source-oriented management priorities

The composition of plastic waste suggests that management interventions should be organized around sources and product groups rather than only around end-of-pipe beach cleaning. Food containers, plastic bags and cutlery are closely linked with tourism, food services and daily consumption. Fishing gear and baskets are linked with coastal livelihoods and require separate collection channels. Hard plastic fragments indicate the breakdown of larger products and may require both rapid removal and upstream controls. Table 6 summarizes the area-specific interpretation and management priorities.

For provincial implementation, CCI monitoring should be linked with existing solid-waste management plans, tourism management and community participation. A quarterly or seasonal monitoring schedule would help identify recurring

hotspots, evaluate the effectiveness of clean-up campaigns and prioritize investment in collection infrastructure. The indicator can also support public communication by presenting beach conditions in a simple classification that local communities and tourism operators can understand.

A monitoring programme based on the results of this study should include four operational steps. The first step is to maintain fixed transects and survey timing so that changes can be compared over time. The second step is to classify plastic items into product groups relevant to local action, such as food-service packaging, bags and films, fishing gear and hard plastic fragments. The third step is to calculate both density and CCI to connect scientific data with management classes. The fourth step is to report findings to local authorities, tourism operators and coastal communities in a concise format that can guide clean-up schedules and prevention measures.

Table 6. Area-specific interpretation and priority management responses

Area	Main pressure	Priority response
Sam Son	Tourism services and beach recreation	Reduce single-use packaging, strengthen service-sector waste rules and maintain daily cleaning during peak periods
Hau Loc	River mouths, fishing villages and boat anchorage	Install collection points for fishing-related plastics and combine beach monitoring with river-mouth interception
Nghi Son	Mixed fisheries, estuarine and industrial-coastal activity	Target seasonal accumulation hotspots and improve coordination among port, fisheries and local waste services

Source: Authors' interpretation based on field survey results

3.6. Scientific and policy relevance

The area contrasts show why a standardized cleanliness index needs site context and a clear sampling denominator. This work applies an established method to a local monitoring problem; it cannot identify causal contributions of winds, river transport, tourism or cleaning from two surveys in different years.

From a policy perspective, the findings are relevant to Viet Nam's ongoing efforts to reduce marine plastic waste and improve coastal environmental management. The study provides evidence for three policy directions: reducing priority single-use plastic items in tourism and food services; improving collection systems for fisheries-related plastics; and strengthening routine monitoring using comparable indicators. These directions are consistent with the shift from episodic clean-up activities toward preventive and source-oriented management.

3.7. Limitations and further research

The study considers visible litter items >5 mm based on two survey campaigns conducted at different times and at selected coastal sites. The interruption of the survey schedule due to COVID-19, as reported by the authors, affected the continuity of the dataset. Therefore, the reported total of 9,697 plastic litter items, an overall CCI of 11.2 and a plastic-specific CCI of 6.9 should be regarded as broad assessments based on the available data.

Future research should integrate beach surveys with riverine plastic monitoring,

microplastic sampling and socio-economic assessment of waste generation sources. Such integration would allow local authorities to move from beach-level cleanliness assessment toward a more complete plastic-flow management system across the land-river-sea continuum.

4. Conclusions

The initial study reports 15,649 debris items >5 mm, including plastics representing 61.97% of items and 67.51% of mass. The retained six site-by-campaign densities correspond to CCI values of 2.78-27.83, with Hau Loc having the highest values in both reported columns. The overall CCI of 11.2 and the plastic-specific CCI of 6.9 are reported in the project source, but remain unreconciled with the approximate plastic density and the site-level summary data. COVID-19-related disruption, as described by the authors, separated the survey windows; this permits a descriptive comparison of observations under different seasonal conditions but not isolation of a monsoon effect from changes between years. The original cell records are required to validate transect indices, item totals and an overall CCI before quantitative claims are finalized.

Local management should prioritize consistent transect monitoring, collection near fishing and estuarine areas, and reduction of disposable packaging at tourism beaches. Subsequent work should document cleaning and measured areas, reconcile polymer categories including EPS, and report plastic count, CCI and uncertainty for each transect and campaign.

Author contribution statement: Vu Dinh Hieu, Nguyen Thi Thuy; original draft preparation: Nguyen Thi Thuy, Nghiem Van Tuan, Nguyen Cao Van; review and editing: Vu Dinh Hieu, Nguyen Thi Thuy.

Acknowledgement: This research was supported by the ministerial-level project entitled "Theoretical and practical basis for proposing solutions for the implementation of the Global Agreement on Plastic Pollution", code TNMT.DL.2025.04.03.

Competing interest statement: The authors declare that this article was the work of the authors, has not been published elsewhere, has not been copied from previous research; there was no conflict of interest within the author group.

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